Petroleum Systems and Geologic Assessment of Oil and Gas in the San Joaquin Basin Province, California

Chapter 13

Miocene Total Petroleum System—Southeast Stable Shelf Assessment Unit of the San Joaquin Basin Province

By Donald L. Gautier and Allegra Hosford Scheirer

Contents

Summary

Boundaries	Neogene-age shelf-slope break of the San Joaquin Basin on the west; onlap of Neogene rocks on Sierran basement to the east; petroleum system limit on the north; White Wolf Fault on the south; topographic surface to crystalline basement.
Source Rocks	Miocene Monterey Formation; possibly minor other sources.
Reservoir Rocks	Mainly Oligocene to Pleistocene and even Holocene sandstones; minor older sandstones and crystalline basement rocks.
Traps	Pinchouts, truncations, tar seals, extensional faults.
Migration	Eastward and up-dip through sandstones, fractures, and faults.
Timing	Oil generation from mid-Pliocene to present from Monterey Formation.
Existing Fields	Ant Hill, Dyer Creek, Edison, Edison Northeast, Fruitvale, Kern Bluff, Kern Front, Kern River, Mount Poso, Mountain View, Poso Creek, Rosedale Ranch, Round Mountain, Union Avenue.
Exploration Status	Heavily explored (2.3 wells per square mile and 67 percent of all sections have at least one exploratory well).
Resource Potential	Mainly growth of reserves in existing fields.

Description

The confirmed stratigraphic and structural-stratigraphic Southeast Stable Shelf Assessment Unit (AU) of the Miocene Total Petroleum System (San Joaquin Basin Province) comprises all hydrocarbon accumulations within the geographic limits of the AU. Traps typically display low dip angles, gentle folds, and normal faults. Reservoirs, which range in age from fractured Mesozoic basement rocks to Holocene nonmarine rocks, are mainly Oligocene to Miocene sandstones from the uppermost slope and adjacent shelf of the San Joaquin Basin, shallow marine shelf sandstones mainly of Miocene age, and nonmarine sandstones and conglomerates mostly of Pliocene-Pleistocene age. Faults have relatively small vertical displacements.

Map boundaries of the assessment unit are shown in figures 13.1 and 13.2; this assessment unit replaces the Southeast Stable Shelf play 1002 considered by the U.S. Geological Survey (USGS) in its 1995 National Assessment (Beyer, 1996).

Stratigraphically, the AU extends from the uppermost crystalline basement to the topographic surface (fig. 13.3). The AU is bounded on the west by the approximate location of the shelf-slope break of the San Joaquin Basin in late Miocene time, thus excluding reservoirs in the deep-water Stevens sand of Eckis (1940). The eastern boundary of the AU is the edge of onlap of Neogene sedimentary sequences on crystalline basement rocks of the Sierra Nevada. The northern AU boundary is placed at the approximate northern extent of oils in shelf-facies reservoirs known to be sourced by the Miocene Total Petroleum System. This northern boundary explicitly excludes the Deer Creek and Jasmin fields, which were included in the corresponding earlier (1995) USGS play (Beyer, 1996), but which are now known to contain oil generated from Eocene source rocks. The White Wolf Fault bounds the AU on the south.

Source Rocks

Oil correlation analyses conducted for the San Joaquin Basin Province assessment (Lillis and Magoon, this volume, chapter 9) confirm earlier studies (Peters and others, 1994), which indicate that all known oil and gas accumulations in this AU are derived from source rocks of middle and late Miocene age. The principal source for oil in this AU is the fine-grained, biosiliceous, organic-rich facies of the Monterey Formation located on the basin's southwest margin (figs. 13.4 and 13.5). However, in considering the resource potential of this assessment unit, it is important to emphasize that the richest (most oil prone) facies of the Monterey Formation were deposited on slopes and in bathyal settings to the west and outside of this AU. Though less likely, pre-Monterey Formation organic-carbon-rich shales, such as those of the Tumey formation of Atwill (1935) and Kreyenhagen Formation, could also have served as hydrocarbon source rocks. However, oils analyzed to date are derived exclusively from Miocene-aged source rocks (Lillis and Magoon, this volume, chapter 9).

Thus, for the purposes of assessment, the Southeast Stable Shelf Assessment Unit is assigned to the Miocene Total Petroleum System, which consists of two pods of active source rock in the Buttonwillow and Tejon depocenters (fig. 13.5; Magoon and others, this volume, chapter 8; Peters, Magoon, Lampe, and others, this volume, chapter 12). On the basis of spatial and geochemical considerations, the most likely provenance for the hydrocarbons found in the assessment unit is the Tejon depocenter, although hydrocarbons generated farther to the northwest in the Buttonwillow depocenter may also have charged reservoirs in the AU (fig. 13.5).

Maturation

The Monterey Formation may have generated sulfur-rich liquids early in its burial history (Fischer and others, 1988), but burial depths of 3 to 4 kilometers are generally thought necessary for significant oil generation in strata of the Monterey Formation (Graham and Williams, 1985; Kruge, 1985). Geochemical analyses and petroleum systems modeling conducted for the San Joaquin Basin Province assessment confirm this interpretation and constrain burial depths of Monterey Formation source rocks to 4 to 4.6 kilometers (Peters, Magoon, Lampe, and others, this volume, chapter 12).

Shales of the Monterey Formation, which are interpreted to be the likely source for all known oil in this AU, probably achieved maturation sufficient for initial oil generation by early Pliocene time (4.6 Ma); generation continues to the present (Peters, Magoon, Lampe, and others, this volume, chapter 12). Since initial maturation of the Monterey source rock, well in excess of four billion barrels of oil and unknown quantities of associated gas have migrated into and through reservoirs of this AU.

Migration

Source rocks within the Monterey Formation, from which the oil in this AU was generated, were deposited in fundamentally different settings than were the reservoir rocks of this AU. Although the eastern boundary of the pod of active source rock lies adjacent to the AU (fig. 13.5), the bulk of thermally mature source rock in the Tejon depocenter lies ~20 miles west-southwest of the center of the assessment unit. Therefore, relatively long and somewhat complex migration pathways are necessary to transport oil from bathyal and slope-deposited source rocks into the upper slope, shelf, and nonmarine sandstone reservoirs of the assessment unit (fig. 13.6). Complex submarine canyon, channel, and fan deposits that intersect the western margins of the shallow shelf are postulated as the conduits for hydrocarbon fluids (Lamb and others, 2003). Up-dip migration pathways are believed to have included faults and fractures, as well as porous and permeable sandstones.

Reservoir Rocks

Oil accumulations have been found in sandstones of nearly all Oligocene- through Pleistocene-age formations that were deposited on the stable southeastern shelf of the San Joaquin Basin (fig 13.4). In addition, oil has been found in older sandstones of the nonmarine Walker Formation of Eocene age in Edison field and in fractured crystalline basement rocks in parts of the Edison (White, 1955) and Mountain View fields (Park, 1966). The most prolific hydrocarbon producing reservoirs in this assessment unit are upper slope, shelfal, and nonmarine sandstones of the Kern River and Chanac Formations, Santa Margarita Sandstone, Jewett Sand, Freeman Silt, and Vedder Sand. Generally, reservoirs tend to pinch out to the east and to pass into deep-water facies to the west (MacPherson, 1978). Reservoirs typically exhibit high porosity and permeability, but diagenesis adversely affects reservoir quality in the deeper parts of the AU.

