SAN JOAQUIN BASIN PROVINCE (010)

By Larry A. Beyer

INTRODUCTION

The San Joaquin Basin Province, which occupies the southern half of the Great Valley of California, is an asymmetrical structural trough filled in places with more than 36,000 ft of Upper Cretaceous and Cenozoic predominantly marine clastic rocks (Callaway and Rennie, 1991). The northern province area formed as part of a Cretaceous-Paleogene forearc basin. The southern area, with some overlap to the north and with a transform-rifted western margin, subsided and was compressed during Neogene time in response to plate motions along the active California margin.

The province is bordered on the east by the Sierra Nevada, on the south by the northern Transverse Ranges, on the west by the San Andreas Fault Zone and southern Diablo Range, and arbitrarily on the north by the Stanislaus-San Joaquin County line. The province is about 200 mi long, averages 65 mi wide, occupies $14,423^2$ mi and contains about 30,000 mi^3 of sedimentary rock (Callaway, 1971; Varnes and Dolton, 1982).

Commercial petroleum development began in the late 1870's when asphalt deposits were mined and in the 1880's and 1890's when shallow wells were hand dug and drilled in the Coalinga, McKittrick, and Kern River, California, areas. Rapid discovery of many of the largest oil accumulations in the province followed during the next several decades. Most discovered oil accumulations occur in Eocene through Pleistocene sandstones. Discovered supergiant and giant oil fields with discovery year and sum of production and estimated reservoirs through 1992 are (California Division of Oil, Gas, and Geothermal Resources, 1993):

- Midway-Sunset (1901, 2.752 BBO, 589 BCFG)
- Kern River (1899, 1.947 BBO, 16 BCFG)
- Elk Hills (1911, 1.521 BBO, 1.840 TCFG)
- South Belridge (1911, 1.201 BBO, 355 BCFG)
- Kettleman North Dome (1928, 460 MMBO, 2.962 TCFG)
- Coalinga (1887, 906 MMBO, 226 BCFG)
- Buena Vista (1909, 674 MMBO, 1.199 TCFG)
- Coalinga East Extension (1938, 508 MMBO, 530 BCFG)
- McKittrick (1896, 283 MMBO, 204 BCFG)
- Mount Poso (1926, 342 MMBO, 2 BCFG)
- Lost Hills (1910, 318 MMBO, 750 BCFG)

Cymric (1909, 311 MMBO, 125 BCFG)

Kern Front (1915, 229 MMBO, 25 BCFG)

Belridge North (1912, 129 MMBO, 723 BCFG)

Coles Levee North (1938, 164 MMBO, 261 BCFG)

Edison (1928, 153 MMBO, 74 BCFG)

Coles Levee South (1938, 60 MMBO, 593 BCFG)

Rio Bravo (1937, 117 MMBO, 142 BCFG)

Paloma (1934, 62 MMBO, 457 BCFG)

Fruitvale (1928, 129 MMBO, 42 BCFG)

Greeley (1936, 115 MMBO, 107 BCFG)

Yowlumne (1974, 117 MMBO, 96 BCFG)

Ten Section (1936, 84 MMBO, 193 BCFG)

Mountain View (1933, 90 MMBO, 88 BCFG)

Poso Creek (1919, 84 MMBO, 9 BCFG)

Round Mountain (1927, 102 MMBO, 2 BCFG)

The four largest fields listed above were among the top eight for production and the top nine for estimated reserves of all U. S. domestic oil fields at the end of 1992 (Phillps, 1993). Twenty-five of the above 26 largest fields were discovered before 1940 and account for 93 percent of province totals in terms of 1992 year-end figures. Cumulative production plus estimated reserves from 110 smaller fields, including 49 fields with < 1 MMBOE each, is 713 MMBO and 1.590 TCFG. Cumulation production plus estimated reserves for entire province through 1992 are 13.573 BBO and 13.292 TCFG (15.788 BBOE).

The two most recent significant discoveries occurred in 1974 (Yowlumne, 133 MMBOE; Metz and Whitworth, 1984) and in 1985 (Landslide, 23 MMBOE; Stolle and others, 1988). For many decades, reserve additions to the San Joaquin Province have been due primarily to upward revisions of recoverable petroleum from existing reservoirs and to the discovery of reservoir extensions, new pools, and new areas assigned to existing fields (Beyer and Bartow, 1988). On a comparative basis, new field discoveries have added few reserves to the province total during the same time period.

The San Joaquin Basin Province is divided into nine confirmed plays and one hypothetical play. These plays are: Pliocene Non-Associated Gas (1001), Southeast Stable Shelf (1002), Lower Bakersfield Arch (1003), West Side Fold Belt Sourced by Post-Lower Miocene Rocks (1004), West Side Fold Belt Sourced by Pre-Middle Miocene Rocks (1005), Northeast Shelf of Neogene Basin (1006), Northern Area Non-Associated Gas (1007), Tejon Platform (1008), Southern Thrust Salient (1009), East Central Basin and Slope North of Bakersfield Arch (1010), and Deep, Overpressured Fractured Rocks of West Side Fold and Overthrust Belt (hypothetical, 1011).

ACKNOWLEDGMENTS

The author thanks W.J.M. Bazeley, V.B. Cherven, T.L. Davis, D.L. Hankins, and T.H. McCulloh for useful discussions, but assumes full responsibility for opinions that exceed available factual information. Scientists affiliated with the American Association of Petroleum Geologists and from various State geological surveys contributed significantly to play concepts and definitions. Their contributions are gratefully acknowledged.

CONVENTIONAL PLAYS

1001. PLIOCENE NONASSOCIATED GAS PLAY

The confirmed structural-stratigraphic play consists of non-associated gas accumulations in mostly Pliocene marine and brackish water sandstones located in the south-central province area. The play is distinguished by the apparent exclusive occurrence of non-associated gas in Pliocene and younger sandstones in the south-central basin area (Rudkin, 1968).

The play boundary is drawn to include all discovered non-associated gas accumulations in the Pliocene-Pleistocene section and adjacent areas believed to contain similar source and reservoir rock relationships.

Reservoirs: Discovered and likely undiscovered reservoirs are Pliocene shallow-water marine sandstones and Pleistocene deltaic and nonmarine sands in the Etchegoin, San Joaquin, and Tulare Formations (oldest to youngest) that generally unconformably overlie upper Miocene rocks and are overlain by Quaternary nonmarine deposits. Porosity and permeability of discovered reservoirs is good to excellent.

Source rocks: Thick Pliocene marine mudstone and claystone surrounding reservoir sandstones probably were the source of biogenic gas. Selected Eocene and Miocene shales, which may be somewhat less oil-prone and more gas-prone east of the basin axis north of the Bakersfield Arch, may be a source of thermogenic gas. The proportions of biogenic and thermogenic gas in discovered accumulations and their original sources are not well understood.

Timing and migration: Traps formed after middle Pliocene time when burial compacted fine-grain capping beds and gentle folds began to form, and regional up-to-the-northeast tilting occurred. Biogenic and thermogenic gas probably were generated and migrating before, during, and after trap formation.

Traps: Discovered traps are mostly elongate gentle domes in which stratigraphic lensing plays a major and sometimes exclusive trapping role. The accumulation in the Harvester field appears to be exclusively a stratigraphic trap (Church, 1965). Seals are fine-grained, low-permeability claystone, mudstone, and tightly cemented sandstone. Depths of discovered accumulations range from less than 1,000 ft to about 4,900 ft in the central basin. Individual reservoirs are mostly less than 30 ft thick.

Exploration status: Exploration in this play is mature and all except the most subtle structures in the Pliocene section have been tested. Larger gas discoveries (> 35 BCFG) with discovery year and cumulative production plus estimated reserves through 1992 are: Buena Vista (1909, 93.4 BCFG), Buttonwillow (1927, 38.3 BCFG), Coles Levee South (1941, 43.9 BCFG), Elk Hills (1919, 249.7 BCFG), and Trico (1934, 201.2 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Thirteen smaller discoveries, including five with < 6 BCFG each, contribute an additional 129 BCFG for a play total of 755 BCFG through 1992. Undiscovered gas probably is similar to discovered gas, which generally is 97 percent or more methane with average heating value of about 1,015 BTU/CFG. Depths of undiscovered accumulations are in the depth range of discovered reservoirs.

