VENTURA BASIN PROVINCE (013)

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INTRODUCTION

The Ventura Basin Province of Southern California consists of the portion of the Western Transverse Ranges that is bounded approximately on the north by the Santa Ynez and Big Pine Faults, on the northeast and east by the San Andreas Fault, on the west by the 3-mi limit of State waters, and on the south by the Santa Monica-Malibu Coast fault system and the 3-mi limit of State waters of the Santa Barbara-Ventura coastal area. The province is as much as 54 mi wide and 183-mi long. It covers approximately 4,327 sq mi on land, including the Northern Channel Islands, and contains an additional 1,018 sq mi of State waters, including the area around the islands.

The province contains a Cretaceous to Pleistocene, mostly marine, sedimentary section in a major fold and thrust belt that began developing during the late Pliocene. The Ventura Basin is the onshore part of the main structural downwarp that formed during this deformation; its foundered offshore extension is the modern Santa Barbara Basin. All of the sedimentary section is productive somewhere in the province, and most reservoirs are sandstones with favorable porosity and permeability. The major ones, of Pliocene and Miocene age, comprise 75-80 percent of the on-land plus State waters production in the province. In general, most traps are anticlinal, modified to some degree by faults and with significant stratigraphic influence.

Six plays are described for the province: the Paleogene–Onshore Play, (1301); the Paleogene–Offshore State Waters Play (1311); the Neogene–Onshore Play (1302); the Neogene–Offshore State Waters Play (1312); the Pliocene Stratigraphic Play (1303); and the Cretaceous Play (1304). Undiscovered petroleum resources are assessed for the Paleogene and Neogene Plays (resource for the Pliocene Play is added to the Neogene Play), but the Cretaceous Play, which was determined to have a low probability of occurrence of an accumulation >1 MMBO or 6 BCFG was not quantitatively assessed. The State waters and onshore areas of these plays are the subject of this report.

The first field discovered in the Ventura Basin was Santa Paula in 1861. Since then, approximately 96 oil and gas fields (depending on how accumulations are grouped) have been discovered, 66 of which have ultimate recovery greater than 1 MMBO or 6 BCFG. Nine gas fields are present along the Santa Barbara coast, but most of the province contains oil accumulations localized along several major anticlinal trends. The

most productive is the Rincon trend with several very large Pliocene accumulations. The largest is made up of three giant (>100 MMBO) fields, Ventura Avenue, Rincon, and San Miguelito, whose combined ultimate recovery is estimated at 1,530 MMBO, 2.65 TCFG, and 153 MMBNGL. Several other important anticlinal trends also contain giant fields. The most recent new field discovery in the onshore area of the province is Rincon Creek found in 1982. New drilling has mainly focused on locating new pools and extending existing fields, with very minor exploration outside of existing fields. In the offshore, where most exploration has focused since the late 1950's and early 1960's–although limited by State and Federal leasing regulations–the most recent new field discovery in State waters is Santa Clara, found in 1971. Cumulative production in the province through 1990 is approximately 2,640 MMBO, 4.64 TCFG, and 160 MMBNGL.

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CONVENTIONAL PLAYS

1301. PALEOGENE–ONSHORE PLAY
1311. PALEOGENE–OFFSHORE STATE WATERS PLAY

Description: The Paleogene Play consists primarily of oil and associated gas accumulations, with condensate, in structural and combination traps. Stratigraphic traps are rare. Non-associated gas is also produced from nine fields in State waters and along the Santa Barbara coast. Reservoirs are sandstones of Paleocene to early Miocene age. Excluding non-prospective and basement areas of the eastern part of the province, the play area includes almost the total remaining province, with the assumption that a Paleogene and (or) lower Miocene section has some potential if present at depths greater than about 20,000-25,000 ft in the Santa Clara Trough.