Figure 13.7 illustrates the paleogeography of the San Joaquin Basin in the Pliocene between 4 and 3 Ma. At this time, the southeast stable shelf occupied an entirely nonmarine depositional environment following a marine regression that began during the middle to late Miocene (Bartow, 1991). The nonmarine Chanac Formation, which is the principal oil reservoir at Rosedale Ranch and Fruitvale fields, was deposited on the basin's southeast margin during the marine regression.

The major reservoir in this assessment unit, the Kern River Formation, was deposited between 8 Ma and 0.7 Ma (Graham and others, 1988), although recent evidence suggests the upper age of the formation may be as old as 6 Ma (Miller, 1999; Golob and others, 2005). The Kern River Formation consists mainly of a series of coarse-grained, braided stream deposits that emanated from the adjacent Sierra Nevada to the east and were delivered to the basin by the ancestral Kern River (Graham and others, 1988). In the subsurface, the lower Kern River Formation grades basinward into marine Etchegoin Formation, while the upper Kern River Formation grades laterally into the San Joaquin and Tulare Formations (Bartow and McDougall, 1984).

Initial reservoir pressures in existing fields of the assessment unit range from 100 to 3,200 pounds per square inch, at reservoir depths of 400 to 7,300 feet, respectively (CDOGGR, 1998). The mean reported reservoir depth of ~3,600 feet indicates that typical exploration depths are moderate. Within the AU, reservoir depths generally decrease from west to east approaching the basin margin. Oil gravity ranges from about 10 degrees API in the Kern River Field to 45 degrees API in the deepest reservoirs of the Mountain View field. Average reservoir porosity varies from 15 to 45 percent, with a median porosity of 30 percent (CDOGGR, 1998).

Traps and Seals

Traps are commonly controlled by high-angle extensional faults (down-to-the-east) that place west-dipping sandstone reservoirs against low-permeability mudstones (fig. 13.8). Stratigraphic traps are present at the lateral limits of sandstone reservoirs, where highly permeable sandstones and conglomerates are adjacent to lower permeability mudstones. Sandstone pinchouts and truncations are common along the eastern margin of the AU. Unusual trapping mechanisms exist in the dominant field of the assessment unit, the Kern River field, within which tar seals and hydrodynamic trapping near the eastern onlap of Neogene sediments on Sierran basement are responsible for the largest accumulations in the AU (fig. 13.9; table 13.1). Gentle structures, including anticlines and faulted anticlines, form traps as well. Diagenetic traps remain a possibility, especially at depth in the AU.

Exploration Status and Resource Potential

The AU has been intensively drilled along the up-dip basin margin to the east and southeast of the Bakersfield Arch (fig. 13.2). Other areas of the AU have also been extensively explored, and little space remains for undiscovered resources other than small, subtle, and difficult-to-find traps. Known accumulations are found at depths between ~8,000 feet and the surface, if oil seeps on the east side of the assessment unit are considered. No new accumulation has been found in this assessment unit in the last several decades in spite of more than 250 exploratory wells drilled since 1960 (fig. 13.10).

The largest discoveries within the Southeast Stable Shelf Assessment Unit, in order of decreasing recoverable oil volume, are shown in table 13.1. Two-thirds of the ~3.7 billion barrels of recoverable oil in this assessment unit are in the Kern River field. Mount Poso and Kern Front fields account for ~9 percent and ~6 percent of the known oil, respectively.

Undiscovered accumulations are expected to be small and located primarily in the deeper areas near the western margin of the AU. Down-dip sandstone objectives at depth in the northern part of the AU have not been as extensively drilled as other areas within the AU. Additionally, sandstones in the Vedder Sand-Jewett Sand stratigraphic interval have not been exhaustively explored, and a high probability exists for the discovery in these sandstones of small (less than 10 million barrels of oil) accumulations in subtle stratigraphic traps.

The estimates of undiscovered petroleum resources in this AU reflect the judgment of the USGS that all but the smallest, most subtle traps have already been tested during more than 100 years of nearly unrestricted exploration. Because the discovery history reveals no accumulations of less than one million barrels, we are convinced that at least one, and probably several, small fields remain to be found. The volume of total undiscovered oil is estimated to be small, however, ranging from nearly nothing to 70 million barrels of oil (MMBO), with a mean of 24 MMBO (fig. 13.11). However, we think that this AU has considerable potential for significant additions to reserves in the form of reserve growth within the large, existing fields as a result of technological developments, extensions, and higher average oil prices in the future (see Tennyson, this volume, chapter 23, for a discussion of reserve growth in Kern River, Fruitvale, Edison, Kern Front, Mount Poso, and Round Mountain fields).

All assessment results and supporting documentation for the Southeast Stable Shelf Assessment Unit of the San Joaquin Basin Province are available in files c100401.pdf (data form for conventional assessment unit), d100401.pdf (summary of discovery history), em100401.pdf (probabilistic estimates), g100401.pdf (graphs of exploration and discovery data for grown volumes), and k100401.pdf (graphs of exploration and discovery data for known volumes). Klett and Le (this volume, chapter 28) summarize the contents of these files.