Resource potential: Undiscovered gas accumulations may exist in erratic "Mya" sands of the San Joaquin Formation in stratigraphic traps (e.g., incised channel-fill sands of Callaway, 1990). Whether or not the size of these and other possible traps warrants exploration for them is not known. There is a high probability that non-associated gas accumulations less than 6 BCFG occur principally in stratigraphic and small fault block traps, but there is a low probability of accumulations greater than 6 BCFG.

1002. SOUTHEAST STABLE SHELF PLAY (1002)

The confirmed stratigraphic and structural-stratigraphic play consists of oil and associated gas accumulations in Oligocene through Pleistocene marine to nonmarine sandstones and fractured pre-Cenozoic basement rocks located on the relatively stable southeast basin margin. The play is distinctive because its traps are mostly characterized by low dip angles and gentle folds or normal faults, and its reservoirs consist mainly of upper-slope and marine shelf and nonmarine sandstones. Some intense faulting is present, but throws typically are relatively small.

The western play boundary generally coincides with the average position of the marine shelf edge/slope during upper Miocene and lower Pliocene time. This western boundary generally excludes the deep water upper Miocene "Stevens" sandstones from this play. The southern play boundary is the White Wolf Fault Zone, and the eastern boundary is the onlap edge of Neogene sediments on the basement rocks of the Sierra Nevada. The northern play boundary is drawn somewhat arbitrarily to include the small discovered accumulations as far north as the Deer Creek field.

Reservoirs: Discovered accumulations occur in Oligocene (and minor older) to Pleistocene sandstone reservoirs in practically every formation, but they are most prolific in the Kern River and Chanac Formations, Santa Margarita (local usage), Jewett Sand, Freeman Silt, and Vedder Sand (Olson, 1988; Link and others, 1990, Tye and others, in press). These upper-slope, shelf, and nonmarine sandstones extend from the vicinity of the Jasmin field southward to, and partly extend across, the White Wolf Fault Zone. Reservoirs tend to wedge out or to be overlapped to the east, and to pass into deep-water facies to the west. Limited production occurs in the nonmarine Walker Formation of Eocene age in one part of the Edison field. Fractured metamorphic rocks form reservoirs in selected areas of the Edison and Mountain View fields (Lohmar, 1984). Undiscovered accumulations may occur in any of the above units. Discovered reservoirs generally have good to excellent porosity and permeability.

Source rocks: Dominant source rocks are the principally middle Miocene Lower Fruitvale and Round Mountain Shales that are the eastern equivalents of the McDonald, Devilwater, and Gould shales on the west side of the San Joaquin Basin. Distinctive oils in selected reservoirs along the downdip western portion of the play (especially north of the Bakersfield Arch) may come from one or more of the Eocene through lower Miocene shales of the Kreyenhagen and Freeman Formations and their equivalents. Source rocks are most deeply buried and most likely to be mature in the western play area and farther west.

Timing and migration: Generation and migration of hydrocarbons from principally middle Miocene shales probably began in middle to late Pliocene time. Generation and migration from Eocene through lower Miocene shales probably began as early as middle Miocene time. Upper Miocene and younger source rocks probably are in early stages of oil generation in structurally lowest areas of the play. Time estimates of maturation and migration for plays 1002 through 1010 are speculative because only rudimentary studies are available (e.g., Zieglar and Spotts, 1978, Fischer and others, 1988). Trap formation and destruction has occurred intermittently at least since late Oligocene time.

Traps: Common discovered traps are generated by high-angle extension (down-to-the-east) faults that put west-dipping sandstone reservoirs in contact with sealing mudstone or shale. Lenses and lenticular pods of sandstone form stratigraphic traps (Callaway and Rennie, 1991). Pinchouts, truncations, tar seals, and permeability barriers are present along the east play margin. Gentle anticlines, some intensely faulted, apparently formed by pre-Miocene compression also form traps. Multiple periods of extension faulting since late Oligocene are documented by extensive drilling in this play. An atypical, but singularly important, trapping mechanism is the apparent hydrodynamic trap of the supergiant Kern River field (Kodl and others, 1990). Diagenetic traps may be present at greater depths in the western part of the play. Traps vary widely in size. Discovered accumulations occur at depths from about 165 to 9,800 ft and range in thickness from about 5 to 2,200 ft.

Exploration status: Exploration is very mature along the updip basin margin east and southeast of the Bakersfield Arch. Downdip areas to the west and the area northeast of the Bakersfield Arch are comparatively less well drilled, although many tests have been completed.

Larger oil discoveries (> 40 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are Edison: Main and West areas (1932, 101 MMBO, 21 BCFG), Edison: Racetrack Hill and Jeppi areas (1944, 42 MMBO, 52 BCFG), Fruitvale: Main area (1928, 127 MMBO, 41 BCFG), Kern Front (1915, 229 MMBO, 25 BCFG), Kern River (1899, 1.946 BBO, 16 BCFG), Mount Poso: Main and Dorsey areas (1926, 322 MMBO, 2 BCFG), Mountain View: Main and Digiorgio areas (1933, 73 MMBO, 63 BCFG), Poso Creek: Enas and Premier areas (1919, 76 MMBO, 9 BCFG), and Round Mountain: Coffee and Main areas (1927, 88 MMBO, 2 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Twenty-four smaller discoveries, including four with < 1 MMBO each, contribute an additional 119 MMBOand 40 BCFG for play totals of 3.123 BO and 271 BCFG at the end of 1992. Undiscovered oil is likely to have API gravities in the range of discovered oil-- from about 12û API in shallow reservoirs to about 43û in deeper reservoirs. Depths of undiscovered accumulations mostly will be in the depth range of deeper discoveries or deeper.

Resource potential: The complexity of basin-margin facies changes and faulting suggest that more, mostly small accumulations will continue to be found. Discovery of small accumulations in new areas or pools to existing fields with resources up to several MMBOE are likely. Discovery of accumulations with recoverable resources substantially greater than 10 MMBOE is unlikely. New discoveries are most probable in downdip areas that have not yet been exhaustively drilled along the western part of the play, especially for Vedder-Jewett targets.

1003. LOWER BAKERSFIELD ARCH PLAY

The confirmed stratigraphic and structural-stratigraphic play consists of oil and associated gas accumulations primarily in turbidite "Stevens" sandstone of upper Miocene age and secondarily in the Vedder-Jewett sandstones of Oligocene to Miocene age and older sandstones located in the south-central part of the San Joaquin Province. The play is distinctive because of the variable style of its traps, the upper Miocene bathyal facies ("Stevens" sands) that separate it from the mostly shelf facies of the Southeast Stable Shelf Play (1002), and the absence of structuring associated with the west side of the basin.

The eastern play boundary generally coincides with the average position of the marine shelf edge/slope during upper Miocene and lower Pliocene time so that lower slope and bathyal depositional facies are included in the play. The western play boundary is drawn to exclude the structuring in the west side of the basin. The northern boundary is the approximate limit of "Stevens" sandstone deposition and the southern boundary is the White Wolf Fault Zone.

Reservoirs: Principal reservoir rocks of this play are the marine turbidite "Stevens" sandstones of upper Miocene age that were derived from the east through a succession of submarine-canyon systems (MacPherson, 1978; Webb, 1981; Hewlett and Jordan, in press). The Oligocene to Miocene Vedder-Jewett sandstones (e.g., Tye and others, in press) and other lower Miocene sands appear to have been partly deposited in a basin-ramp setting with sediment sources also from the east. Several accumulations have been discovered in these pre-Stevens sandstones, making them reservoir targets. Discovered reservoirs have fair to excellent porosity and permeability.

Source rocks: Principal source rocks for the "Stevens" reservoirs are the Fruitvale and Round Mountain shales that are eastern equivalents of the McDonald Devilwater and Gould shales on the west side of the basin. Oil accumulations in pre-Stevens sandstones may, in part or whole, be sourced from upper Eocene and (or) Oligocene shales, especially on the north flank of the Bakersfield Arch. In the play area on the south flank of the Bakersfield Arch, it is less clear if pre-Monterey source rocks have provided hydrocarbons to discovered accumulations. Upper Eocene through middle Miocene shales, though not reached by drill, are thought to underlie parts of this area and are present to the south of the White Wolf Fault Zone.

Timing and migration: Generation and migration from Eocene and Oligocene shales probably began as early as middle Miocene time. Generation and migration of hydrocarbons from lower and middle Miocene shales probably began in middle to late Pliocene time. Trap formation has occurred intermittently at least since late Oligocene time.