Reservoirs: Important reservoirs are sandstones of the nonmarine, Eocene to early Miocene Sespe Formation in the areas both north and south of the Santa Clara Trough. The Sespe commonly has good to excellent reservoir properties and is up to 7,000 ft thick in the subsurface. Another important reservoir, commonly coproduced with the Sespe, is the overlying shallow-marine Vaqueros Formation. The Vaqueros is up to 300 ft thick, has excellent reservoir properties in places, and is overlain by the Rincon Shale–an excellent regional seal. Limited porosity and permeability data from Vaqueros and Sespe reservoirs show a range of 10-30 percent porosity and 18-900 mD permeability. Average reservoir thickness ranges from 50-3,000 ft, and the average depth to the top of reservoirs is 100-11,500 ft. Other reservoirs of minor importance are the Matilija Formation, Coldwater Sandstone, and Llajas Formation of Eocene age. Paleocene clastic rocks south of the Santa Clara Trough are also minor reservoirs.

Source rocks: Source rocks are probably mainly the organic-rich mudrocks of the Rincon Shale and Monterey, Modelo, Sisquoc, and Santa Margarita Formations. However, carbon isotopic data suggest that another hydrocarbon source, probably Eocene marine shale, is present in the western coastal area of the play. Marine shale of the Paleocene-Eocene Santa Susana Formation and the Eocene Llajas Formation also appear to be suitable sources south of the Oak Ridge Fault where oil is produced from Sespe sandstones and interbedded sandstones in the Llajas. Most hydrocarbons in the play were probably generated from Miocene source rocks in the Santa Clara Trough and other deep areas. Migration from Miocene and possibly older source rocks probably took place after the onset of late Pliocene compressional tectonics, which formed most of the structural traps. Burial reconstructions north of the Santa Clara

Trough suggest that Eocene and older source rocks could have generated hydrocarbons before and during the early Miocene, before the 90¡ Miocene rotation of the province to its present orientation. South of the trough along the Oak Ridge Trend, recent reconstructions by Hathon (1992) show that the Paleocene and Eocene Santa Susana "Shale" entered the early phase of generation on the crest of South Mountain during the late Pliocene and the main phase of generation on the flanks of South Mountain during the Pleistocene.

Traps: Traps are mainly anticlines and faulted anticlines. South of the Oak Ridge Fault along the Oak Ridge Trend, the major producing trend in the play, anticlinal accumulations in Eocene and Oligocene sandstones are found in numerous oil fields. Other important anticlinal trends parallel the Santa Barbara coast. Additional traps include a homocline with tar seal and other permeability barriers, significant unconformities, and closure created by faults and dip reversals. Marine shale units within the Paleogene and Neogene sequences all provide seals. The areas of maximum production range from 50 acres at the Oat Mountain field to 2,970 acres for the Sespe field. Many fields produce from multiple stacked reservoirs in more than one formation--accounting for large volumes of petroleum production from relatively small land areas.

Exploration status: Since the discovery of the Sespe field in 1887, some areas of the play have been extensively explored, but not the rugged mountainous areas of the north or areas where a thick overlying Neogene sequence is productive. Of the 32 significant oil and gas fields in the play (>1 MMBO or 6 BCFG), 10 also produce from the Neogene section and 6 are gas fields. The largest oil accumulation in the South Mountain area has produced 124 MMBO from reservoirs in this play; the largest gas field, Molino Offshore, has produced 258 BCFG. The average size of the gas fields is 94 BCFG. Cumulative production in the play through 1990 is 525 MMBO, 1.23 TCFG, and 33.3 MMBNGL. In the onshore the average field size is approximately 28 MMBOE. In the offshore it is 17 MMBOE.

Resource potential: The play has a good to medium potential for undiscovered oil and gas. Although not well documented province wide, in many places the presence of laumontite as a pore-filling, especially in the pre-Miocene section, is an important limiting factor for reservoir quality. Potential of the play is thought to be good in the relatively unexplored offshore extensions of major structural trends. In the Santa Clara Trough, possible reservoir rocks may be too deep to retain favorable porosity and

permeability; however, this potential remains untested. Undiscovered recoverable resources probably remain in the onshore on the north and south margins of the Santa Clara Trough. Relatively unknown potential remains in poorly known deeper structures that formed prior to Miocene rotation of the province.