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Figures

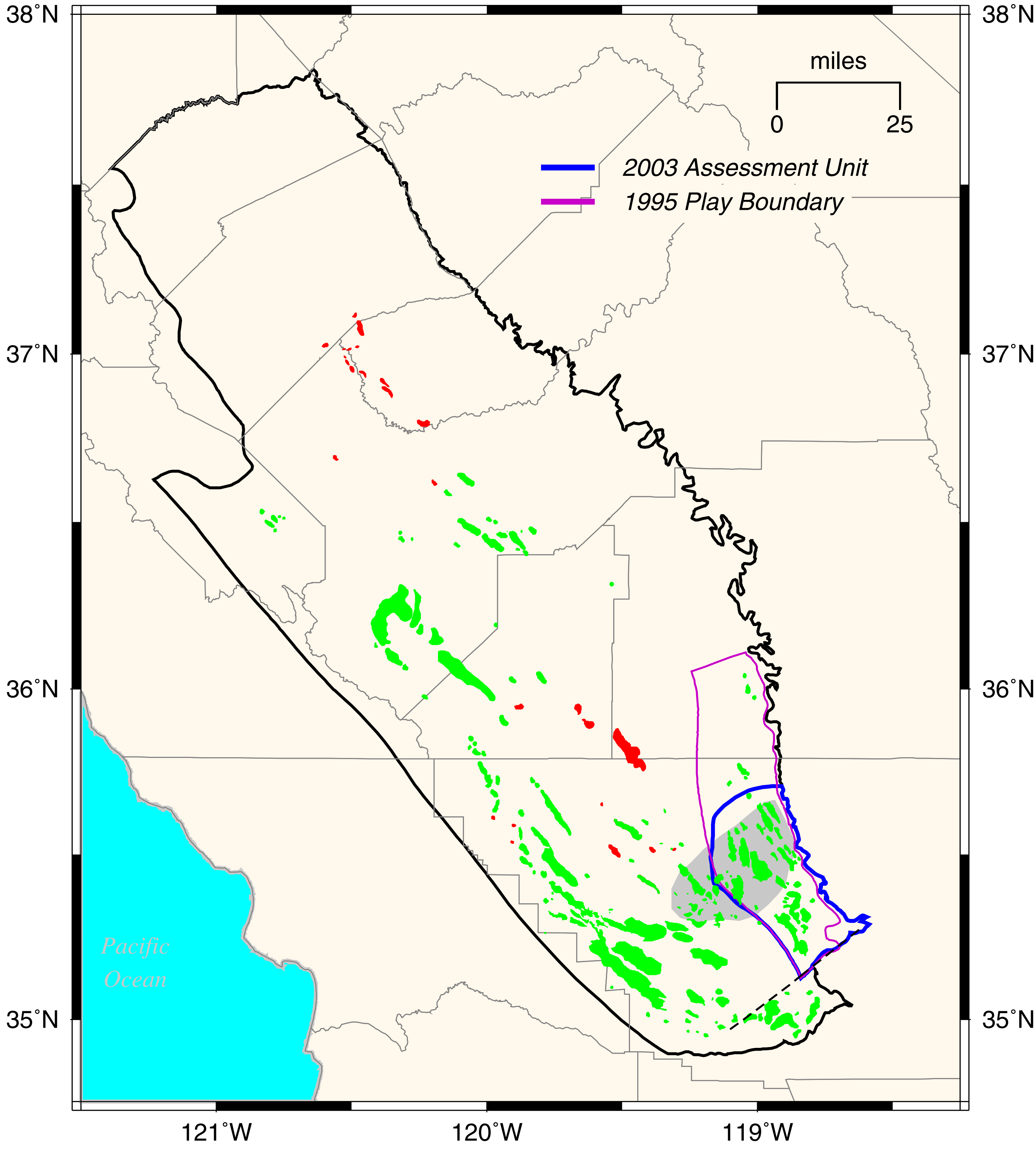

Figure 13.1. Map of the San Joaquin Basin, illustrating San Joaquin Basin Province boundary (bold line), county boundaries (thin gray line), Southeast Stable Shelf Assessment Unit boundary (blue line), play boundary from previous USGS assessment (purple line), and oil (green) and gas (red) fields in the province. Gray shading shows the location of the Bakersfield Arch, which is mapped on the basement surface in a three-dimensional geologic model of the basin (Hosford Scheirer, this volume, chapter 7). In figures 13.1 and 13.2, dashed line indicates surface and subsurface traces of the White Wolf Fault, as modeled by Bawden (2001).

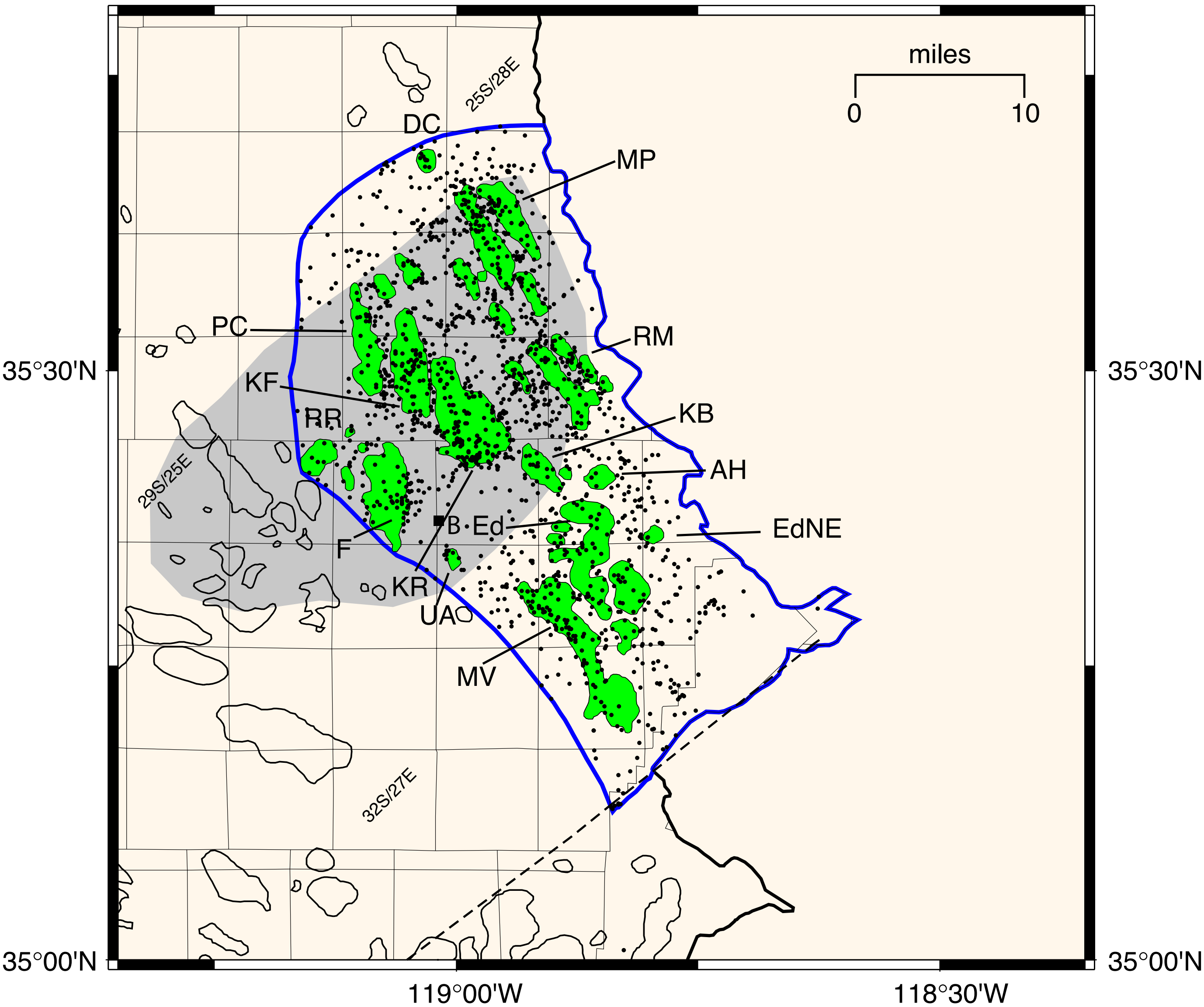

Figure 13.2. Detailed map of Southeast Stable Shelf Assessment Unit (AU). The blue line indicates the geographic limit of the AU. Oil fields in the AU are colored green. Fields outside the AU are outlined in black. Filled circles represent 1705 exploratory wells drilled for petroleum within the AU between 1901 and 1995. Well locations are from the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, and are available in databases at ftp://ftp.conservation.ca.gov/pub/oil/maps/dist4. Township and range grid is indicated for scale and location; scattered labels are relative to the Mount Diablo baseline and meridian. Gray shading shows the location of the Bakersfield Arch. City of Bakersfield (B) denoted with filled square. Oil field labels are: AH=Ant Hill, DC=Dyer Creek, Ed=Edison, EdNE=Edison Northeast, F=Fruitvale, KB=Kern Bluff, KF=Kern Front, KR=Kern River, MP=Mount Poso, MV=Mountain View, PC=Poso Creek, RR=Rosedale Ranch, RM=Round Mountain, and UA=Union Avenue.

