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

Chapter 19

Eocene Total Petroleum System—North and East of the Eocene West Side Fold Belt Assessment Unit of the San Joaquin Basin Province

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Contents

Summary

Boundaries	Extent of Kreyenhagen Formation on the north; limit of Eocene Total Petroleum System on the east; north flank of Bakersfield Arch on the south; San Andreas Fault, base of Moreno Formation in outcrop, and limit of structural deformation on the west; topographic surface to crystalline basement.
Source Rocks	Principally siliceous marine shale of the Kreyenhagen Formation and secondarily, shale of the Tumey formation of Atwill (1935).
Reservoir Rocks	Mainly Paleocene to Miocene marine and nonmarine sandstones.
Migration	Up-dip through complex feeder systems.
Timing	Early Pliocene oil generation and expulsion from the Kreyenhagen Formation and Tumey formation of Atwill (1935).
Primary Fields	Burrel, Burrel Southeast, Deer Creek, Helm, Jasmin, Raisin City, Rio Bravo, Riverdale, San Joaquin, Tulare Lake, Vallecitos, Van Ness Slough, Wasco.
Secondary Fields	Camden, Cantua Creek, Cantua Nueva, Deer Creek North, Five Points, Hanford, Jasmin West, Kettleman City, Terra Bella, Turk Anticline, Westhaven.
Exploration Status	Lightly explored (0.1 well per square mile and 12 percent of all sections have at least one exploratory well).
Resource Potential	Small accumulations in subtle traps mainly deep in the southwest part of the assessment unit.

Description

The North and East of Eocene West Side Fold Belt Assessment Unit (AU) of the Eocene Total Petroleum System of the San Joaquin Basin Province comprises all hydrocarbon accumulations within the geographic and stratigraphic limits of this confirmed AU. Oil and associated gas accumulations occur in Paleocene through early-middle Miocene marine to nonmarine sandstones found on the comparatively stable northeast shelf of the basin. The assessment unit is located north and east of the thickest accumulation of Neogene sediments and the west side fold belt. The area enclosed by the AU has been affected by only mild deformation since Eocene time. Traps containing known accumulations are mostly low-relief domes, anticlines, and up-dip basin margin traps with faulting and stratigraphic components.

Map boundaries of the assessment unit are shown in figures 19.1 and 19.2; this assessment unit replaces the Northeast Shelf of Neogene Basin play 1006, the East Central Basin and Slope North of Bakersfield Arch play 1010, and part of the West Side Fold Belt Sourced by Pre-middle Miocene Rocks play 1005 considered by the U.S. Geological Survey (USGS) in their 1995 National Assessment (Beyer, 1996). Stratigraphically, the AU includes rocks from the uppermost crystalline basement to the topographic surface. In the region of overlap with the Central Basin Monterey Diagenetic Traps Assessment Unit, the North and East of Eocene West Side Fold Belt AU extends from basement rocks to the top of the Temblor Formation (figs. 19.3 and 19.4). In map view, the northern boundary of the assessment unit corresponds to the northernmost extent of Eocene-age Kreyenhagen Formation. The northeast boundary is the eastern limit of possible oil reservoir rocks near the eastern edge of the basin. The southeast boundary corresponds to the pinch-out of Stevens sand of Eckis (1940) to the south, which approximately coincides with the northern flank of the Bakersfield Arch (fig. 19.1). The AU is bounded on the southwest by the limit of major west side structural deformation and to the northwest by the San Andreas Fault and the limit of hydrocarbon-prospective strata in the Coast Ranges.

As described by Gautier and others (this volume, chapter 2), existing oil fields in the San Joaquin Basin Province were assigned to assessment units based on the identified petroleum system and reservoir rocks in each field. Vallecitos oil field in the extreme northwest corner of the basin was assigned to the Eocene Total Petroleum System, because oil analyses conducted for this San Joaquin Basin assessment indicate that Eocene oil charged the reservoir rocks (Lillis and Magoon, this volume, chapter 9). Some literature classifies the Vallecitos oil field as part of the northernmost fold of the basin's west side fold belt (see, for example, Rentschler, 1985; Bartow, 1991), but because of the oil field's spatial separation and differing trend from the west side fold belt, Vallecitos field was considered here to be within the North and East of Eocene West Side Fold Belt Assessment Unit rather than in the other assessment unit in the Eocene Total Petroleum System, the Eocene West Side Fold Belt.

Primary fields in the assessment unit are defined as those containing hydrocarbon resources greater than the USGS minimum threshold for assessment (0.5 million barrels of oil); secondary fields contain smaller volumes of oil but constitute a significant show of hydrocarbons.

Source Rocks

This AU is classified as part of the Eocene Total Petroleum System (Magoon and others, this volume, chapter 8). Most known oil accumulations within the AU are believed to have been sourced by shale of the Eocene Kreyenhagen Formation, which is thermally mature in the Buttonwillow depocenter located on the west side of the San Joaquin Basin (fig. 19.5) (Peters, Magoon, Lampe, and others, this volume, chapter 12). The Eocene Tumey formation of Atwill (1935), hereafter referred to as Tumey formation, may also have produced and expelled oil in this assessment unit, as evidenced particularly in the Deer Creek and Jasmin oil fields (Lillis and Magoon, this volume, chapter 8). For both source rocks, oil generation began in latest Miocene to earliest Pliocene time (Peters, Magoon, Lampe, and others, this volume, chapter 12).

Thermally mature biosiliceous shale of the Miocene Monterey Formation located on the basin's west side and south of the Bakersfield Arch could, in principle, be a source for hydrocarbons within this AU. In particular, Monterey Formation-derived oil may have charged reservoir rocks in the Rio Bravo field. Rio Bravo field is located just north of the Greeley field, where analyses of oil samples confirm a Monterey Formation source (see fig. 9.12 in Lillis and Magoon, this volume, chapter 9). In the absence of oil samples from Rio Bravo field, the question of hydrocarbon source remains complicated, because reservoir rocks within that field occur in Olcese and Vedder Sands, which lie stratigraphically between the oil-generative shales of the Kreyenhagen and Monterey Formations (figs. 19.4 and 19.6). Further, Rio Bravo field clearly is excluded from the Miocene Lower Bakersfield Arch Assessment Unit (Gautier, this volume, chapter 14) located immediately to the south of this AU because of the absence of Stevens sand of Eckis (1940). Rio Bravo field also does not belong to the Miocene Central Basin Monterey Diagenetic Traps Assessment Unit (Hosford Scheirer and others, this volume, chapter 17), which geographically overlaps with this AU but requires diagenetic trapping mechanisms within the quartz facies of the McLure Shale Member of the Monterey Formation. Until samples are collected and analyzed from Rio Bravo field, the source of hydrocarbons in the field remains speculative. To date, no Monterey Formation-derived oil has been identified within the assessment unit (Lillis and Magoon, this volume, chapter 9).