Traps: Discovered and likely undiscovered traps are more randomly oriented than in adjacent plays and include differential compaction of shale over turbidite, channel, and overbank sands (Sanem and Stoddard, 1965). Other common traps include pinchouts of distal turbidite or channel sands on structural flanks, sealing by updip overlap, and mostly down-to-the-basin syn- and post-depositional faults. Sizes of discovered individual traps vary widely. Discovered accumulations occur at depths from about 5,600 to 11,800 ft and range in thickness from thin stringers to 400 ft.

Exploration status: Exploration is mature for "Stevens" and younger sandstones in the central part and somewhat less mature on the north and south flanks of the Bakersfield arch. Larger discovered oil accumulations (> 10 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are: Canal (1937, 26 MMBO, 26 BCFG). Canfield Ranch: East Gosford area (1949, 28 MMBO, 28 BCFG). Greeley (1936, 115 MMBO, 107 BCFG), Rio Bravo (1937, 117 MMBO, 132 BCFG), Strand: Main area (1939, 15 MMBO, 12 BCFG), and Ten Section (1936, 84 MMBO, 184 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Twenty-three smaller discoveries, including 13 with < 1 MMbbls each, contribute an additional 46 MMBO and 42 BCFG for play totals of 431 MMBO and 531 BCFG at the end of 1992. Undiscovered oil is likely to have gravities in, or higher than, the 28û API to 40û API range of discovered oils. Depths of undiscovered accumulations will be in the depth range of discoveries and deeper.

Resource potential: Discovery of mostly modest sized accumulations is very likely because of the complexity of the sand deposystems and trap types in the play area. Many of these accumulations will be classified as new pools or areas of existing fields. Less well drilled areas on the north and south flanks of the Bakersfield Arch may contain somewhat larger new-field undiscovered accumulations. Careful reexamination of "Stevens" and pre-"Stevens" sandstone deposystems, trapping mechanisms, diagenetic facies, pre-upper Miocene source rocks, and the timing and migration routes of oil from all potential source rocks ought to lead to discovery of at least several new-field accumulations. Possible degradation of permeability and porosity with increasing depth due to diagenesis dampens expectations for discovery of deeper, prolific pre-upper Miocene reservoirs.

1004. WEST SIDE FOLD BELT SOURCED BY POST-LOWER MIOCENE ROCKS PLAY

The confirmed stratigraphic and structural-stratigraphic play consists of oil and associated gas accumulations in upper Miocene to Pleistocene sandstone reservoirs and in upper Miocene to lower Pliocene fractured siliceous rocks and diatomite located in the west side of the San Joaquin Basin. The play is distinctive because reservoirs are mostly in upper Miocene and younger rocks, stratigraphic and combination traps formed from structuring and (or) marine transgressive cycles during and since late Miocene time, and most oil is thought to be derived from middle Miocene and younger source rocks. These characteristics distinguish the oil accumulations of this play from those derived from pre-middle Miocene source rocks that are located mostly in pre-upper Miocene reservoirs in the same play area (play 1005). Structuring that affected trap formation in this play include late Miocene compression, Pliocene extension, and Pliocene to Recent compression (Harding, 1976).

The western play boundary is the western extent of possible upper Miocene and younger reservoir rocks or the San Andreas Fault Zone. The northern play boundary is the approximate northern limit of oil accumulations from middle and upper Miocene source rocks. The eastern play boundary is the approximate eastern limit of significant west side-type structuring that trapped oil from middle and upper Miocene source rocks. The southern boundary is the White Wolf Fault Zone and its westward extension that generally terminate west side-type structuring against the late Neogene north-vergent thrusting and folding of the southern basin margin.

Reservoirs: Principal discovered reservoirs include (1) sinuous and discontinuous upper Miocene submarine-canyon to distal-turbidite sandstones, often enclosed in fine-grained biogenic siliceous rocks (e.g., Quinn, 1990; Reid, 1990), (2) upper Miocene diatomite, diatomaceous mudstone with thin sand interbeds, porcelaneous shale, and fractured cherty rocks (e.g., Schwartz, 1988; Bowersox, 1990), and (3) Pliocene shelf sands that grade upward into Pleistocene deltaic and nonmarine sands (e.g., McPherson and Miller, 1990; Farley, 1990). Undiscovered reservoirs may occur in any of these units. Sandstone facies include distal to proximal turbidites, shelf deposits, and deltaic/fluvial units. Biogenic siliceous sediments formed on banks and basinal areas undiluted by terrigenous sediment and today range from diatomite to brittle, fractured, quartz-rich units. Discovered sandstone reservoirs generally have good to excellent porosity and permeability while fine-grained siliceous rock reservoirs have fair to excellent porosity, but poor to fair permeability.

Source rocks: Miocene source rocks include, from oldest to youngest, the Gould, Devilwater, and McDonald shales. The McLure (Antelope) shale, Reef Ridge Shale and Etchegoin Formation may be source rocks in those areas where they have been maximally buried. The richness and maturity of these units, especially the McDonald and McLure Shale Members, are well established in and adjacent to the play area.

Timing and migration: Generation and migration of hydrocarbons from middle Miocene shales probably began in middle to late Pliocene time. Upper Miocene and younger source rocks probably recently reached maturity only in structurally lowest areas. Trap formation began in late Miocene time and continued intermittently to present.

Traps: Discovered and likely undiscovered traps include pinchouts, tilted lenses, folded or domed shelf, channel and lobe sands, differential compaction of shale over sand lobes or channels, faults (Young and Callaway, 1968), diagenetic/permeability barriers (Schneeflock, 1978; McGuire and others, 1983), and at least one hybrid hydrodynamic-gravity drainage trap (Chamberlain and Madrid, 1986). Seals are mostly low-permeability claystone, mudstone, or biogenic siliceous rocks. Discovered accumulations occur at depths from about 200 to 14,100 ft and range in thickness from about 5 to 2,400 ft.

Exploration status: Exploration is mature in most areas of the play. Larger oil discoveries (> 50 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are: Belridge North (post-middle Miocene) (1912, 59 MMBO, 65 BCFG), Belridge South (1911, 1.201 BBO, 355 BCFG), Buena Vista (all except Mya gas) (1909, 674 MMBO, 1.106 TCFG), Coles Levee North (post-middle Miocene)(1938, 164 MMBO, 249 BCFG), Coles Levee South (post-middle Miocene)(1939, 69 MMBO, 549 BCFG), Cymric: McKittrick Front and Welport (post-middle Miocene)(1909, 236 MMBO, 24 BCFG), Elk Hills (post-middle Miocene)(1911, 1.378 BO, 1.394 TCFG), Elk Hills: Northwest area (1973, 138 MMBO, 87 BCFG), Lost Hills (1910, 318 MMBO, 750 BCFG), McKittrick: Main area (1896, 199 MMBO, 34 BCFG), Midway-Sunset (1901, 2.752 BBO, 589 BCFG), Paloma (1939, 62 MMBO, 434 BCFG), and Yowlumne (1974, 117 MMBO, 96 BCFG)(California Division of Oil, Gas, and Geothermal Resources, 1993).

Sixteen smaller discoveries, including five with < 1 MMBO, contribute an additional 169 MMBO and 106 BCFG for a play total of 7.527 BBO and 5.838 TCFG. Undiscovered oil is likely to have gravities in the 10û API to 20û API range of discovered shallow accumulations, the 28û to 38û API range of discovered deeper reservoirs, or even higher gravities. Depths of undiscovered new-field accumulations mostly will be in the depth range of deeper discoveries or deeper.

Resource potential. A very large amount of oil has been found in this play and the largest undiscovered accumulations probably will be new pool or new area discoveries in existing fields, new field discoveries in the deeper eastern part of the play, and reservoirs in fine grained upper Miocene rocks that depend on recovery technology and economics. Most future new field discoveries will be subtle stratigraphic traps of moderate to small size and will be found at greater depth than discovered accumulations. At greater depth, diagenesis generally degrades reservoir properties, but in places, may be the mechanism for entrapment. Future developments in extraction technology may greatly increase oil production from the large volume of petroliferous mostly fine-grained upper Miocene rocks in this play.

1005. WEST SIDE FOLD BELT SOURCED BY PRE-MIDDLE MIOCENE ROCKS PLAY

The confirmed stratigraphic and structural-stratigraphic play consists oil and associated gas accumulations mostly in Eocene to middle Miocene sandstone reservoirs and Eocene fractured siliceous rocks in the west side of the San Joquin Basin. Several reservoirs as young as lower Pliocene are found in the Coalinga, California, region.