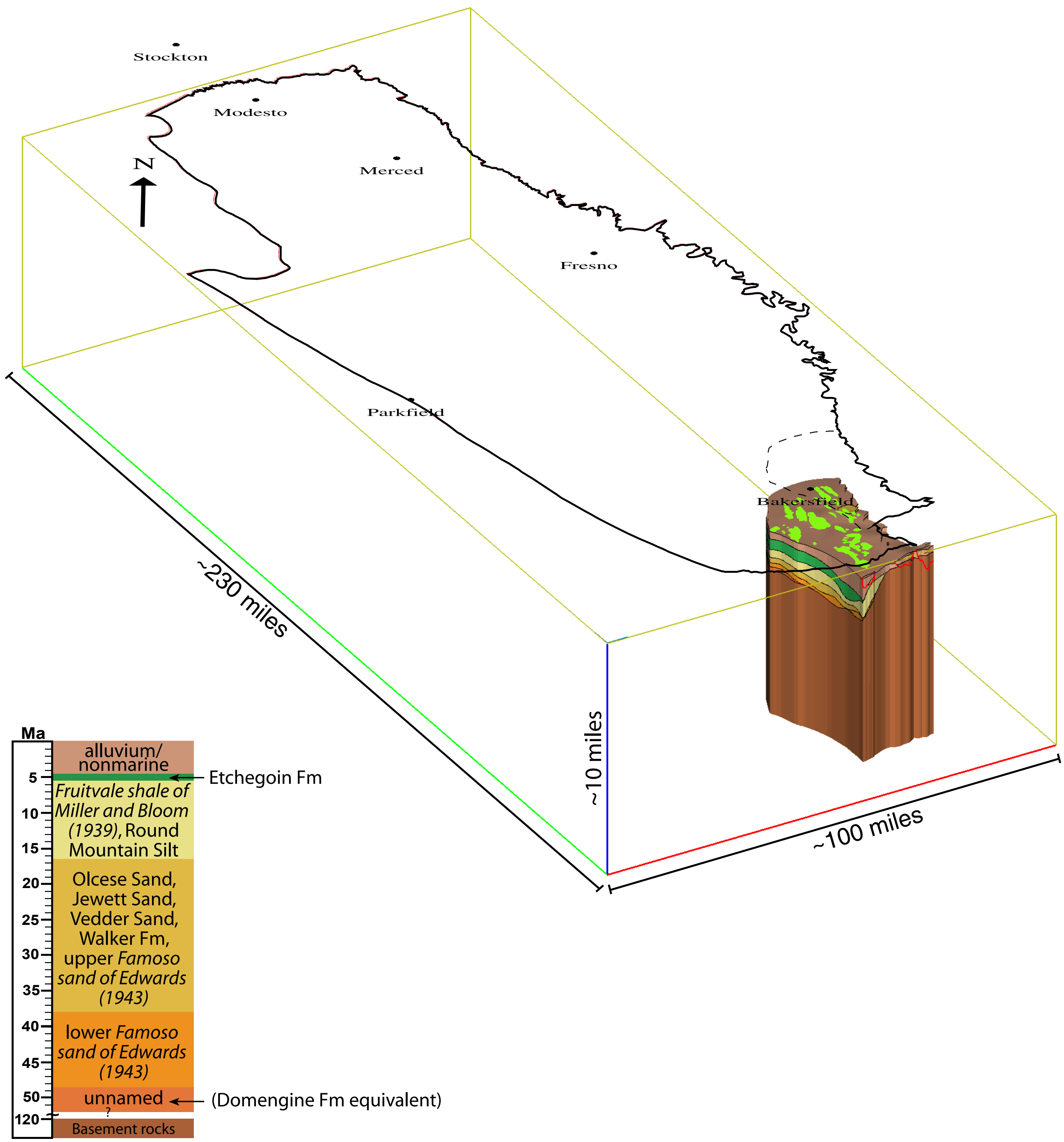

Figure 13.3. Three-dimensional stratigraphy model of the Southeast Stable Shelf AU extracted from the EarthVision® model of the basin by Hosford Scheirer (this volume, chapter 7). The bounding polygonal block illustrates the model space within which the EarthVision® model is constructed. The major stratigraphic units within the AU are listed; see figure 13.4 for stratigraphic relationships between the units. Formation names in italics are informal. Note that Eocene-aged rocks rest directly on basement, indicating the absence of Cretaceous rocks on and south-southeast of the Bakersfield Arch. Pliocene-aged San Joaquin Formation is absent in this AU. Oil fields (green) are draped on the topographic surface. The San Joaquin Basin Province boundary (bold line), AU boundary (dashed line), and city names and locations float above the surface of the model. View is from due south at a 30° inclination angle. Vertical exaggeration is 4. EarthVision is a registered trademark (Marca Registrada) of Dynamic Graphics, Inc., Alameda, Calif. Fm, Formation.

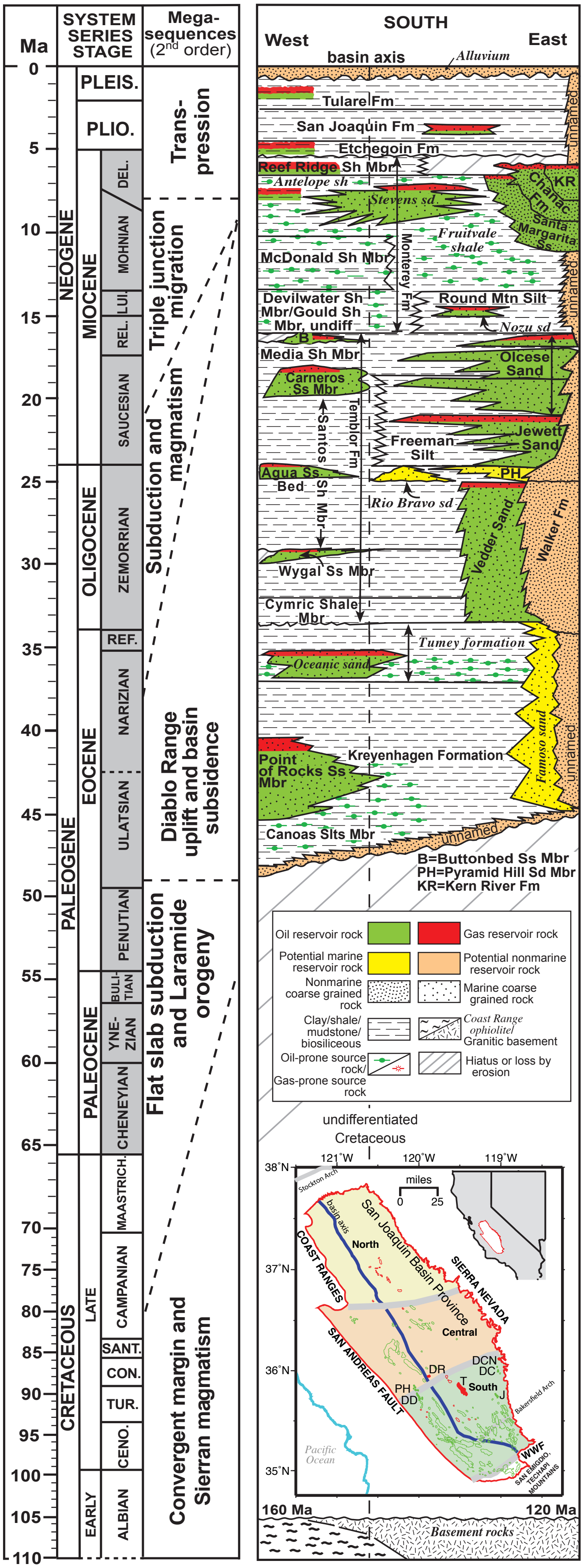

Figure 13.4. Generalized stratigraphic column for the southern San Joaquin Basin, showing hydrocarbon reservoir rocks and potential hydrocarbon source rocks. See Hosford Scheirer and Magoon (this volume, chapter 5) for complete explanation of the figure. Formation names in italics are informal and are defined as follows: Antelope shale of Graham and Williams (1985), Stevens sand of Eckis (1940), Fruitvale shale of Miller and Bloom (1939), Nozu sand of Kasline (1942), Rio Bravo sand of Noble (1940), Oceanic sand of McMasters (1948), Tumey formation of Atwill (1935), and Famoso sand of Edwards (1943).