1302. NEOGENE–ONSHORE PLAY
1312. NEOGENE–OFFSHORE STATE WATERS PLAY

The Neogene Play is characterized by oil and associated gas accumulations in structural and combination traps in clastic reservoirs of early Miocene to Pleistocene age. Discovered accumulations in purely stratigraphic traps are rare. The play covers Å 130 mi of the east-west length of the province. The north and south boundaries of the play, in some places a fault, are defined by the extent of the Neogene sequence in the subsurface. The northern boundary is approximately equivalent to the southern edge of the Santa Ynez and Topa Topa Uplifts. The southern boundary, along the north side of the Santa Monica Mountains, is equivalent to the southern boundary of Neogene Basin remnants.

Reservoirs: Major reservoirs are unlithified turbidite sands of the Pliocene and Pleistocene Pico Formation. Other important reservoirs are in the Miocene and lower Pliocene section, predominantly marine sandstone but also fractured, fine-grained rocks of the Rincon, Monterey, Modelo, Sisquoc, and Santa Margarita Formations. Fractured, fine-grained siliceous rocks of the Monterey Formation are important reservoirs in only a few fields in the onshore and State waters. Average reservoir thicknesses range from less than 100 ft to as much as 5,000 ft. Average depth to the top of reservoirs is also variable, ranging from about 150 ft to 14,250 ft. Data on discovered reservoirs indicate a range of 14-35 percent porosity and 13-5,500 mD permeability for the Pico and younger reservoirs, and 11-27 percent porosity and 7-480 mD permeability for the Monterey and Modelo Formations.

Source rocks: Potential source rocks are organic-rich mudrocks of Miocene and early Pliocene age, including the Rincon, Monterey, Modelo, Sisquoc, Santa Margarita, and possibly part of the lower Pico Formations, although the Monterey Formation is thought to be the main source. The Monterey contains excellent oil-prone source rocks with total organic carbon contents Å 3-5 percent on average, but as high as 23 percent in some beds. Organic matter is marine and mixed marine-continental in origin. Most of the oil was probably generated in the Santa Clara Trough and other deep areas of the play where the Pliocene and Pleistocene sequence reaches a thickness of approximately

20,000 ft. Migration probably took place, for the most part, after the onset of late Pliocene compressional tectonics, which formed most of the structural traps in the play.

Traps: Traps are mainly anticlinal with associated faulting, but stratigraphy is an important control in the traps of numerous fields. The area of maximum production ranges from 50 acres at Weldon Canyon to 3,410 acres at the Ventura Ave. field, with multiple stacked reservoirs in many fields. Purely stratigraphic traps are rare. One of the potentially important targets for stratigraphic trapping, Pliocene turbidite sand units in the flat to gently dipping central Santa Clara Trough, is described as a separate play but is assessed with the total Neogene Play because of the small amount of resource discovered to date. Adequate seals are provided by impermeable shales and fine-grained rocks in the Neogene sequence. The deepest well in the basin, drilled in the onshore Rincon Trend, reached a total depth of 21,500 ft, bottoming within the upper Miocene section. Thickness of the lower Miocene to Pleistocene sedimentary sequence varies, with the maximum estimated to be greater than 26,000 ft.

Exploration status: The play has been extensively explored since 1861 when the Santa Paula field was discovered. In the onshore part of the play, 33 oil fields produce solely from the Neogene. Eight have both Paleogene and Neogene production. Oil fields average approximately 66 MMBOE. The largest accumulation, at 1,871 MMBOE, is the combined Ventura Ave., San Miguelito, and Rincon fields. Cumulative production through 1990 is 1,890 MMBO, 3.23 TCFG, and 157 MMBNGL. In the State offshore, the three oil fields producing in this play average 73 MMBOE; cumulative production through 1990 is 188 MMBO, 183 BCFG, and 1.14 MMBNGL.