Maturation and Migration

Oil generation in the Kreyenhagen Formation began about 5.5 Ma in the northern part of the pod of active source rock and about 4.2 Ma in the southern part of the pod (fig. 19.5; Peters, Magoon, Lampe, and others, this volume, chapter 12). Generation ended about 3.6 Ma in the north but continues to the present day in the south. Due to the absence of sufficient samples of Tumey formation, no quantitative information is available on the timing of maturation and hydrocarbon generation for this source rock (Peters, Magoon, Lampe, and others, this volume, chapter 12). Timing of generation is thus assumed to be the same for shales of the Tumey formation and Kreyenhagen Formation.

Critical to the analysis of this AU is the fact that mature source rocks are known to exist in the southwest corner of the assessment unit (fig. 19.5), implying relatively long and complex migration pathways from source rock to reservoir rock. The relatively small volume of discovered oil within this AU (table 19.1) implies that these pathways may also be leaky and the traps small. Further, the absence of known oil accumulations north of Raisin City field implies a lack of adequate migration, charge, traps, and/or seals in the northern third of the assessment unit. Petroleum system modeling by Peters, Magoon, Lampe, and others (this volume, chapter 12) indicates that effective seals appear to be missing from the eastern margin of the northern San Joaquin Basin, in that migrating hydrocarbons are modeled to flow through the basin and beyond the calculation space (fig. 19.7).

Reservoir Rocks

Known accumulations occur in the Paleocene to Eocene Lodo Formation, in the Eocene Domengine and Kreyenhagen Formations, and in Oligocene-Miocene Temblor Formation-equivalent rocks such as the Olcese and Vedder Sands (fig. 19.4 and table 19.1). Miocene nonmarine sandstone of the Zilch formation of Loken (1959) and Miocene shallow water Santa Margarita Sandstone also serve as reservoir rocks, mostly toward the eastern edge of the AU. Continuous (unconventional) fractured shale reservoirs are possible, but their likelihood and sizes are unknown, and this class of potential hydrocarbon resources was not quantitatively assessed.

Reservoir rocks in known fields have fair to good reservoir quality, with average porosities of 34 percent in the Santa Margarita Sandstone in Deer Creek field, of 30 to 36 percent in reservoirs at several fields in the Zilch formation of Loken (1959), of 14 to 40 percent in Temblor Formation equivalent reservoirs, and of 12 to 33 percent in Eocene and Paleocene-aged reservoir rocks (CDOGGR, 1998). Known reservoirs span a large range of average production depths, varying from about 400 feet in the Kreyenhagen Formation at the Los Pinos Canyon area of Vallecitos field to 15,000 feet in the Kreyenhagen Formation at Wasco field. Productive sand thickness varies between 10 and 400 feet within the assessment unit (CDOGGR, 1998).

Traps and Seals

The North and East of Eocene West Side Fold Belt Assessment Unit contains a large variety of trapping styles ranging from low-relief domes and anticlines with faulting and stratigraphic components, such as at Rio Bravo (fig. 19.6), Vallecitos (fig. 19.8), and Helm (fig. 19.9) fields, to up-dip structural or stratigraphic traps near basin margins, such as at Deer Creek oil field (fig. 19.10). Diagenetic mechanisms may also create hydrocarbon traps, particularly at depth in the southwestern part of the assessment unit (for example at Tulare Lake field, McCullough and Horton, 1993).

Structural elements of traps in this assessment unit probably formed prior to the late Miocene. In contrast to the large-offset faults that contribute to major oil accumulations on the basin's west side (see for example, Tennyson, this volume, chapter 15 and chapter 18), faults within the central basin tend to have limited geographic extent and small offset (Bartow, 1991). For example, a structure contour map on the top of the oil zone within the Kreyenhagen Formation at Helm field shows at least eight faults with trends that are transverse to the elongated anticline (fig. 19.9), but these faults average only about one mile in length and displacements decrease gradually from 50 to 100 feet at the top of the Domengine Formation to nearly zero at the level of the McLure Shale Member of the Monterey Formation (Frame, 1950).

Exploration Status and Resource Potential

Table 19.1 lists the 13 primary fields within the assessment unit that have recoverable oil of more than 0.5 million barrels. Of these, Rio Bravo and Raisin City fields account for nearly two-thirds of the total recoverable oil, whereas Helm and Riverdale fields account for an additional 22 percent of the total.

On the basis of the results of thermal maturity modeling (Peters, Magoon, Lampe, and others, this volume, chapter 12), Eocene-aged oil-prone source rocks are mature only in the southwest corner of the assessment unit, thereby necessitating long migration pathways from source to trap for much of the AU. This interpretation is consistent with the discovery of only dry gas accumulations in the northern area of the AU, suggesting that factors favorable to oil accumulation are probably absent north of Raisin City field. Throughout the middle and southeastern parts of the AU, the combination of inadequate volumes of locally mature source rocks, mostly thin reservoir units, and generally small traps make discovery of accumulations larger than 0.5 million barrels unlikely.

In the southwestern portion of the AU, a few charged deep reservoirs exist between the mature source rocks of the Kreyenhagen Formation, Tumey formation, and Monterey Formation (fig. 19.5). The recently discovered Kettleman City and Tulare Lake fields are two examples of these deep accumulations (fig. 19.11); in both fields, reservoir rock depths exceed 12,500 feet and porosity averages less than 20 percent. Although reservoir quality and trapping mechanisms remain problematical in this part of the AU, a few more of these deep accumulations may be discovered.

The embayment area to the west that includes the Vallecitos Syncline is highly structured with geographically and volumetrically restricted sections of sedimentary rocks, making this area unfavorable for significant future discoveries. Although regarded as highly unlikely, the possibility of fractured shale reservoirs in this AU cannot be dismissed. Finally, other rocks such as the Famoso sand of Edwards (1943), located in the southeastern corner of the AU between Deer Creek and Tulare Creek fields, and the sands of the Lodo Formation in the central basin may prove prospective in the future.

The USGS assessment of the potential for future petroleum discoveries in this assessment unit reflects the complex migration pathways, great distances from thermally mature source rocks, and the relatively advanced state of exploratory drilling in the area. We anticipate that future discoveries will be comparatively small and sparse, reflecting the continuation of the discovery history of the last few decades. Specifically, we predict that the number of undiscovered oil accumulations greater than the minimum-considered size of 0.5 million barrels (MMB) in the assessment unit ranges between one and ten, but this distribution is highly skewed as the most likely number of accumulations left to be found is estimated as two. The sizes of these accumulations range from 0.5 MMB to 30 MMB, with a median size of about four MMB. Accordingly, the estimated mean volume of potential additions to reserves in this assessment unit is about 12 MMB.