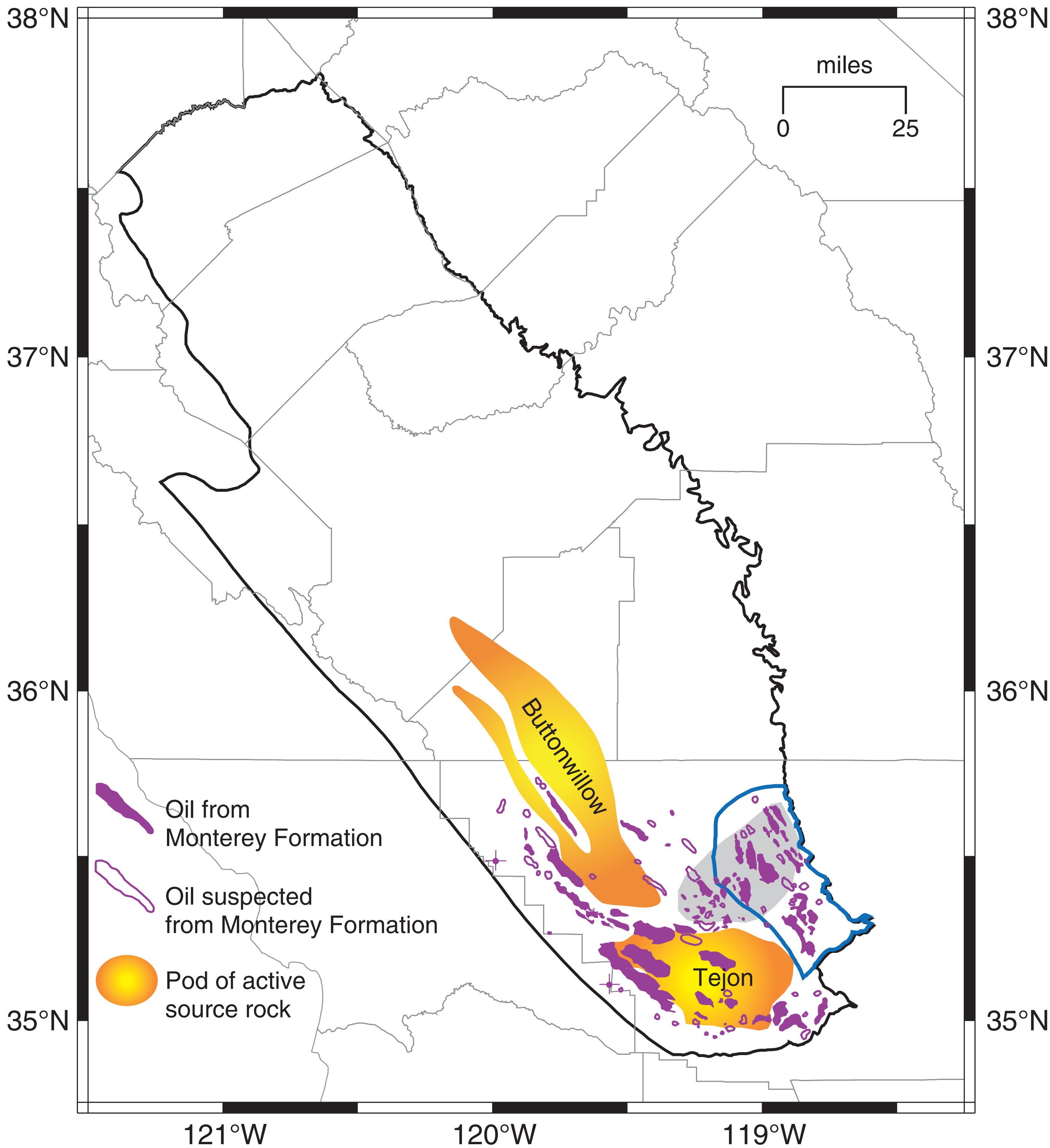

Figure 13.5. Location of Southeast Stable Shelf AU (blue line) with respect to the pods of active source rock of the Miocene Total Petroleum System as mapped by Peters, Magoon, Lampe, and others (this volume, chapter 12). The bold line is the San Joaquin Basin Province boundary, and thin gray lines are county boundaries. Gray shading shows the location of the Bakersfield Arch. See Magoon and others (this volume, chapter 8) for details of oil field assignment to petroleum systems based on geochemical analyses.