This play is distinctive because reservoirs are mostly in middle Miocene and older rocks, most oil is thought to be derived from pre-middle Miocene source rocks, and many traps have overprints of many periods of distinctive types of deformation. Structuring that affected trap formation include early Oligocene compression, later Oligocene extension, early Miocene extension, later Miocene compression, Pliocene extension, and Pliocene to Recent compression (Harding, 1976; Davis and Lagoe, 1988). Depositional systems and lithofacies are diverse (Graham, 1985).

The western play boundary is the San Andreas Fault Zone. The northern play boundary is the likely northern extent of oil accumulations from pre-middle Miocene source rocks. The northern part of the eastern play boundary is the approximate northeast edge of the Neogene sub-basin and northeast limit of the west side structural style. The southern part of the eastern play boundary is the approximate eastern limit of significant Oligocene to present west side structuring that trapped oil from pre-middle Miocene source rocks. This boundary is located with less certainty because little drill-hole penetration of the pre-Miocene section is available in this area. The southern boundary is the White Wolf Fault Zone and its westward extension that generally terminate Neogene west side structuring against the late Neogene north-vergent thrusting and folding of the southern basin margin.

Reservoirs: Principal discovered reservoirs from oldest to youngest include the "Gatchell" sandstone of the Lodo Formation, Point of Rocks Sandstone Member of the Kreyenhagen Formation, "Oceanic" sand of the Tumey/Wagonwheel Formation, and Wygal, Agua, Carneros, and Buttonbed Sandstone Members of the Temblor Formation. Lower Pliocene sandstones also form reservoirs at the Coalinga field. Many other local sandstones of uppermost Cretaceous through lower Miocene age have reservoired oil. All sandstones are considered reservoirs for undiscovered accumulations. Fractured Keyenhagen Formation produces oil in the Kettleman North Dome, Kettleman Middle Dome, and possibly in the Kettleman City fields and is considered a possible reservoir where fracture porosity and permeability create economic accumulations. Discovered sandstone reservoirs have fair to excellent porosity and permeability.

Source rocks: Source rocks include from oldest to youngest the Moreno Formation (Upper Cretaceous), Kreyenhagen Formation (Eocene), Tumey/Wagonwheel Formation (Eocene-Oligocene), and Cymric (Salt Creek), Santos, and Media Shale Members of the Temblor Formation (Oligocene to Lower Miocene). Very small amounts of oil in the Coalinga and Vallecitos, California, areas are thought to be derived from the Moreno Formation, although the extent of Moreno rocks in the oil window is uncertain. The Kreyenhagen is oil-prone and mature in parts of the play area and is regarded as the primary source rock of this group. Shale units in parts of the Temblor Formation have also been described as oil prone and possibly mature in some structurally low areas.

Timing and migration: Oil generation and migration probably commenced by early to middle Miocene time in the Moreno Formation; by middle Miocene time in the Kreyenhagen Formation; and by latest Miocene or early Pliocene time in the Temblor Formation. Older traps formed at least as early as Oligocene and often include the effects of, or may have been destroyed by, later deformation. Some traps in the Coalinga, California, region formed as recently Pliocene-Recent and have negligible imprints of older structuring.

Traps: Most discovered traps involve truncations below unconformities, offlaps or overlapped faults with or without structural elements on homoclines, noses, domes, or anticlines. Hydrodynamic and permeability/diagenetic traps also are present in several places (Schneeflock, 1978). A wide variety of stratigraphic or combination trap types is expected for undiscovered accumulations. Seals are mostly low-permeability shale or other tightly cemented rocks. Traps vary widely in size. Discovered accumulations occur at depths from about 100 to 13,300 ft and range in thickness from about 6 to 1,500 ft.

Exploration status: Exploration is mature in parts of this play. Large oil discoveries (> 30 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are: Belgian Anticline (1946, 49 MMBO, 177 BCFG), Belridge North (Temblor and older reservoirs) (1912, 70 MMBO, 658 BCFG), Coalinga (1900, 906 MMBO, 226 BCFG), Coalinga East Extension (1938, 508 MMBO, 530 BCFG), Cymric: Salt Creek Main area (Temblor) (1946, 32 MMBO, 8 BCFG), Cymric: Welport and McKittrick Front areas (Temblor and older reservoirs) (1945, 35 MMBO, 80 BCFG), Guijarral Hills: Main area (1948, 43 MMBO, 67 BCFG), Kettleman North Dome (1928, 460 MMBO, 2.962 TCFG),. and McKittrick: Northeast area (Temblor) (1964, 45 MMBO, 166 BCFG)(California Division of Oil, Gas, and Geothermal Resources, 1993). Forty-six smaller discoveries, including 24 with < 1 MMBOE, contribute an additional 145 MMBO and 441 BCFG for play totals of 2.293 BBO and 5.315 TCFG.

Undiscovered oil is likely to have gravities in the 10û API to 20û API range of discovered shallow accumulations to as high as the 50û API to 60û API range of discovered deeper reservoirs. Depths of undiscovered accumulations mostly will be in the depth range of deeper discoveries or deeper.

Resource potential: Many areas of the play have not thoroughly tested because pre-middle Miocene rocks are at great depth or traps are not evident. Diagenesis reduces expectations for discovery of good quality reservoirs at greater depth, but fractured rock reservoirs might be present. Stratigraphic and structural complexity of the play suggests that accumulations of moderate to small size will continue to be found, mostly in subtle stratigraphic, combination, or diagenetic traps.

1006. NORTHEAST SHELF OF NEOGENE BASIN PLAY

The confirmed structural-stratigraphic play consists of oil and associated gas accumulations in Paleocene through Miocene marine to nonmarine sandstones located on the more-or-less stable northeast shelf and upper slope of the Neogene sub-basin. The play is distinguished by its location northeast of the thick accumulation of Neogene sediments and west side-style structuring, its mild deformation since Eocene time, and the likelihood that most oil is derived from pre-middle Miocene source rocks.

The southwest play boundary corresponds approximately to the northeast edge of the Neogene sub-basin, which in part also is the eastern limit of the structural style of the west side. The northern boundary is the approximate northern extent of oil accumulations derived from oil-prone source rocks in the southern San Joaquin Basin. The eastern boundary is drawn to include the area for which reservoir rocks, traps, and oil migration from mature source rocks seem possible. The south boundary is common with play 1002 and is somewhat arbitrarily drawn.

Reservoir rocks: Discovered and likely undiscovered reservoirs are sandstones in the Paleocene Lodo Formation, Eocene Domengine Sandstone and Kreyenhagen Formation, Miocene nonmarine Zilch Formation, and Miocene to lower Pliocene shallow-water Santa Margarita Formation. Discovered sandstone reservoirs have fair to good porosity and permeability.

Source rocks: Mature source rocks are believed to be mostly located in the extreme western part of the play and to the west and southwest of the play. The principal source rock is the Eocene Kreyenhagen Formation. The Upper Cretaceous Moreno Formation and Oligocene-lower Miocene shales of the Temblor Formation may be mature source rocks where they are most deeply buried, although firm evidence is lacking. Upper Miocene shales in the northeastern part of the Neogene sub-basin are believed to be mature only selectively in volumetrically small amounts.

Timing and migration: Oil generation in the Moreno Formation could have commenced by early to middle Miocene time. Oil generation and migration probably began by middle to late Miocene in the Kreyenhagen Formation and somewhat later in Temblor shales. Structural elements of traps appear to have formed prior to upper Miocene time (Callaway, 1971).

Traps: Discovered traps are mostly low-relief domes and anticlines with faulting and stratigraphic components. Depths of discovered accumulations range from about 4,700 to 9,200 ft and range in thickness from about 5 to 50 ft.

Exploration status: The relatively low potential area has been moderately explored. Larger oil accumulations (> 20 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are: Helm (1941, 32 MMBO, 79 BCFG), Raisin City (1941, 44 MMBO, 15 BCFG), and Riverdale (1941, 22 MMBO, 30 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Seven smaller discoveries, including four with < 1 MMBOE each, contribute an additional 5 MMBOand 4

BCFG for play totals of 103 MMBOand 128 BCFG at the end of 1992. Undiscovered oil probably has gravities in the 20û API to 49û API range of discovered accumulations. Depths of undiscovered accumulations mostly will be in the depth range of deeper discoveries or deeper.

Resource potential: The combination of inadequate volumes of nearby mature source rocks, mostly thin reservoir units, and generally small traps limit the potential for large amounts of undiscovered oil. Mostly small accumulations, principally in subtle stratigraphic or combination traps, remain to be discovered in this comparatively low-potential play.