All assessment results and supporting documentation for the North and East of Eocene West Side Fold Belt Assessment Unit of the San Joaquin Basin Province are available in files c100302.pdf (data form for conventional assessment unit), d100302.pdf (summary of discovery history), em100302.pdf (probabilistic estimates), g100302.pdf (graphs of exploration and discovery data for grown volumes), and k100302.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

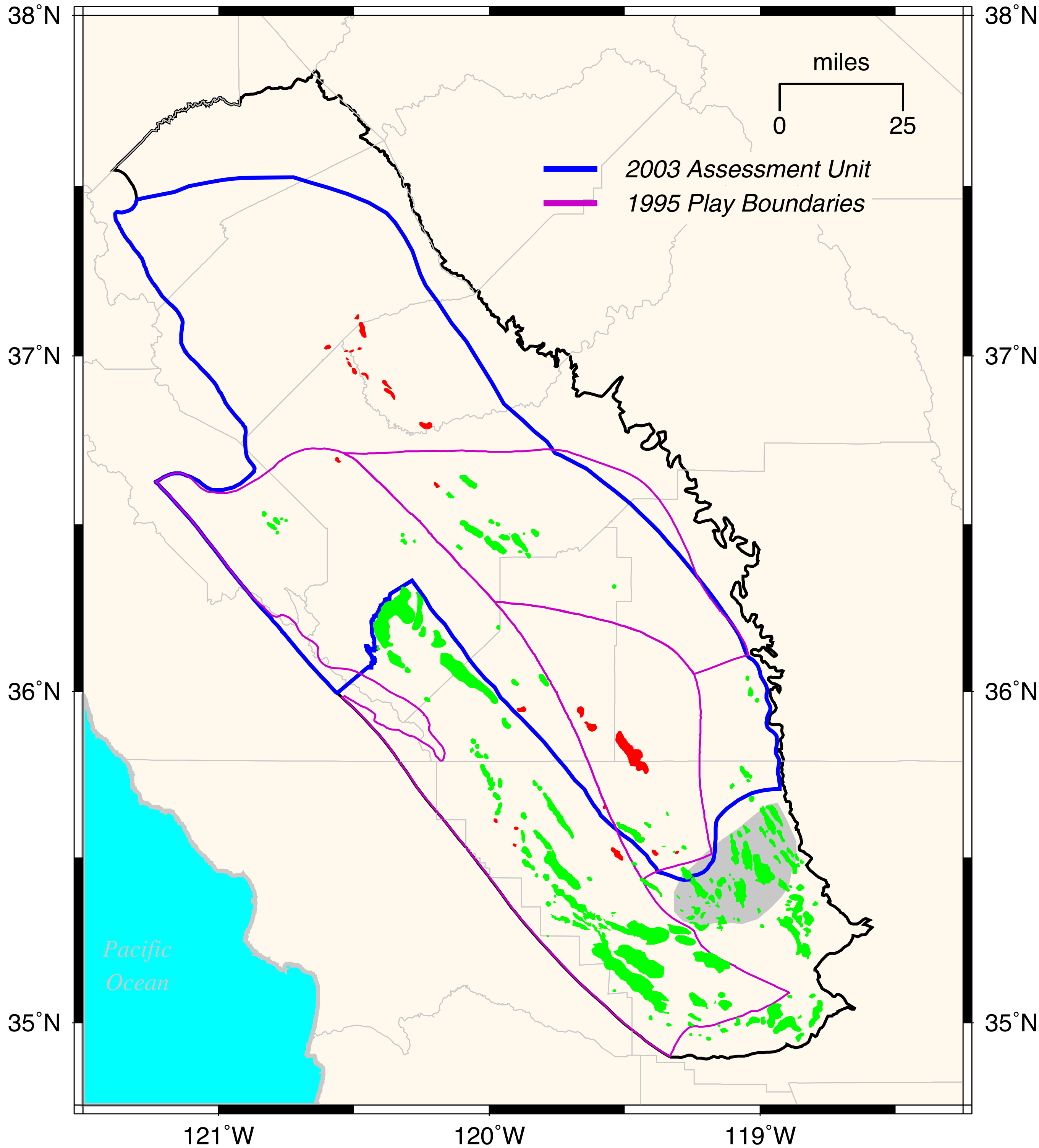

Figure 19.1. Map of the San Joaquin Basin, illustrating San Joaquin Basin Province boundary (bold line), county boundaries (thin gray line), North and East of Eocene West Side Fold Belt Assessment Unit boundary (blue line), corresponding play boundaries from previous USGS assessment (purple line), and oil (green) and gas (red) fields in the basin. 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).