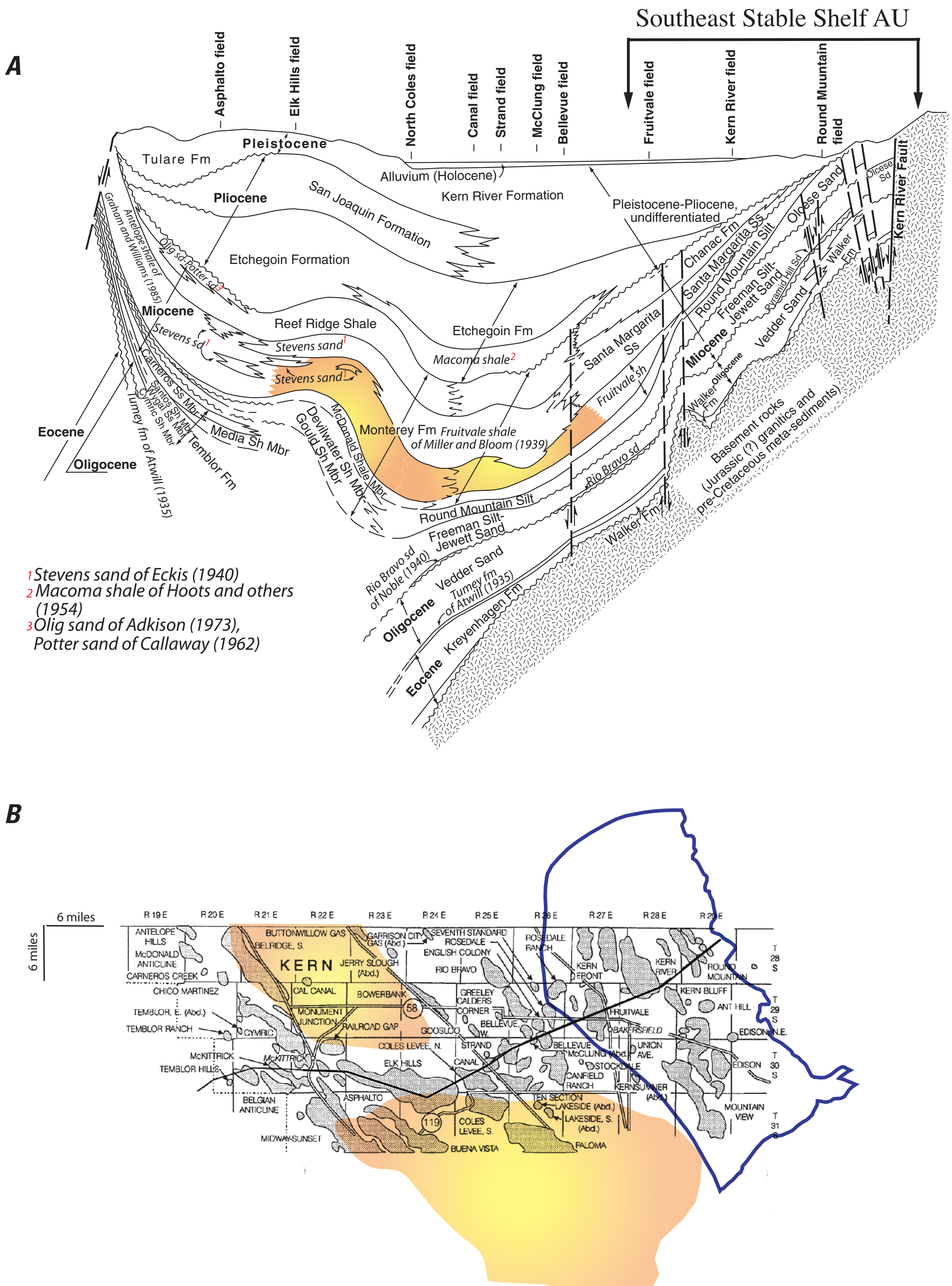

Figure 13.6. *A*, Generalized geologic cross section of the southern San Joaquin Basin. Orange fill denotes approximate location of oil-generative shales of the Monterey Formation. Formations in italics denote informal geologic names. Informal units not previously defined include the Macoma shale of Hoots and others (1954), the Olig sand of Adkison (1973), and the Potter sand of Callaway (1962). *B*, Map view illustrating cross-section location, as well as the AU boundary and the pods of active source rock as mapped by Peters, Magoon, Lampe, and others (this volume, chapter 12). Figure modified from CDOGGR (1998). Fm, Formation; fm, formation; Mbr, Member; Sd, Sand; sd, sand; Ss, Sandstone; Sh, Shale; sh, shale.

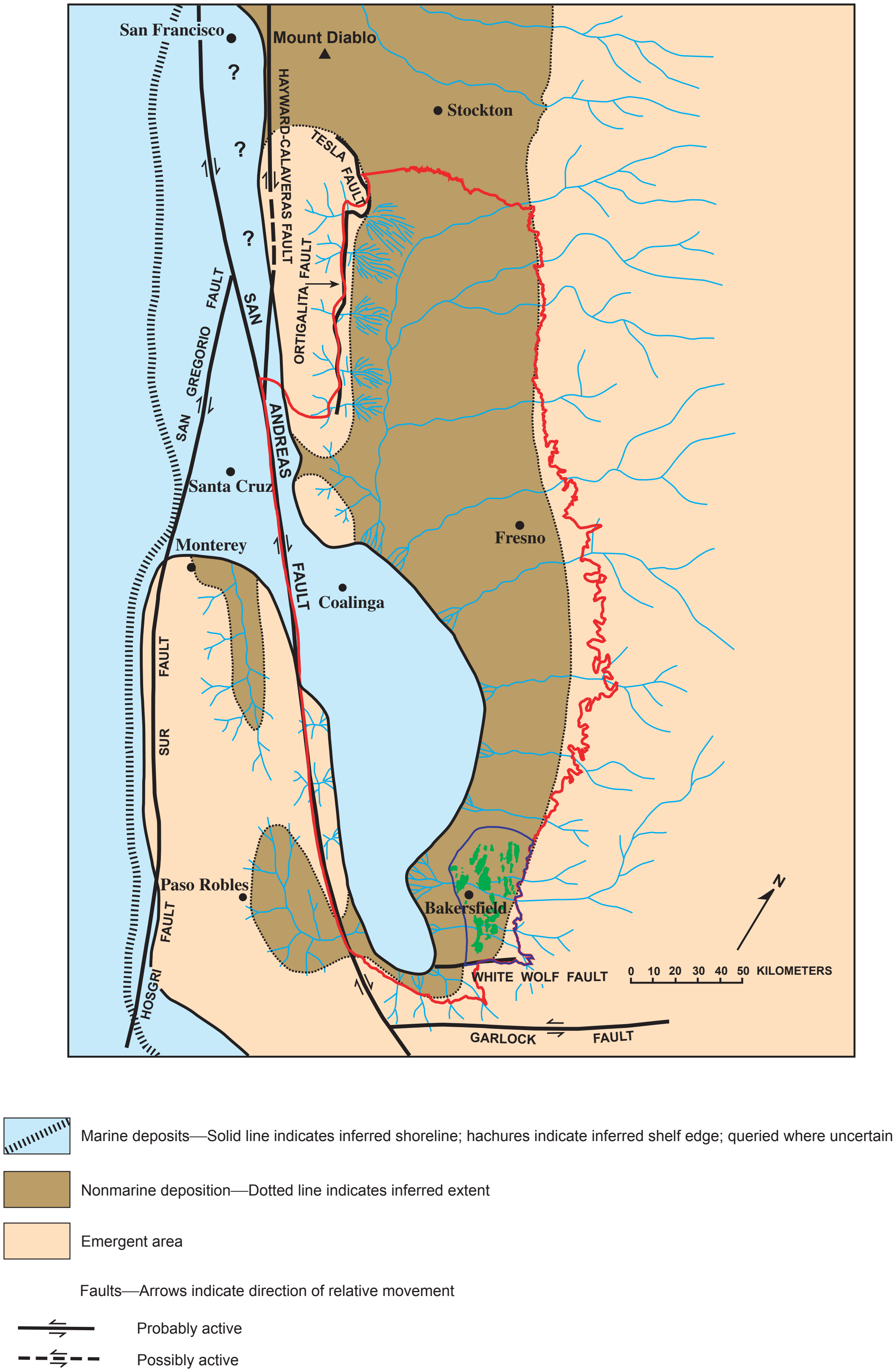

Figure 13.7. Paleogeography of the San Joaquin Basin (red outline) during the early Pliocene (4 to 3 Ma). The Southeast Stable Shelf AU (blue line) and known oil fields (green) are superimposed for reference. Deposition of the major reservoir rock in the AU, the Kern River Formation, began in the late Miocene. Figure modified from Bartow (1991).