1007. NORTHERN AREA NONASSOCIATED GAS PLAY

The confirmed stratigraphic and structural-stratigraphic play consists of non-associated gas accumulations in Late Cretaceous through Miocene marine to nonmarine sandstones located in the northern province area. The play is located in the south half of the late Mesozoic to early Paleogene forearc basin of the Great Valley and is almost entirely north of the oil province of the San Joaquin Basin. The play is distinguished by the apparent exclusive occurrence of non-associated gas accumulations derived from Upper Cretaceous shales.

The northern play boundary is the Stanislaus-San Joaquin County line and coincides with the province boundary. The eastern play boundary is the approximate eastern extent of possible gas accumulations derived from Cretaceous source rocks. The southern boundary, drawn slightly south of the southernmost non-associated gas discovery, is the approximate southern extent of possible non-associated gas accumulations derived from Cretaceous source rocks. The western play boundary, drawn in the upturned basin section along the eastern flank of the Diablo Range, excludes older Cretaceous rocks to the west that are unlikely to contain viable gas reservoirs.

Reservoirs: Potential reservoirs are sandstones in submarine fans, slope-channel deposits, prograding deltas, and shelf sequences that were deposited intermittently from east, north, and west sources during late Campanian through early Eocene time (Cherven, 1983; Callaway, 1964). Non-associated gas accumulations have been discovered in the sands of the Panoche, Moreno, and Lodo Formations, the Domengine Sandstone, basal sands of the Kreyenhagen Shale, and the nonmarine Zilch Formation (Rudkin, 1968). These sandstones bracket the entire section except for older Panoche sandstones. Undiscovered reservoirs are likely to be found in any of the above units. Discovered sandstone reservoirs have fair to good porosity and permeability.

Source rocks: Most Cretaceous shales of the Great Valley are gas prone, and the gas accumulations just north of the province presumably came from the Delta depocenter in the Sacramento Basin (Zieglar and Spotts, 1978; Callaway and Rennie, 1991). Gas generated in the Delta depocenter is unlikely to have migrated far into the play because of the intervening Stockton Fault and Arch. The absence of discovered gas fields in the northern San Joaquin Province has been attributed to the high sand/shale ratio of potential Cretaceous source rocks and relatively low geothermal gradient (Callaway and Rennie, 1991). Source rocks for the comparatively small amounts of discovered non-associated gas in this play probably are shales in the very thick Cretaceous section in the basin trough just east of the Diablo Range. Paleocene to lower Eocene gas-prone shales may also be source rocks.

Timing and migration: Generation and migration of gas in the Cretaceous section of the northern San Joaquin Province probably began in Late Cretaceous or early Paleogene time, based on the great thickness of Upper Cretaceous rocks exposed on Joaquin Ridge just north of Coalinga, California. Stratigraphic traps were immediately available in the Upper Cretaceous section, and structuring during and after Paleocene time provided subsequent combination and structural traps.

Traps: Discovered accumulations occur in stratigraphic traps in shelf facies and gentle anticlines with stratigraphic components and minor faulting. The Upper Cretaceous through lower Eocene section contains a number of angular unconformities; disconformities; locally thick, condensed or missing units; transgressive-regressive cycles; and structural deformation that, in combination, present a variety of possible stratigraphic trapping mechanisms. Discovered accumulations occur at depths from about 2,700 to 8,000 ft and range in thickness from about 5 to 200 ft.

Exploration status: Exploration has been sporadic and moderate in this play. Until 1988, all significant discoveries of new non-associated gas accumulations had been made between 1934 and 1943, except for the minimal discovery of the San Joaquin Northwest field in 1965. In 1988 a new pool discovery of gas in Panoche sandstones in the Gill Ranch field was quickly followed by another discovery in Panoche sandstones about 17 mi to the northwest.

Larger gas discoveries (> 30 BCFG) with discovery year and cumulative production plus estimated reserves through 1992 are: Chowchilla (1934, 35 BCFG) and Gill Ranch (1943, 83 BCFG) (Division of Oil, Gas, and Geothermal Resources, 1993). Four smaller discoveries, including two with < 6 BCFG each, contribute an additional 32 BCFG for a play total of 150 BCFG. Undiscovered gas is likely to have compositions and heating values similar to the 43 to 98 mole percent methane and 400 to 1,170 BTU/CFG ranges of discovered gas. Nitrogen is abundant in gases with lower mole percent methane. In the Cheney Ranch field, 118 MB of 50û API oil also was produced along with natural gas. Depths of undiscovered accumulations mostly will be in the depth range of discovered gas or deeper.

Resource potential: Most easily detected structures have been tested in this play, although large areas remained undrilled. 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 account for some future discoveries. Discovery for the first time of a high-heat-value gas in Panoche sandstones in 1988 may portend future Panoche discoveries. The probability of discovery of non-associated gas accumulations less than 6 BCFG is very high. Discovery of large accumulations is improbable. Discovery of reservoirs that also produce small amounts of high-gravity oil or condensate is possible in the southernmost part of the play.

1008. TEJON PLATFORM PLAY

The confirmed stratigraphic and structural-stratigraphic play consists of oil and associated gas accumulations in upper Eocene through upper Miocene sandstones located on the Tejon Platform in the extreme southeast part of the San Joaquin Province (Goodman and Malin, 1988). The play is distinguished as a separate structural block that had separate south-sourced Miocene deposystems. While trap type and mild deformation generally are similar to the Southeast Stable Shelf Play (1002), burial and paleotemperature history were different, some discovered oils are genetically distinct and come from pre-upper Miocene source rocks, and the marine shelf from late Oligocene to latest Miocene time was narrower so that more turbidites were deposited.

The northern play boundary is the White Wolf Fault Zone. The eastern and part of the southern play boundaries is the contact between sedimentary units and basement rocks of the Tehachapi Mountains. The southwestern play boundary is the northeast-verging Pleito Thrust Fault that separates this play from the Southern Thrust Salient Play (1009).

Reservoirs: Discovered accumulations occur in southeast-sourced Miocene shelf, ramp(?), and turbidite sandstones (Hirst, 1988) and in upper Eocene and lower Oligocene marine sandstones. These sandstones are the primary targets for undiscovered accumulations. None of the above units have been reached by drill north of the White Wolf Zone, except to the east, south of the town of Arvin, California, in play 1002 (Kiser and others, 1987). Discovered sandstone reservoirs have fair to good porosity and permeability.

Source rocks: Principally middle Miocene, Round Mountain, and Lower Fruitdale shales, both south and north of the White Wolf Fault Zone, probably are the principal source rocks for reservoired oil in the younger, structurally higher reservoirs. Distinctive oils in older reservoirs on the Tejon Platform probably come from one or more shale units in the Eocene through lower Miocene section (Tejon, San Emigdio, Freeman-Jewett sequences).

Timing and migration: Generation and migration of hydrocarbons from Eocene to lower Miocene shales probably began as early as middle Miocene time. Generation and migration from principally middle Miocene shales probably began in middle to late Pliocene time. Structural trapping elements started to form at least by early to middle Miocene time.

Traps: Discovered traps include truncations, pinchouts, permeability barriers, normal faults on gently dipping anticlines, and a generally north-dipping homocline with a permeability barrier. In the distinctive Wheeler Ridge field, north-vergent thrust faults on a prominent anticline contribute to trap formation. Any of these trap types may be responsible for undiscovered accumulations. Discovered traps occur at depths from about 450 to more than 11,000 ft and range in thickness from about 5 to 2,000 ft.

Exploration status: The Tejon Platform is well drilled with progressively fewer exploratory wells located northwestward to and into the White Wolf Fault Zone. Larger oil discoveries (> 10 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are: Tejon: Central area (1937, 17 MMBO, 16 BCFG), Tejon: Western area (1945,14 MMBO, 4 BCFG, Tejon Hills (1948, 14 MMBO, 3 BCFG), Tejon North (1956, 24 MMBO, 230 BCFG), Wheeler Ridge: Central area (1923, 40 MMBO, 77 BCFG), and Wheeler Ridge: Windgap area (1959, 16 MMBO, 10 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Seven smaller discoveries, including three with < 1 MMBOE each, contribute an additional 8 MMBOand 7 BCFG for play totals of 133 MMbbls and 347 BCFG. Undiscovered oil is likely to have gravities similar to those of discovered accumulations--16û API in shallow reservoirs to as high as 44û API in deeper reservoirs. One small gas-condensate reservoir occurs in the Windgap area of the Wheeler Ridge field.