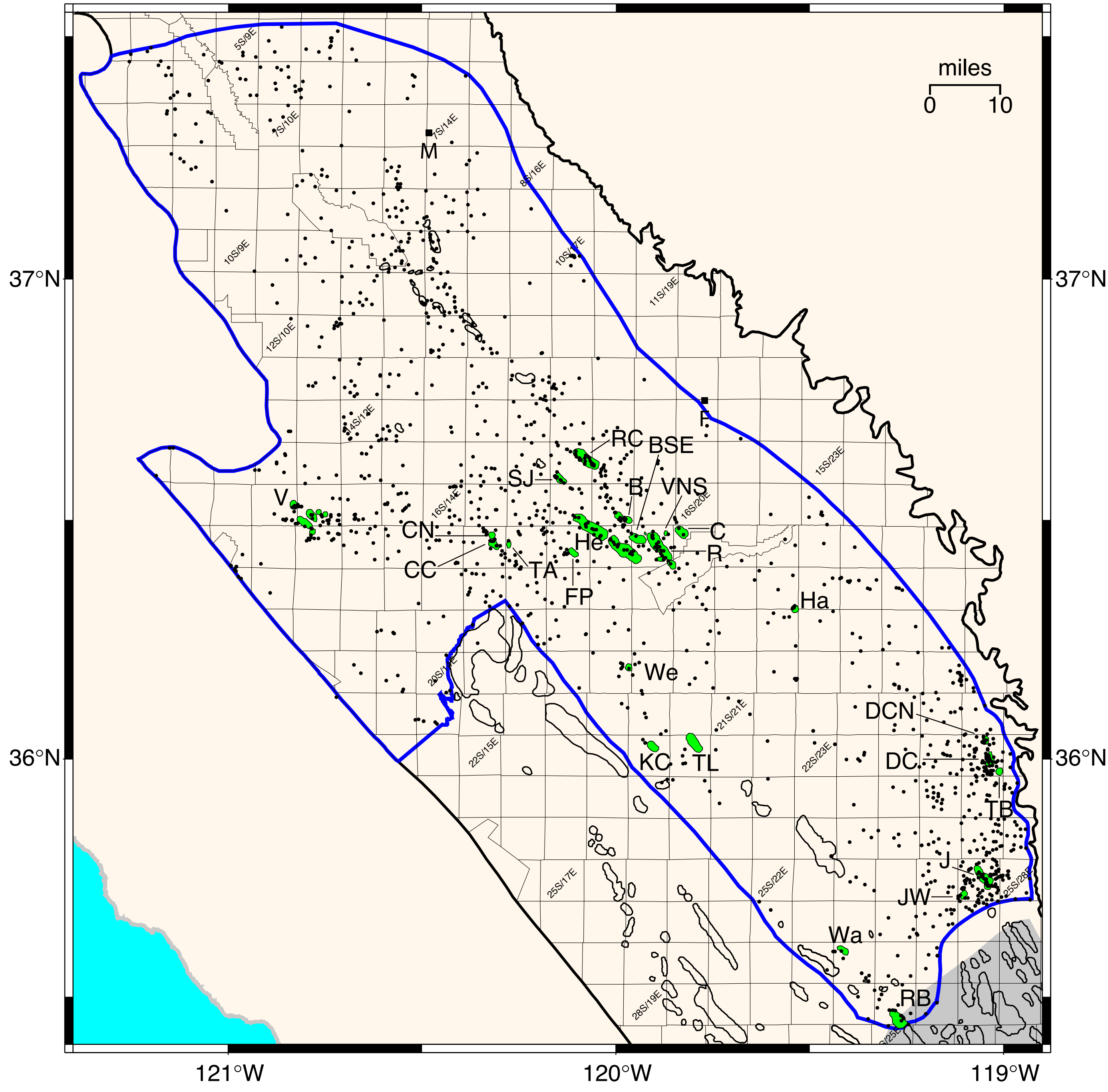

Figure 19.2. Detailed map of North and East of Eocene West Side Fold Belt Assessment Unit. The blue line indicates the geographic limits of the AU. Oil fields in the AU are colored green. Fields outside the AU are outlined in black. Filled circles represent 1,543 wells drilled for petroleum within the AU between 1909 and 2001. Well locations are from the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, and are available in databases at ftp://ftp.conserv.ca.gov/pub/oil/maps/dist4 and ftp://ftp.conserv.ca.gov/pub/oil/maps/dist5. 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. Cities of Merced (M) and Fresno (F) are denoted with filled squares. Primary and secondary (*) oil field labels are: B=Burrel, BSE=Burrel Southeast, C=Camden*, CC=Cantua Creek*, CN=Cantua Nueva*, DC=Deer Creek, DCN=Deer Creek North*, FP=Five Points*, Ha=Hanford*, He=Helm, J=Jasmin, JW=Jasmin West*, KC=Kettleman City*, RC=Raisin City, RB=Rio Bravo, R=Riverdale, SJ=San Joaquin, TB=Terra Bella*, TL=Tulare Lake, TA=Turk Anticline*, V=Vallecitos, VNS=Van Ness Slough, Wa=Wasco, and We=Westhaven*.

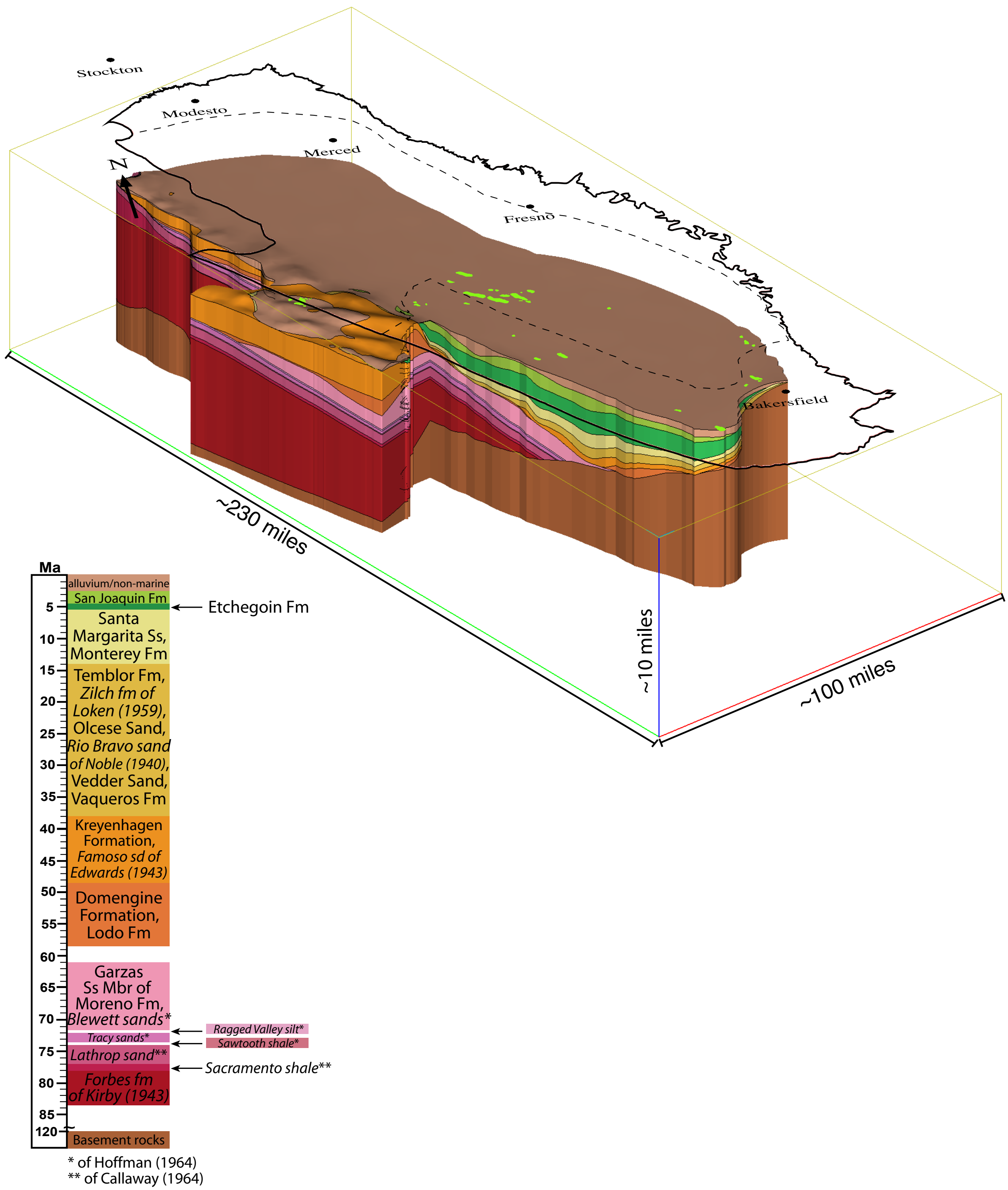

Figure 19.3. Three-dimensional stratigraphic model of the North and East of Eocene West Side Fold Belt Assessment Unit extracted from the EarthVision® model of the basin by Hosford Scheirer (this volume, chapter 7). The bounding polygonal block illustrates the model space within which the EarthVision® model is constructed. The major stratigraphic units within the assessment unit are listed; see figure 19.4 for stratigraphic relationships between the units. Formation names in italics are informal. Oil fields (green) are draped on the topographic surface. The San Joaquin Basin Province boundary (bold line), assessment unit boundary (dashed line), and city names and locations float above the model. View is from 10° west of south at a 30° inclination angle. Vertical exaggeration is 4. Fm, Formation; fm, formation; Mbr, Member; sd, sand; Ss, Sandstone. EarthVision is a registered trademark (Marca Registrada) of Dynamic Graphics, Inc., Alameda, Calif.