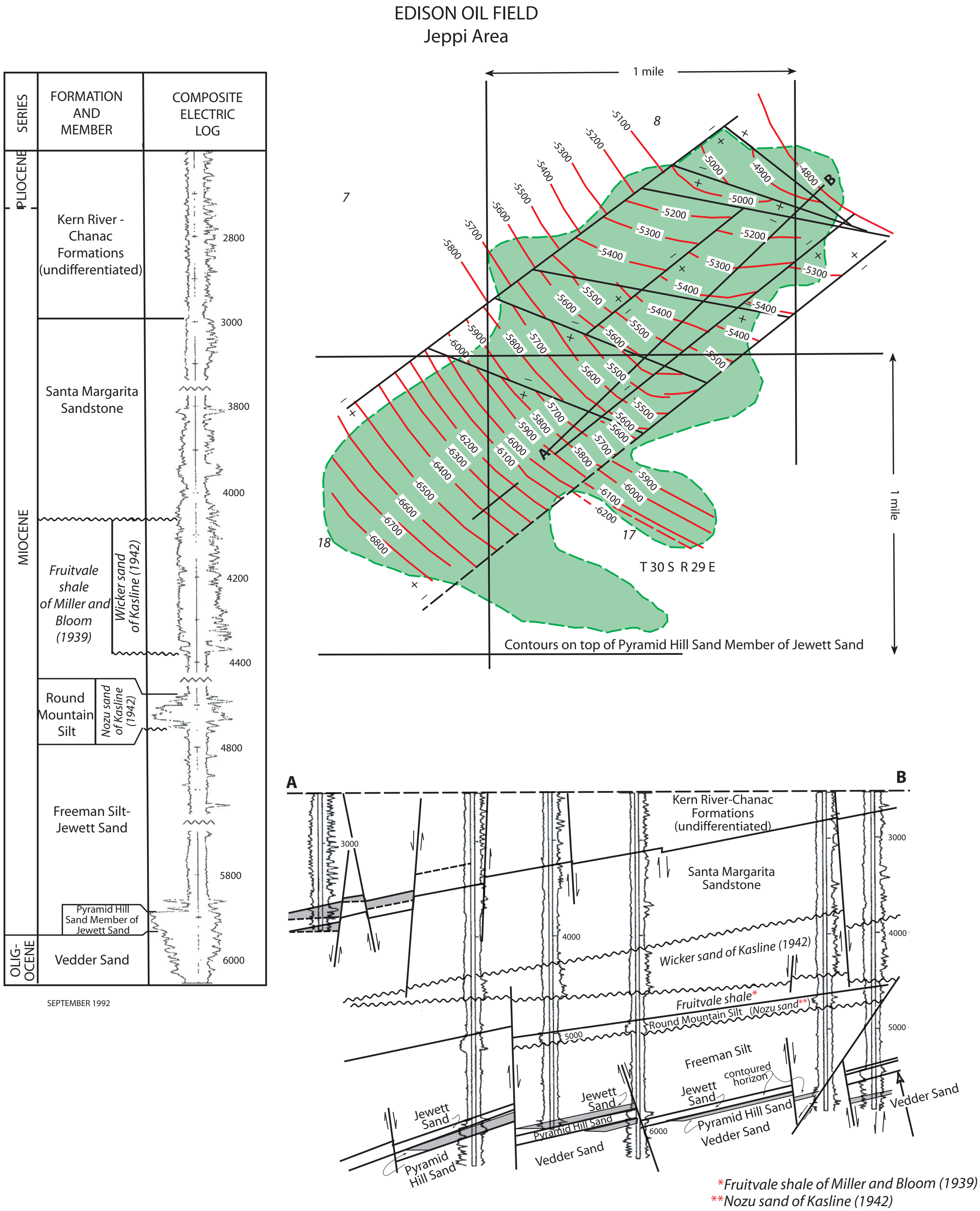

Figure 13.8. Figure of the Jeppi area of Edison oil field, illustrating typical trapping mechanism in the assessment unit in which down-to-the-east normal faults place sandstone reservoirs against mudstones. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the field. All depths are in feet. Formations in italics denote informal geologic names. Township-range grid in figures 13.8 and 13.9 is relative to the Mount Diablo baseline and meridian; one mile by one mile sections within the township-range grid are numbered in italics. See figure 13.2 for location of field. Figure modified from CDOGGR (1998).

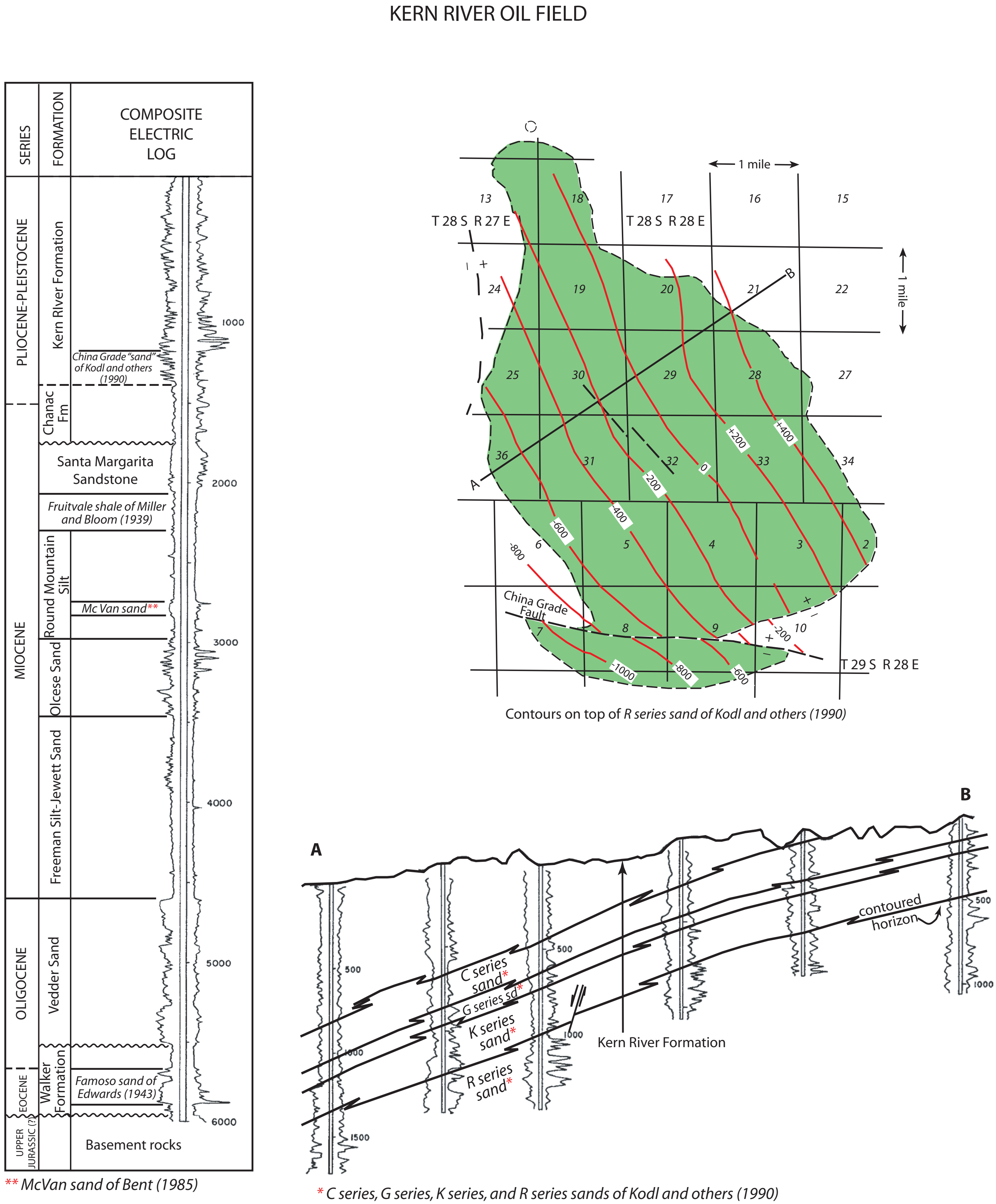

Figure 13.9. Figure of Kern River oil field, illustrating the absence of typical trap types such as those created by faults. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the field. All depths are in feet. Formations in italics denote informal geologic names. See figure 13.2 for location of field. Figure redrafted from CDOGGR (1998). Fm, Formation; sd, sand.