Resource potential: There is high probability that small accumulations will be discovered in the explored areas because of the complexity of the turbidite depositional systems and likely subtle stratigraphic, diagenetic or combination traps. Medium-sized undiscovered accumulations associated with the White Wolf Fault Zone along the northern play boundary are possible, but reservoir-degrading diagenesis increases with depth.

1009. SOUTH END THRUST SALIENT PLAY

The confirmed structural-stratigraphic play consists of oil and associated gas accumulations in Eocene through Pliocene marine sandstone in the extreme southwest corner of the San Joaquin Province. The play is distinguished by its complex structural history of multiple periods of folding and north-vergent thrust faulting separated by periods of normal faulting (Davis and Lagoe, 1988). Extensive overthrusting is postulated by balanced-cross-section analysis (Davis and others, 1987). Proximal to distal facies in upper Eocene through lower Miocene sediments generally extend from east to west or northwest (Nilsen, 1987; DeCelles, 1986, Lagoe, 1987). In contrast, facies development in overlying upper Miocene to Recent rocks generally is south to north in conformity with the Neogene sub-basin margin.

The northern play boundary is the White Wolf Fault Zone and its westward extension. The eastern play boundary is the Pleito Thrust Fault. The southern boundary is the suggested southern extent of postulated sub-detachment sedimentary units. The western play boundary is somewhat arbitrarily drawn to approximately separate the south-southeast structural trends in the Temblor Range from the west-northwest structural trends in the San Emigdio Mountains.

Reservoirs: Discovered and likely undiscovered reservoirs from oldest to youngest include sandstones in the Eocene Tejon Formation, Oligocene-middle Miocene Temblor Formation, and Miocene-Pliocene Etchegoin Formation. Discovered reservoirs have poor to excellent porosity and permeability.

Source rocks: Principally middle Miocene Round Mountain and Lower Fruitdale shales and their western equivalents, the Devilwater, McDonald and McLure shales in the adjacent deep Neogene sub-basin to the north probably were the source of oil in the youngest reservoir rocks. Limited amounts of distinctive oil found in older reservoir rocks in this play and play 1008 probably were sourced from shales of the Eocene age Tejon and San Emigdio Formations, Oligocene age Pleito Formation, and (or) Oligocene-Miocene age Temblor Formation.

Timing and migration: Generation and migration of hydrocarbons from principally middle Miocene shales probably began in middle to late Pliocene time. Generation and migration from older shales is less certain in this area but probably commenced no later than middle Miocene time. Structural history of this play indicates that trap formation (and destruction) has occurred intermittently since the Oligocene.

Traps: Discovered traps include folds and fault truncations in hanging-wall and footwall blocks of the White Wolf and Pleito Fault Zones. A small accumulation occurs in an apparent sandstone lense on the flank of a homocline. Undiscovered traps will have structural, stratigraphic or combination elements. Secondary porosity, fracturing, and permeability barriers may influence traps. Seals are low-pemeability shales or fault zones. Trap size probably will be small. Discovered traps occur at depths from about 815 to 13,000 ft and range in thickness from about 50 to 750 ft.

Exploration status: Exploration in hanging-wall blocks is mature. Exploration in footwall or sub-detachment blocks is extensive but less mature. The largest oil discovery with discovery year and cumulative production plus estimated reserves through 1992 is: Pleito: Ranch area (1957, 9 MMBO, 6 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Five smaller oil discoveries, including three with < 1 MMBOE each, contribute an additional 4 MMBO and 8 BCFG for play totals of 13 MMBO and 14 BCFG at the end of 1992. Undiscovered oil is likely to have gravities similar to those of discovered accumulations--14û API to 19û API in shallow reservoirs to as high as 46û API in deeper reservoirs. Depths of undiscovered accumulations are in the depth range of deeper discovered reservoirs or deeper.

Resource potential: Discovery of additional accumulations is likely because of complex structure and incomplete exploration of sub-detachment structures. Most undiscovered accumulations probably are small due to questionable size and quality of possible reservoir rocks. Risks are connected with uncertainties of postulated sub-detachment structures, probabilities of suitable reservoir rocks, the availability and timing of reservoir charging with oil or gas, and reservoir preservation in the most tectonically disrupted area of the San Joaquin Province.

1010. EAST CENTRAL BASIN AND SLOPE NORTH OF BAKERSFIELD ARCH PLAY

The confirmed stratigraphic and structural-stratigraphic play consists of oil and associated gas accumulations in Eocene through Pliocene marine to nonmarine sandstones in the east-central part of the Neogene sub-basin. The play is distinctive because of the comparative absence of discovered oil accumulations and limited numbers of internal and marginal trapping structures that are more abundant in other play areas.

The western play boundary is the approximate eastern limit of significant west side-type structuring during the Neogene, although Buttonwillow, Bowerbank, and Semitropic Anticlines in the southwest corner of the play probably are associated with west side structuring. The north and east play boundaries approximately coincide with the average position of the marine shelf edge/slope during upper Miocene and lower Pliocene time. The western part of the southern play boundary is drawn to approximate the northern limit of "Stevens" sandstone deposition (play 1003) and is drawn eastward somewhat arbitrarily to meet the western boundary of the Southeast Stable Shelf Play (1002). These boundaries have the effect of leaving only minor discovered oil accumulations in the play.

Reservoir rocks: Discovered and likely undiscovered sandstone reservoirs occur in the Oligocene-Miocene Vedder Sand, Freeman Silt, and Jewett Sand, and in the Pliocene Etchegoin Formation. Fractured shale of the Kreyenhagen Formation forms a minor reservoir in the Wasco field in the southwest part of the play. Other sandstones of the Miocene and Pliocene marine and nonmarine sequences are present and may form reservoirs. Older sandstones in the Paleocene Lodo Formation, Eocene Domengine Sandstone, and Famoso Formation might contain accumulations but are more problematical reservoirs because they are stratigraphically and usually structurally below the most favorable source rocks (Reid, 1988). Discovered sandstone reservoirs have poor to good porosity and permeability.

Source rocks: Principal source rocks presumably are shales of the Eocene Kreyenhagen and Oligocene-lower Miocene Temblor Formations in the western play area where they are most deeply buried. Middle Miocene shales in this northeastern part of the Neogene sub-basin may be only selectively or marginally mature in volumes that are much smaller than volumes in areas west and south of the play.

Timing and migration: Oil generation and migration probably began by middle to late Miocene in the Kreyenhagen Formation and by middle to late Pliocene in Miocene shales. Upper Miocene and younger source rocks probably reached maturity only recently and selectively in structurally lowest areas. Prominent gentle anticlines in the southwest corner of the play began forming during latest Pliocene or Pleistocene time and may have deep-seated fault control. The structuring of the Greely-Wasco Trend appears to have begun before or during Miocene with little post-Miocene movement.

Traps: Discovered traps include anticlines with and without faulting and stratigraphic components. The trapping mechanism of the fractured shale reservoir in the Wasco field is unknown. Discovered traps occur at depths from about 7,400 to 17,600 ft and range in thickness from about 40 to 2,750 ft.

Exploration status: Parts of this play are moderately well explored. Oil discoveries (> 1 MMBO) with discovery year and cumulative production plus estimated reserves through 1992 are: Semitropic (Oligocene, Pliocene sandstones) (1935, 3 MMBO, 1 BCFG) and Wasco (Eocene fractured shale; Oligocene, Pliocene sandstones) (1938, 5 MMBO, 3 BCFG) (California Division of Oil, Gas, and Geothermal Resources, 1993). Three smaller discoveries, each with < 1 MMBOE, do not add significantly to the total discovered oil and gas in the play. Undiscovered oil is likely to have gravities in the 28û API to 42û API range of discovered accumulations. Depths of undiscovered accumulations will be in the depth range of discovered oil or deeper.

Resource potential: The comparatively few discovered accumulations in this play suggest a weak element in the necessary progression of generation, migration and entrapment of oil. Compared to the southern San Joaquin Basin as a whole, oil generation probably has been less prolific in this play, although still adequate. Migration pathways, especially faults, appear to be less abundant than elsewhere. Development of large-scale structures over extended periods of time did not occur in this play. Gentle anticlines in the southwest corner of the play are very young and appear to have not yet entrapped much oil. Also, the ratios of discovered trap numbers or areas to overall play area is very small compared to most other plays. Stratigraphic trapping is less well evaluated. Seals to prevent updip migration to the east are uncertain for much of the play area. Deeply buried sandstones may be poor reservoirs due to diagenesis but may be fractured locally. Comparatively very small accumulations will be discovered. Discovery of medium-sized accumulations is very problematical except possibly in fractured rocks or in stratigraphic traps that are presently unrecognized.