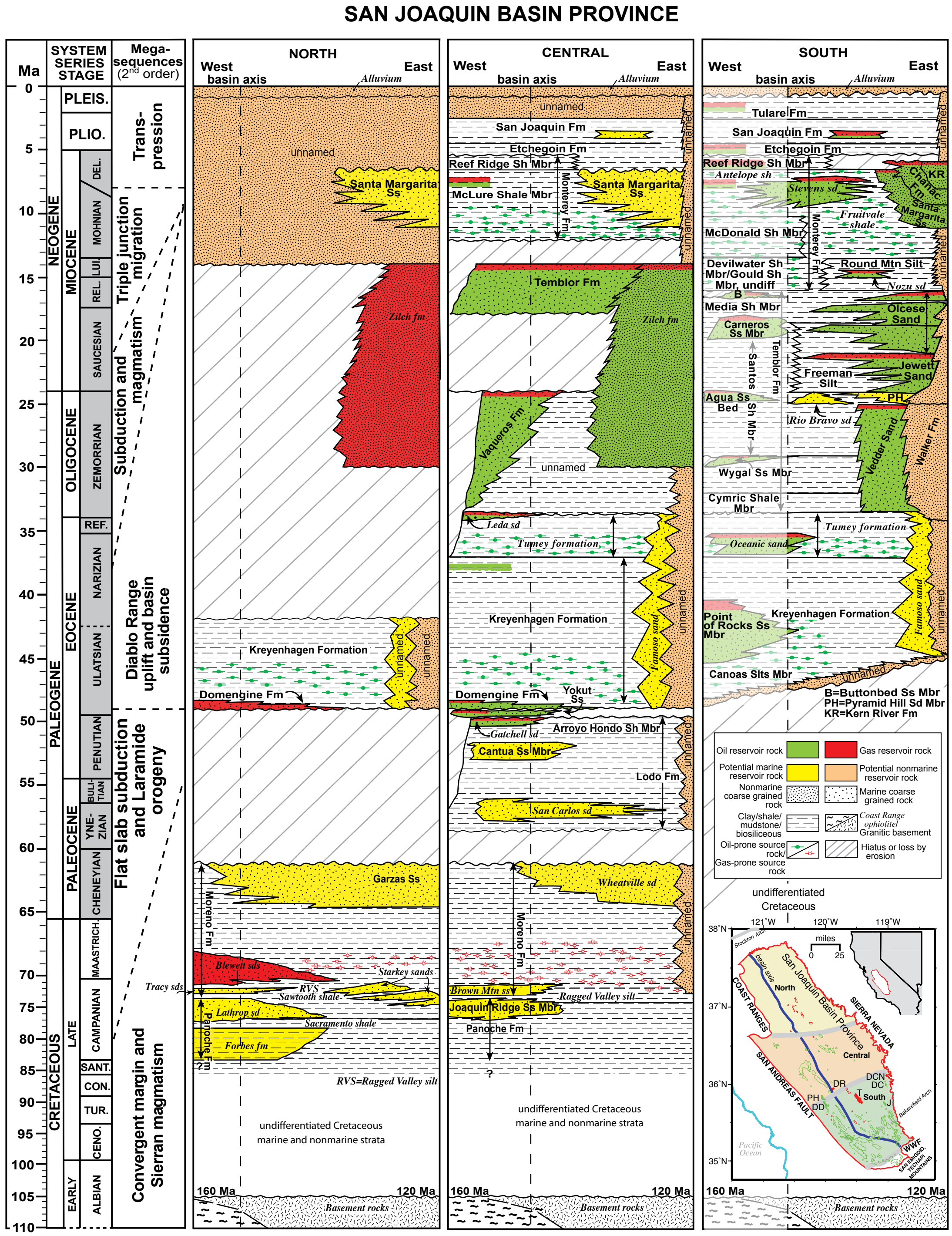

Figure 19.4. San Joaquin Basin Province stratigraphy showing hydrocarbon reservoir rocks and potential hydrocarbon source rocks. See Hosford Scheirer and Magoon (this volume, chapter 5) for complete explanation of the figure. Stratigraphic relationships on the west side of southern San Joaquin Basin are masked with transparency to indicate that the southwest margin does not strictly fall within the assessment unit. Formation names in italics are informal and are defined as follows (in approximate age order): Forbes formation of Kirby (1943), Sacramento shale and Lathrop sand of Callaway (1964), Sawtooth shale and Tracy sands of Hoffman (1964), Brown Mountain sandstone of Bishop (1970), Ragged Valley silt, Starkey sands, and Blewett sands of Hoffman (1964), Wheatville sand of Callaway (1964), San Carlos sand of Wilkinson (1960), Gatchell sand of Goudkoff (1943), Oceanic sand of McMasters (1948), Leda sand of Sullivan (1963), Tumey formation of Atwill (1935), Famoso sand of Edwards (1943), Rio Bravo sand of Noble (1940), Nozu sand of Kasline (1942), Zilch formation of Loken (1959), Stevens sand of Eckis (1940), Fruitvale shale of Miller and Bloom (1939), and Antelope shale of Graham and Williams (1985).