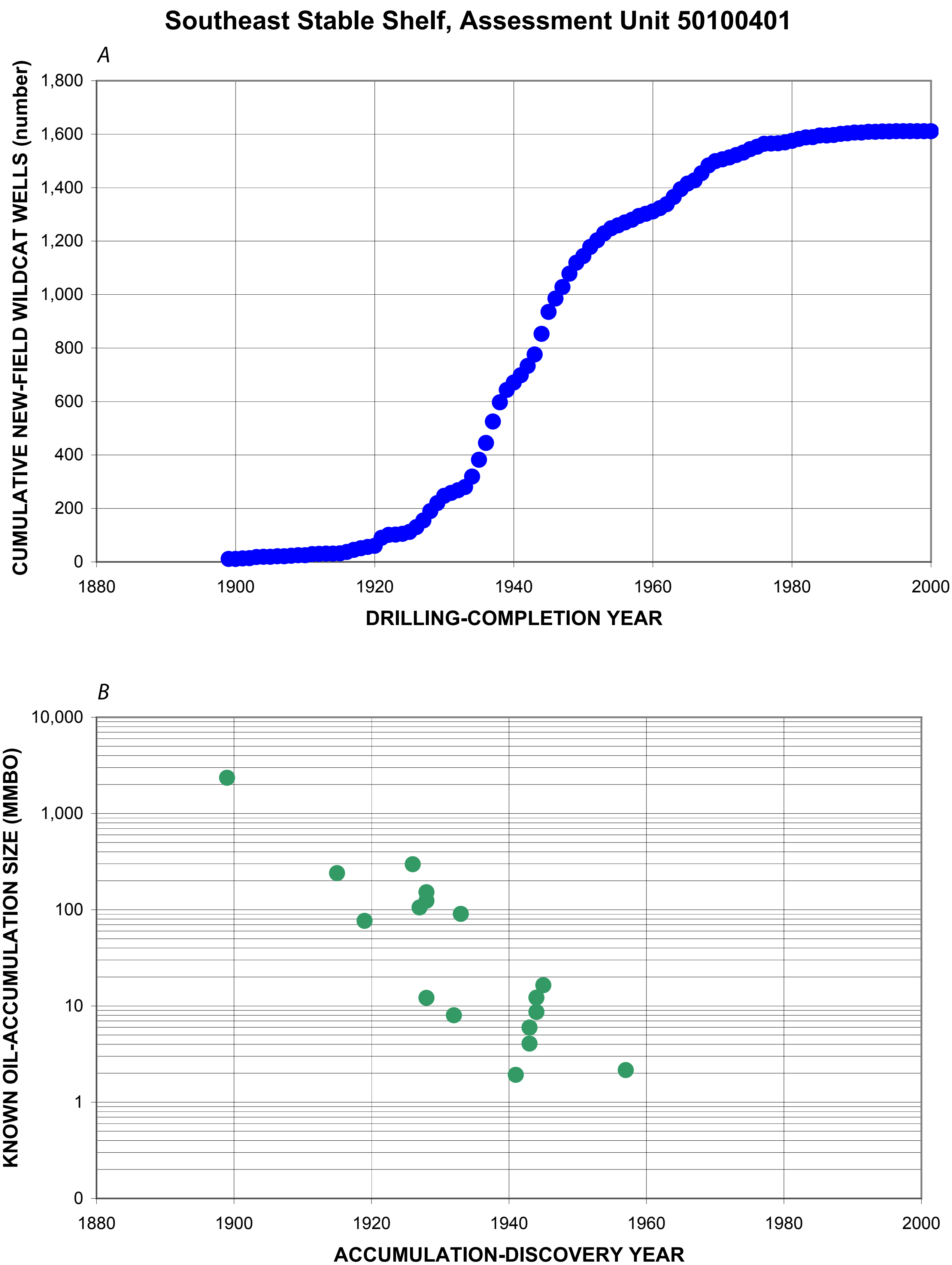

Figure 13.10. A, Cumulative number of new-field wildcat wells versus drilling completion year in the Southeast Stable Shelf AU. B, Oil accumulation size versus year of accumulation discovery in the Southeast Stable Shelf AU. Both graphs are excerpted from data file k100401.pdf (see Klett and Le, this volume, chapter 28, for explanation of data file).

50100401
Southeast Stable Shelf
Monte Carlo Results

Forecast: Oil in Oil Fields

Summary:
Display range is from 0.00 to 70.00 MMBO
Entire range is from 0.52 to 92.66 MMBO
After 50,000 trials, the standard error of the mean is 0.06

Statistics:	Value
Trials	50000
Mean	23.78
Median	21.39
Mode	---
Standard Deviation	14.04
Variance	196.99
Skewness	0.73
Kurtosis	3.12
Coefficient of Variability	0.59
Range Minimum	0.52
Range Maximum	92.66
Range Width	92.13
Mean Standard Error	0.06

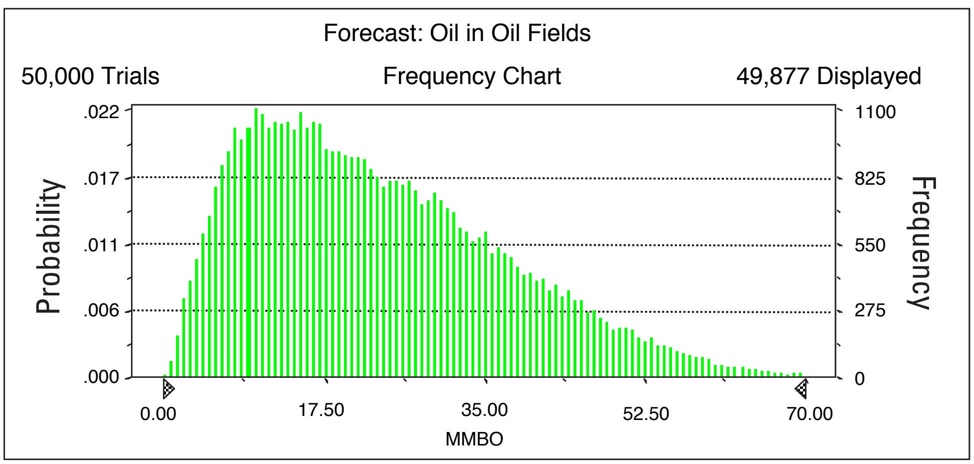

Figure 13.11. Probabilistic estimate of total oil volume in undiscovered oil fields in the Southeast Stable Shelf AU. Figure is excerpted from data file em100401.pdf (see Charpentier and Klett, this volume, chapter 26, for details of the calculation and Klett and Le, this volume, chapter 28, for explanation of data file).

Table 13.1. Production statistics for primary fields in the Southeast Stable Shelf Assessment Unit

[Recoverable oil is the sum of cumulative production and estimated proved reserves. Data source is CDOGGR (2003). MMB, millions of barrels. Primary fields are defined as those with recoverable oil equal to or greater than 0.5 MMB]

Field	Recoverable Oil through 2002 (MMB)	Percent of Total	Number of Producing Wells in 2002
Kern River	2451.3	67.0	8600
Mount Poso	313.8	8.6	548
Kern Front	216.9	5.9	688
Round Mountain	180.7	4.9	207
Edison	153.1	4.2	812
Fruitvale	125.8	3.4	233
Mountain View	91.0	2.5	157
Poso Creek	86.5	2.4	333
Rosedale Ranch	16.9	0.5	35
Kern Bluff	12.2	0.3	35
Ant Hill	8.6	0.2	17
Union Avenue	1.9	0.1	4
Total	3658.7	100	11669