1011. DEEP, OVERPRESSURED FRACTURED ROCKS OF WESTSIDE FOLD AND OVERTHRUST BELT PLAY

This hypothetical play consists of non-associated gas reservoirs in fractured rock that might exist, perhaps aided by abnormal fluid pressures (Berry, 1973; Yerkes and others, 1990; Unruh and others, 1992), at great depth in traps due to the postulated fold and thrust belt structuring along the west side of the San Joaquin Basin (Wentworth and others, 1984; Namson and Davis, 1988; Medwedeff, 1989).

The play boundary is drawn to include areas where known folds are suspected to be related to blind thrusts and areas westward where sub-detachment sedimentary wedges due to all periods of overthrusting might be located.

Reservoirs: Reservoirs are postulated to be fractured rocks, possibly as young as Miocene in some areas but more likely to be Upper Cretaceous or Paleogene age in thrust-system blocks or fold-bend kinks at depths of about 13,000 to 26,000 ft.

Source Rocks: Source rocks are postulated to be primarily gas-prone Upper Cretaceous shales and, secondarily, oil-prone Paleogene shales mostly in or below the gas window. Source rocks of Miocene age might occur in selected areas.

Timing and migration: Maturation and expulsion of natural-gas fluids from Cretaceous shales probably began prior to or during Paleocene time. Oil generation and expulsion are believed to have begun from the Eocene-aged Kreyenhagen Formation by middle to late Miocene time and from younger shales by latest Miocene and Pliocene time. Postulated trap formation might be related to west-directed folding and thrusting during Oligocene to early Miocene time or to later structuring, especially east-directed folding and thrusting during late Cenozoic time.

Traps: Hypothetical fractured rock traps might be (1) a function of lithofacies, (2) localized stress concentrations such as may occur near fold bends or faults, (3) structurally bounded reservoirs due to faulting or folding mainly beneath detachment faults, or (4) traps caused by diagenetically sealed rocks adjacent to bodies of fractured rocks.

Exploration status: Moderately deep wells along the west side of the San Joaquin Province confirm the presence of abnormally high pore-fluid pressures, and a few are compatible with postulated large-scale detachment faulting. However, moderately deep drilling results indicate that occlusion of intergranular porosity is likely at great depth, unless accompanied by abnormal fluid pressure. Also, deeper wells drilled along the west side have not unambiguously examined much of the postulated blind fold and east-vergent thrust-system models. Observed high pore-fluid pressures along the west side may be due to tectonic compression and (or) generation of hydrocarbon or diagenetic fluids during burial.

Resource potential: Source rocks in the sedimentary section of the San Joaquin Basin indicate that gas generation at great depth along the west side is conceivable. The probability of traps and charged, viable reservoirs at great depth in postulated sub-detachment blocks and imbricate or back-thrust structures is extremely low but is perhaps worthy of further examination.

UNCONVENTIONAL PLAYS

There are no unconventional plays described in this province report. However, unconventional plays listed in the surrounding provinces may include parts of this province. Individual unconventional plays are usually discussed under the province in which the play is principally located.

REFERENCES

Beyer, L. A., and Bartow, J. A., 1988, Summary of geology and petroleum plays used to assess undiscovered recoverable petroleum resources, San Joaquin Basin Province, California: U. S. Geological Survey Open-File Report 87-450Z, 80 p., 4 pls.

Berry, F. A. F., 1973, High fluid potentials in the California Coast Ranges and their tectonic significance: American Association of Petroleum Geologists Bulletin, v. 57, p. 1219-1249.

Bowersox, J. R., 1990, Geology of the Belridge diatomite, northern South Belridge field, Kern County, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 215-223.

California Division of Oil, Gas, and Geothermal Resources, 1993, 78th Annual Report of the State Oil & Gas Supervisor: California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. PR06, 163 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.

Callaway, D. C., 1971, Petroleum potential of San Joaquin Basin, California, *in* Cram, U. S., 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., 1990, Organization of stratigraphic nomenclature for the San Joaquin Basin, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, Society of Economic Paleontologists and Mineralogists Publication 64, American Association of Petroleum Geologists Publication GB65, p. 5-21.

Callaway, D. C., and Rennie, E. W., Jr., 1991, San Joaquin Basin, California, *in* Gluskoter, H. J., Rice, D. D., Taylor, R. B., eds., Economic Geology, U. S., The Geology of North America: Geological Society of America, v. P-2, p. 417-430.

Chamberlain, E. R., and Madrid, V. M., 1986, Influence of uplift on oil migration: Tulare heavy oil accumulations, west side San Joaquin Valley, California [abs.]: American Association of Petroleum Geologists Bulletin, v. 70, p. 940.

Cherven, V. W., 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.

Church, H. V., 1965, Pliocene gas and oil in the Semitropic-Trico area, San Joaquin Valley, California, *in* Rennie, E. W.,ed., A symposium of papers presented at the Annual Pacific Section: American Association of Petroleum Geologists Convention, 40th, 1965, p. 20-39.

Davis, T. L., and Lagoe, M. B., 1988, A structural interpretation of major tectonic events affecting the western and southern margins of the San Joaquin Valley, California, *in* Graham, S. A., and Olson, H. C., eds., Studies of the geology of the San Joaquin Basin: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 60, p. 65-87.

Davis, T. L., Namson, J. S., Dibblee, T. W., Jr., and Lagoe, M. B., 1987, Structural evolution of the western Transverse Ranges, *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. 99-156.

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

Farley, Thomas, 1990, Heavy oil reservoirs in the Tulare fold belt, Cymric-McKittrick fields, Kern County, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 181-203.

Fischer, K.J., Heasler, H.P., and Surdam, R.C., 1988, Hydrocarbon maturation modeling of the Tertiary San Joaquin basin, California, *in* Graham, S.A., and Olson, H.C., eds., Studies of the geology of the San Joaquin Basin: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 60, p. 53-64.

Goodman, E. D., and Malin, P. E., 1988, Comments on the geology of the Tejon Embayment from seismic reflection, borehole, and surface data, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 89-108.

Graham, S. A., ed., 1985, Geology of the Temblor Formation, western San Joaquin Basin, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 44, 202 p.

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.

Hewlett, J. S., and Jordan, D. W., [in press], Stratigraphic and combination traps within a seismic sequence framework, Miocene Stevens turbidites, Bakersfield Arch, California: American Association of Petroleum Geologists Memoir, in press.

Hirst, B. M., 1988, Early Miocene tectonism and associated turbidite deposystems of the Tejon area, Kern County, California, *in* Graham, S. A., and Olson, H. C., eds., Studies of the geology of the San Joaquin Basin: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 60, p. 207-221.

Kiser, S. C., Foss, Charles, Reid, S. A., Metz, Randy, and Hirst, Brian, 1987, Correlation Section 25, San Joaquin Valley, California: American Association of Petroleum Geologists, Pacific Section, 1 sheet.

Kodl, E. J, Eacmen, J. C., and Coburn, M. G., 1990, A geologic update of the emplacement mechanism within the Kern River Formation at the Kern River field, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists and Mineralogists, v. 64, p. 59-71.

Lagoe, M. B., 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.

Link, M. H., Helmold, K. P., and Long, W. T., 1990, Depositional environments and reservoir characteristics of the upper Miocene Etchegoin and Chanac Formations, Kern Front oil field, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 215-223.

Lohmar, J. M., 1984, Heavy oil production from fractured schist and alluvial fan reservoirs of the Edison oil field, San Joaquin Valley, California: San Joaquin Geological Society, Selected Papers, v. 6, p. 32-39.

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, p. 2243-2274.

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, Pacific Section, p. 171-183.

McPherson, J. G., and Miller, D. D., 1990, Depositional settings and reservoir characteristics of the Plio-Pleistocene Tulare Formation, South Belridge field, San Joaquin Valley, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 215-223.

Medwedeff, D. A., 1989, Growth fault-bend folding at southeast Lost Hills, San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 73, p. 54-67.

Metz, R. T., and Whitworth, J. L., 1984, The Yowlumne oil field: The first ten years: Selected Papers, San Joaquin Geological Society, v. 6, p. 3-23.

Namson, J. S., and Davis, T. L., 1988, Seismically active fold and thrust belt in the San Joaquin Valley, central California: Geological Society of American Bulletin, v. 100, p. 257-273.