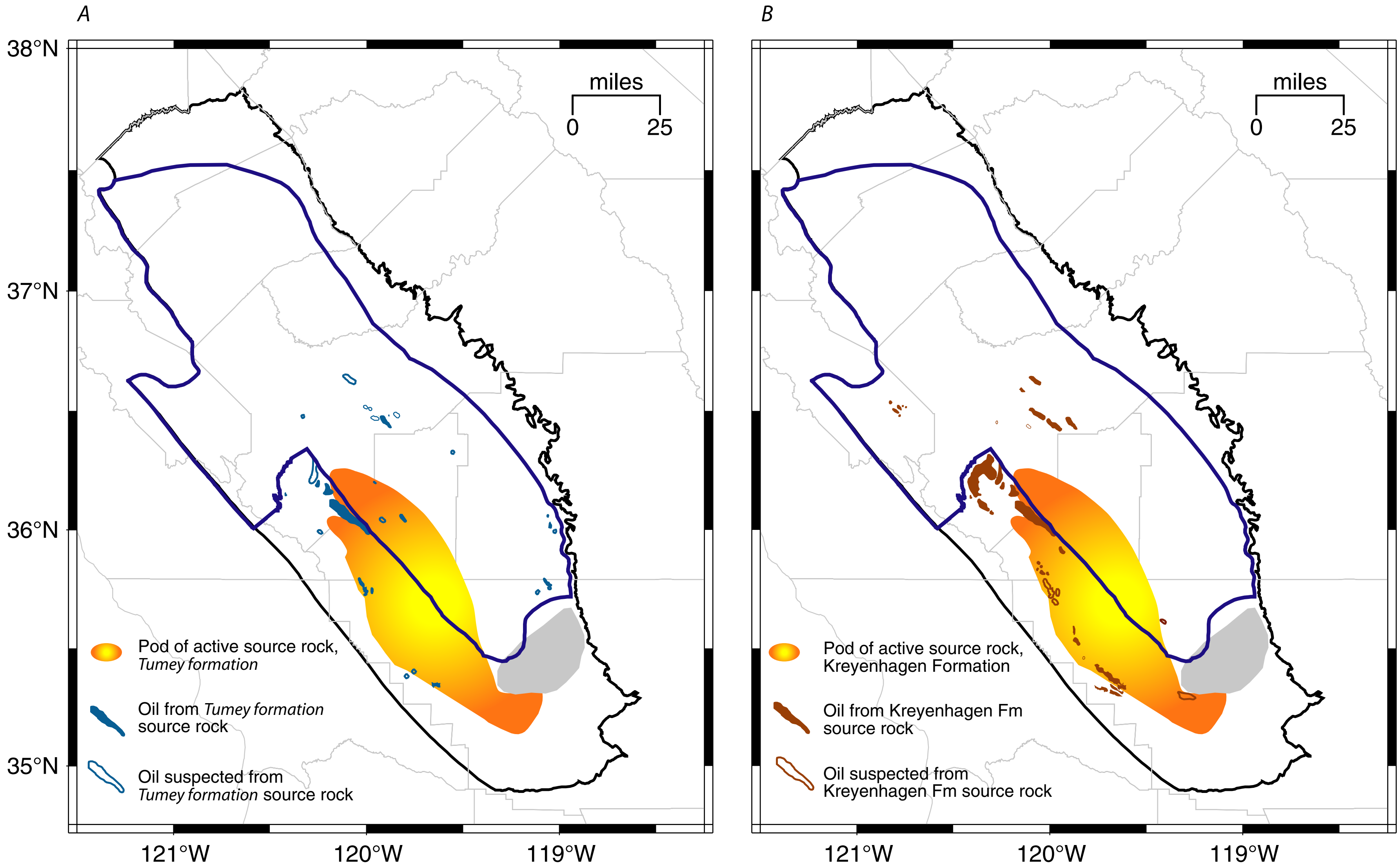

Figure 19.5. Location of North and East of Eocene West Side Fold Belt Assessment Unit (blue line) with respect to the pods of active source rock of the Tumey formation (*A*) and Kreyenhagen Formation (*B*) of the Eocene Total Petroleum System as mapped by Peters, Magoon, Lampe, and others (this volume, chapter 12). Because of a lack of geochemical data, the pod of active source rock for the Tumey formation is assumed to be the same as the pod of active source rock for the Kreyenhagen Formation. 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. Italics denote informal geologic name.

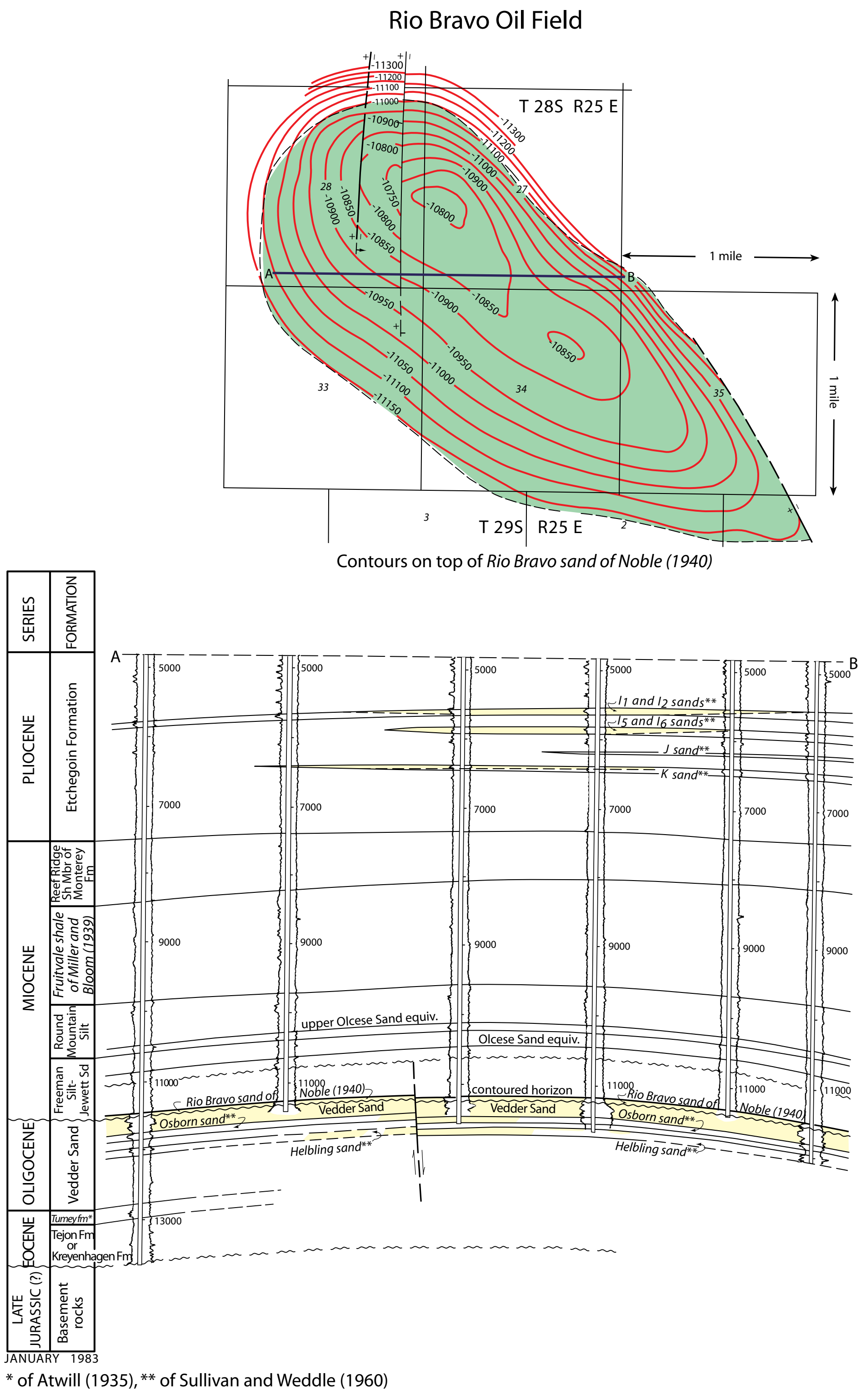

Figure 19.6. Figure of the Rio Bravo oil field, illustrating the asymmetrical dome structure of the field. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the field. All depths are in feet. Formations in italics denote informal geologic names. Informal units not previously defined include the I1, I2, I5, I6, J, K, Helbling, and Osborn sands of Sullivan and Weddle (1960). Township-range grid in figures 19.6 and 19.8 through 19.11 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 19.2 for location of field. Figure modified from CDOGGR (1998). Fm, Formation; fm, formation; Mbr, Member; Sd, Sand; Sh, Shale; equiv., equivalent.