Resource potential: The future resource potential of the play is estimated to be very good, especially in the relatively unexplored offshore extensions of major structural trends in the play and also beneath the hanging wall of the San Cayetano Thrust Fault. Undiscovered accumulations might also be found along the well-explored major structural trends in the onshore, particularly adjacent to the Santa Clara Trough and in the eastern Ventura Basin. Relatively little known potential exists for targets deeper than Å15,000 ft as well as for prospects dominated by diagenetic and stratigraphic trapping mechanisms. However, within the Santa Clara Trough, stratigraphic potential may be good in sand units within the upper and lower Pliocene section, as found at Fillmore and also Saticoy as well as other areas in the footwall of the Oak Ridge Fault.

1303. PLIOCENE STRATIGRAPHIC PLAY

The Pliocene Stratigraphic Play, which is both on land and in State waters, is characterized by stratigraphically trapped oil and associated gas accumulations in turbidite sand units of the Pliocene and Pleistocene Pico Formation. Discovered accumulations in pure stratigraphic traps are rare in this province. The play covers an elongate area Å 35 mi east to west and Å 10 mi north to south. The play is bounded on the north by the San Cayetano Fault and on the south by the Oak Ridge Fault and occupies the relatively flat to gently dipping portion of the central Santa Clara Trough or syncline between these faults.

Reservoirs: Major discovered reservoirs are unlithified turbidite sands of the middle part of the Pico Formation of Pliocene and Pleistocene age found in two zones of the Fillmore field. Other possible reservoirs might be in the lower Pliocene section, predominantly marine sandstone. Average reservoir thicknesses range from 35 to 50 ft, with net sand thicknesses up to 80 ft. Average depth to the top of reservoirs ranges from about 13,750 to 13,900 ft. Data on reservoirs of the Fillmore field indicate a range of 20-22 percent porosity and 50-150 mD permeability for the Pico. Other Pico and younger reservoirs in structural traps have a range from 14 to 35 percent porosity and 13 to 5,500 mD permeability. The sediments deposited in this area created one of the thickest known sections of Pliocene and Pleistocene sediment, 15,000-20,000 ft.

Source rocks: Potential source rocks are organic-rich mudrocks of Miocene and early Pliocene age, including the Monterey, Modelo, Sisquoc, Santa Margarita, and possibly part of the lower Pico Formations, although the Monterey Formation may be the main source. The Monterey contains excellent oil-prone source rocks with total organic carbon contents Å 3-5 percent on average, but as high as 23 percent in some beds. Organic matter is marine and mixed marine-continental in origin. The oil was generated in the Santa Clara Trough where the Pliocene and Pleistocene sequence reaches a thickness of as much as approximately 20,000 ft. Migration in the trough probably took place close to the time of, and also after, the onset of late Pliocene compressional tectonics, which formed most of the structural traps in the province, including possibly the faulting of already formed stratigraphic traps that are now in the Pliocene succession of the footwall of the Oak Ridge Fault.

Traps: Trapping is dominantly stratigraphic by pinch out of sand bodies. The most important potential targets are Pliocene turbidite sand units in the flat to gently dipping central Santa Clara Trough. At Fillmore, the area of maximum production is Å500

acres; both larger and smaller trap sizes are possible. Adequate seals are provided by impermeable shales and fine-grained rocks in the Neogene sequence. The deepest well in the basin reached a total depth of 21,500 ft, bottoming within the upper Miocene section.

Exploration status and resource potential: The play has been explored a good deal since the discovery of the Fillmore field in 1954. Except for several accumulations (the Saticoy field, the Bridge pool at South Mountain, and pools at Bardsdale and Shiells Canyon) in the footwall of the Oak Ridge Fault which may have been stratigraphically controlled before the onset of late Pliocene deformation, no other fields like Fillmore have been found. Therefore, this play is described separately, but assessed with the total Neogene Play because of the small amount of resource that has been discovered after a good deal of exploration on land. There has not been any offshore exploration for the play by drilling in State waters. Cumulative production at Fillmore through 1990 is 13.2 MMBO, 19.5 BCFG, and 600 MBNGL; ultimate recovery is projected to 28.2 MMBOE. The future resource potential of the play may be good, especially in the unexplored areas of the Santa Clara Trough and possibly in its offshore extension. There may also be potential in the footwall of the San Cayetano Thrust Fault. Relatively little is known of the potential for targets deeper than Å15,000 ft.