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

Olson, H. C., 1988, Oligocene-Middle Miocene depositional systems north of Bakersfield, California: Eastern basin equivalents of the Temblor Formation, *in* Graham, S. A., and Olson, H. C., eds., Studies of the Geology of the San Joaquin Basin: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 60, p. 189-205.

Phillps, S. C., 1993, Declining oil giants significant contributors to U. S. production: Oil and Gas Journal, v. 91, p. 100-103.

Quinn, M. J., 1990, Upper Miocene Stevens sands in the Maricopa depocenter, southern San Joaquin Valley, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 97-113.

Reid, S. A., 1988, Late Cretaceous and Paleogene sedimentation along the east side of the San Joaquin Basin, *in* Graham, S. A., and Olson, H. C., eds., Studies of the geology of the San Joaquin Basin: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 60, p. 157-171.

Reid, S. A., 1990, Trapping characteristics of upper Miocene deposits, Elk Hills field, Kern County, California, *in* Kuespert, J. G., and Reid, S. A., eds., Structure, stratigraphy and hydrocarbon occurrences of the San Joaquin Basin, California: Pacific Sections, American Association of Petroleum Geologists, v. GB65, Society of Economic Paleontologists, v. 64, p. 141-156.

Rudkin, G. H., 1968, Natural gas in San Joaquin Valley, California, *in* Beebe, B. W., ed., Natural gases of North American: American Association of Petroleum Geologists Memoir 9, v. 1, p. 113-134.

Sanem, R. E., and Stoddard, R. R., 1965, Strati-structural traps in the Stevens sand [abs.]: American Association of Petroleum Geologists Bulletin, v. 49, p. 1089.

Schneeflock, T.R., 1978, Permeability traps in Gatchell (Eocene) sand of California: American Association of Petroleum Geologists Bulletin, v. 62, p. 848-853.

Schwartz, D. E., 1988, Characterizing the lithology, petrophysical properties, and depostional setting of the Belridge diatomite, South Belridge field, Kern County, California, *in* Graham, S. A., and Olson, H. C., eds., Studies of the geology of the San Joaquin Basin: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 60, p. 281-301.

Stolle, J. M, Nadolny, K. A., Collins, B. P., Greenfield, D. S., and March, K. A., 1988, Landslide oil field, Kern County, California: A success story--An exploration/development case history: Selected Papers, San Joaquin Geological Society, v. 7, p. 1-13.

Tye, R. S., Hewlett, J. S., Thompson, P. R., Goodman, David, [in press], Integrated stratigraphic and depositinal facies analysis of parasequences in a transgressive systems tract, San Joaquin Basin, California: American Association of Petroleum Geologists Memoir.

Unruh, J. R., Davisson, M. L., Criss, R. E., and Moores, E. M. 1992, Implications of perennial saline springs for abnormally high fluid pressures and active thrusting in western California: Geology, v. 20, p. 431-434.

Varnes, K. L., and Dolton, 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, ll p.

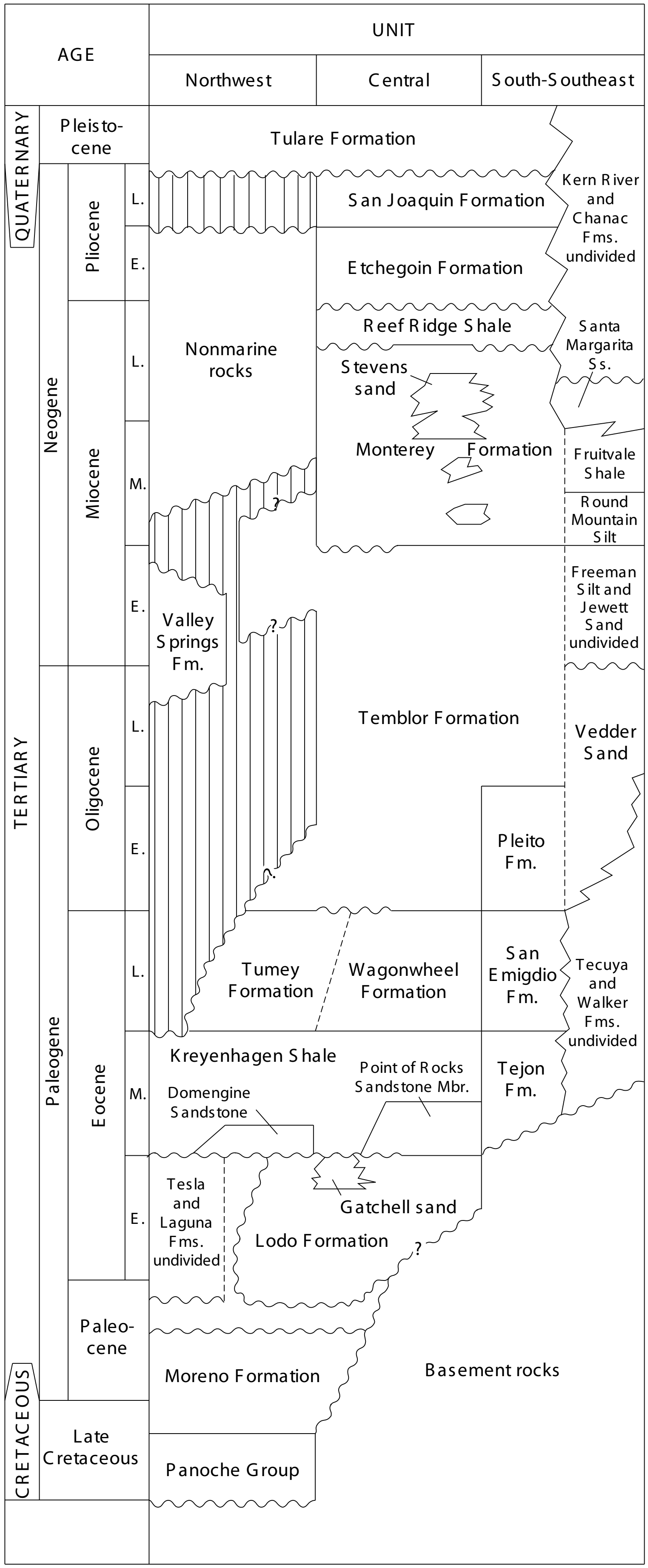
Webb, G. W., 1981, Stevens and earlier Miocene turbidite sandstones, southern San Joaquin Valley, California: American Association of Petroleum Geologists Bulletin, v. 65, p. 438-465.

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., Jr., ed., Franciscan geology of northern California: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 43, p. 163-173.

Yerkes, R. F., Levine, P., and Wentworth, C. M., 1990, Abnormally high fluid pressures in the region of the Coalinga earthquake sequence and their significance, *in* Rymer, M. J., and Ellsworth, W. L., eds., The Coalinga, California, earthquake of May 2, 1983: U. S. Geological Survey Professional Paper 1487, p. 235-257.

Young, R. J., and Callaway, D. C., 1968, West side oil fields: Subsurface map committee, *in* 1968 Guidebook, Geology and Oilfields, West side southern San Joaquin Valley: Pacific Sections, American Association of Petroleum Geologists, Society of Exploration Geophysicists, Society of Economic Paleontologists and Mineralogists Annual Meeting, 43rd, 1968, p. 56-85.

Zieglar, J. S., and Spotts, J. H., 1978, Reservoir and source-bed history of Great Valley, California: American Association of Petroleum Geologists Bulletin, v. 62, p. 813-826.


AGE
UNIT
Northwest
Central
South-Southeast
QUATERNARY
TERTIARY
CRETACEOUS
Neogene
Paleogene
Pleisto-cene
Pliocene
Miocene
Oligocene
Eocene
Paleo-cene
Late Cretaceous
L.
E.
M.
Tulare Formation
San Joaquin Formation
Kern River and Chanac Fms. undivided
Etchegoin Formation
Reef Ridge Shale
Santa Margarita Ss.
Nonmarine rocks
Stevens sand
Monterey Formation
Fruitvale Shale
Round Mountain Silt
Freeman Silt and Jewett Sand undivided
Valley Springs Fm.
Temblor Formation
Vedder Sand
Pleito Fm.
Tumey Formation
Wagonwheel Formation
San Emigdio Fm.
Tecuya and Walker Fms. undivided
Kreyenhagen Shale
Point of Rocks Sandstone Mbr.
Tejon Fm.
Domengine Sandstone
Tesla and Laguna Fms. undivided
Gatchell sand
Lodo Formation
Moreno Formation
Basement rocks
Panoche Group
?