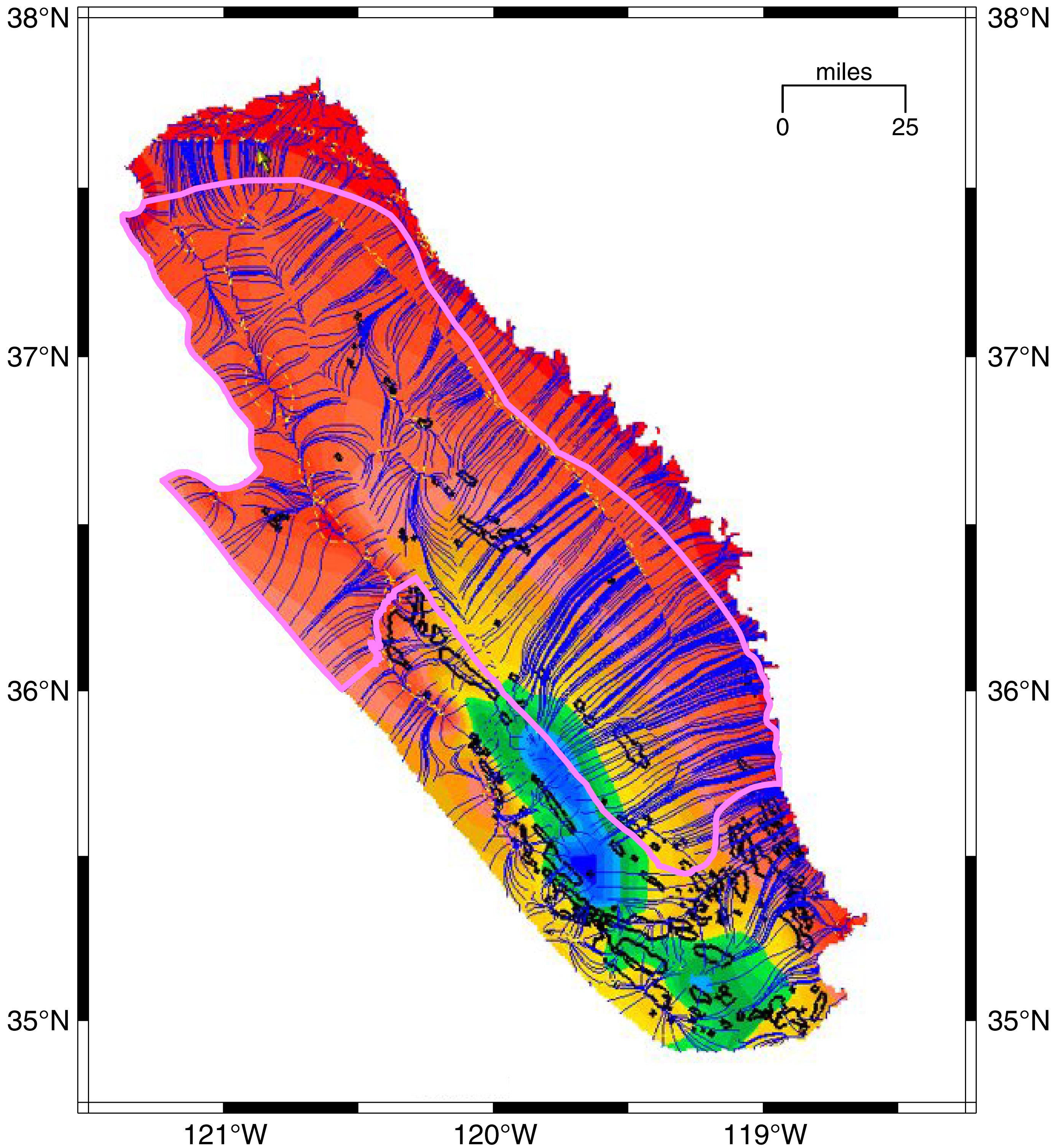

Figure 19.7. Pathways (blue line) of migrating hydrocarbons at the top of the Point of Rocks Sandstone Member of the Kreyenhagen Formation derived from a four-dimensional petroleum system model of the San Joaquin Basin (Peters, Magoon, Lampe, and others, this volume, chapter 12). Underlying shading schematically illustrates depth to the top of the Point of Rocks Sandstone; cool colors are relatively deeper than warm colors. Oil and gas fields are outlined in black and the AU boundary is shown in purple. Note the absence of hydrocarbon accumulations on the eastern margin of the San Joaquin Basin.