1304. CRETACEOUS PLAY (HYPOTHETICAL)

The Cretaceous Play consists of oil and associated gas accumulations, but also hypothetical dry gas accumulations, in structural, stratigraphic, and combination traps. The two fields in the play, now abandoned, have together produced less than a million barrels of oil; however, gas production is known from a test within the play area. Reservoirs are sandstones of Late Cretaceous age located south of the Santa Clara Trough in areas where the top of the Upper Cretaceous is thought to be present at depths of 15,000 ft or less, and also where the thick Miocene volcanic succession is absent. The Cretaceous section north of the Santa Clara Trough has tested minor oil and gas in a few places; however, it is believed to have very low porosity and permeability (and therefore potential) due, in part, to laumontite formation. Therefore, this area is not included in the play.

Reservoirs: Reservoirs are marine sandstones of Late Cretaceous age. Oil production in the two discovered fields is from depths to the top of reservoirs of 4,150 and 7,200 ft, in intervals 500 and 200 ft thick respectively. The Upper Cretaceous section consists of sandstone, conglomerate, and shale. It ranges in thickness to greater than 6,500 ft in the areas of the Simi Uplift and the Santa Monica Mountains and is likely to be greater than 5,000 ft thick in much of the Ventura Basin (Nagle and Parker, 1971). Few data are available, but reservoir quality of the Cretaceous section in the play area is expected to be quite variable and generally poor in most areas. However, in the vicinity of the discovered fields near the Simi Uplift, Nagle and Parker (1971) describe the Cretaceous rocks as having "attractive reservoir potential," comparable to those of younger rocks which yielded commercial production elsewhere."

Source rocks: Possible source rocks include marine shales in the Cretaceous section, which are hypothesized to be gas prone due to a greater proportion of continentally derived plant material in the organic matter. Little is known of their potential for generating oil or gas south of the Santa Clara Trough; however, a number of analyses north of the Santa Clara Trough (Frizzell and Claypool, 1983) characterize this organic matter as having poor capacity for petroleum generation. Other potential sources are marine shales within the Paleocene, Eocene, and Miocene sections, which may have sourced the Cretaceous rocks during favorable structural juxtaposition. Recent reconstructions by Hathon (1992) show that the Eocene and Paleocene Santa Susana "Shale" south of the Santa Clara Trough at South Mountain became mature beginning during the late Pliocene, coincident with the formation of structural traps during the

most recent tectonism. The Miocene Monterey Formation is believed by many to be the main source of the oil in most fields south of the Santa Clara Trough, oil generation having begun in the trough during the Pliocene and then migration proceeding since that time.

Traps: Traps may be structural or stratigraphic or a combination of both. Structural traps may have formed during tectonism since the late Pliocene or in earlier periods of deformation, which are not as well understood. More study of Cretaceous depositional systems is necessary to understand the potential for stratigraphic trapping in the play. The size of discovered traps, 20 and 30 acres, is small, but larger traps may be present. Marine shale units within and overlying the Cretaceous, as well as other permeability barriers such as unconformities, could provide seals.

Exploration status: Two oil fields have been discovered in the play in the area of the Simi Uplift. The Horse Meadows field was discovered in 1952 and abandoned in 1966 after producing 136,556 bbl of oil and 86,746 MCFG. The Mission field produced 536,621 bbl of oil and 301,411 MCFG from Cretaceous sandstone as well as a pool in Pliocene sand between its discovery in 1953 and abandonment in 1977. Oil and gas in shows and production tests are reported for several wells throughout the province.

Resource potential: This play has not been well explored because of the many favorable prospects in the overlying Tertiary section. Also, pre-Pliocene structures, and therefore trapping, are not well understood in most of the province because of the strong overprint by younger tectonism. However, undiscovered resources probably remain south of the Santa Clara trough. Most certainly laumontite formation and other factors will preclude favorable porosity and permeability in some areas; however, porosity and permeability are favorable in the area of existing fields, and the possibility of finding other favorable areas cannot be ruled out until more exploration is done in this play.

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.

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