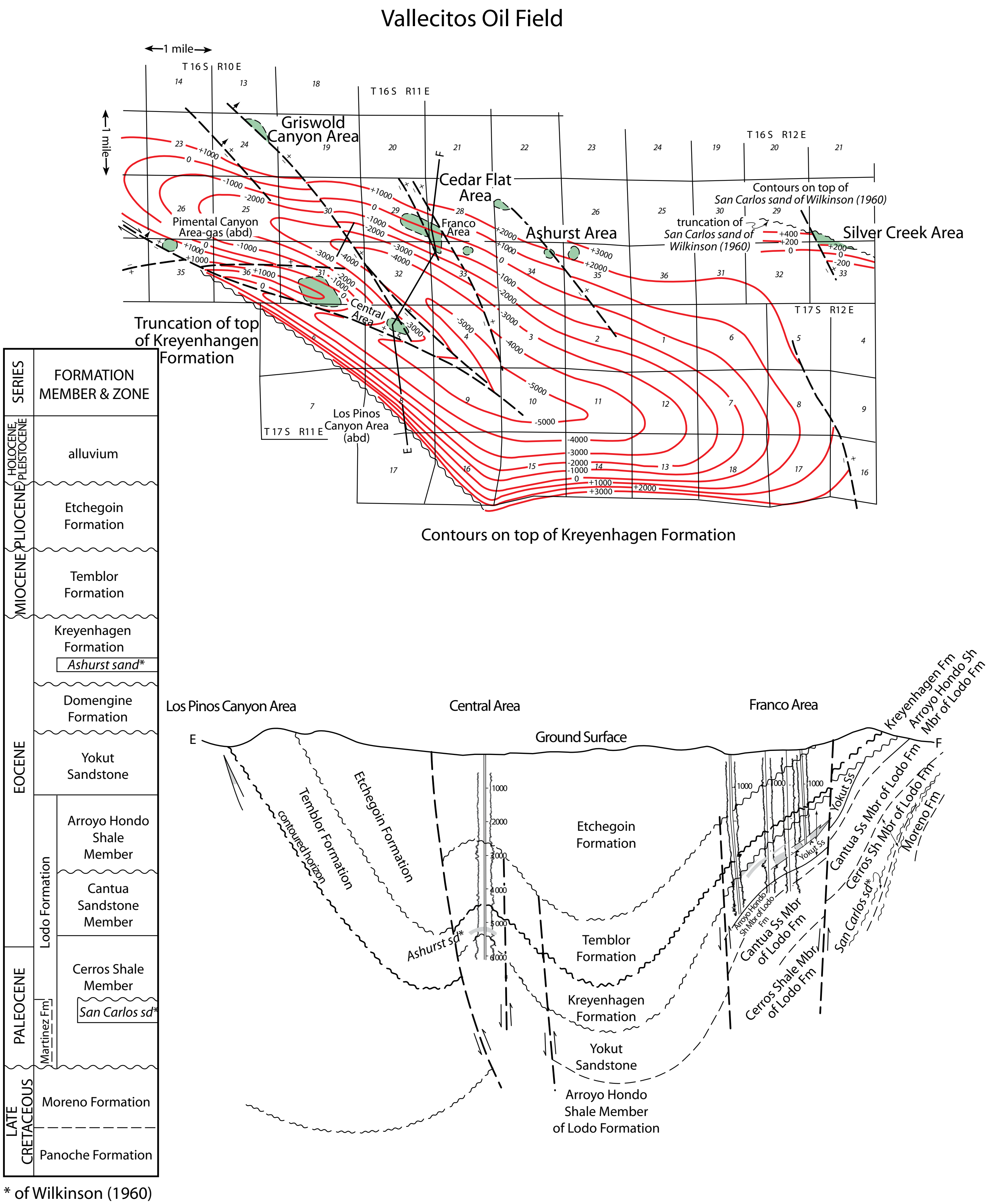

Figure 19.8. Figure of the Vallecitos oil field, illustrating the synclinal structure of the region. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the field. All depths are in feet. Formations in italics denote informal geologic names. Informal units not previously defined include the Ashurst sand and San Carlos sand of Wilkinson (1960). See figure 19.2 for location of field. Figure modified from CDOGGR (1998). Fm, Formation; Mbr, Member; Sh, Shale; sd, sand; Ss, Sandstone; abd, abandoned.

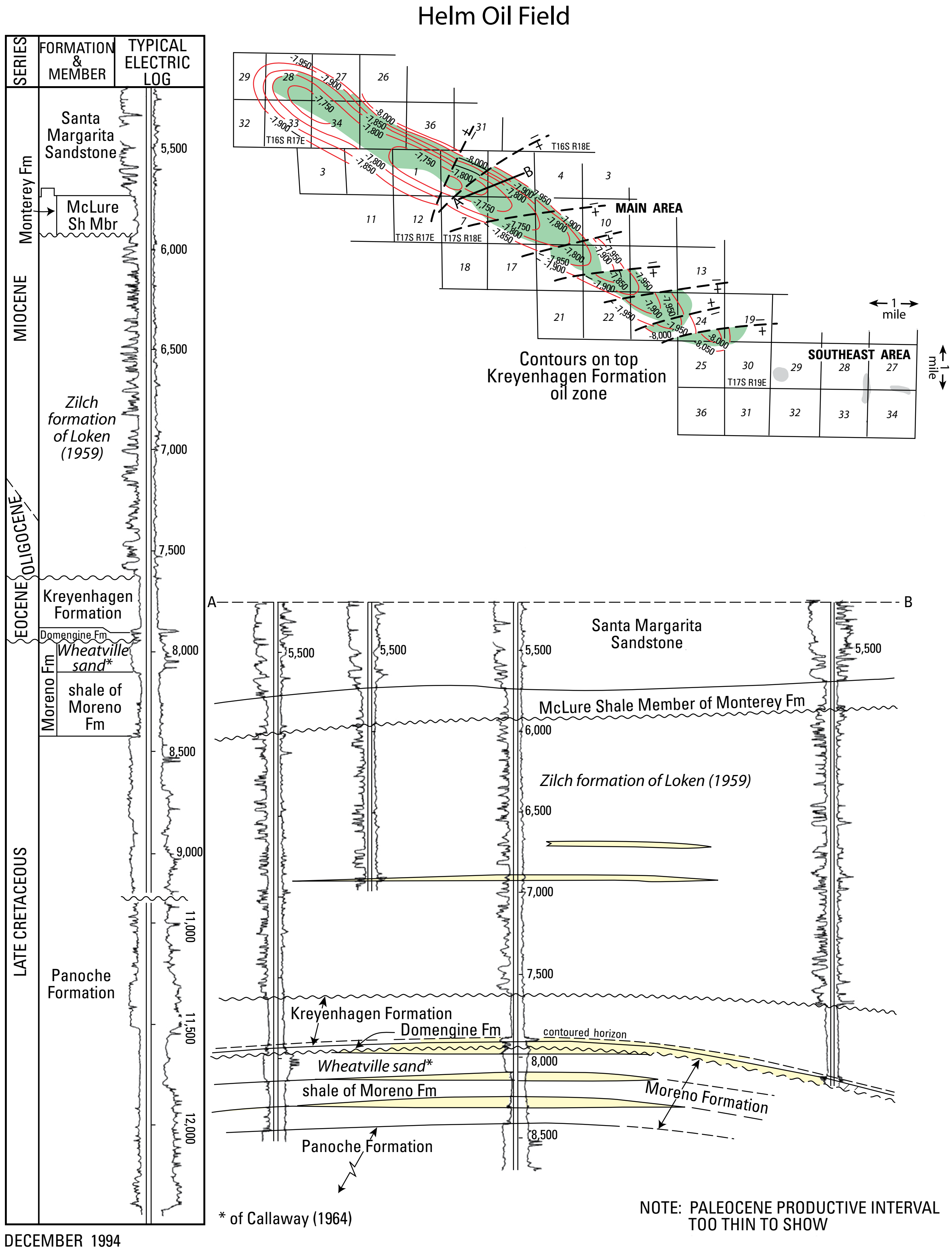

Figure 19.9. Figure of the Helm oil field, illustrating anticlinal trapping mechanism in the assessment unit. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the field. All depths are in feet. Formations in italics denote informal geologic names. See figure 19.2 for location of field. Figure modified from CDOGGR (1998). Fm, Formation; Mbr, Member; Sh, Shale.

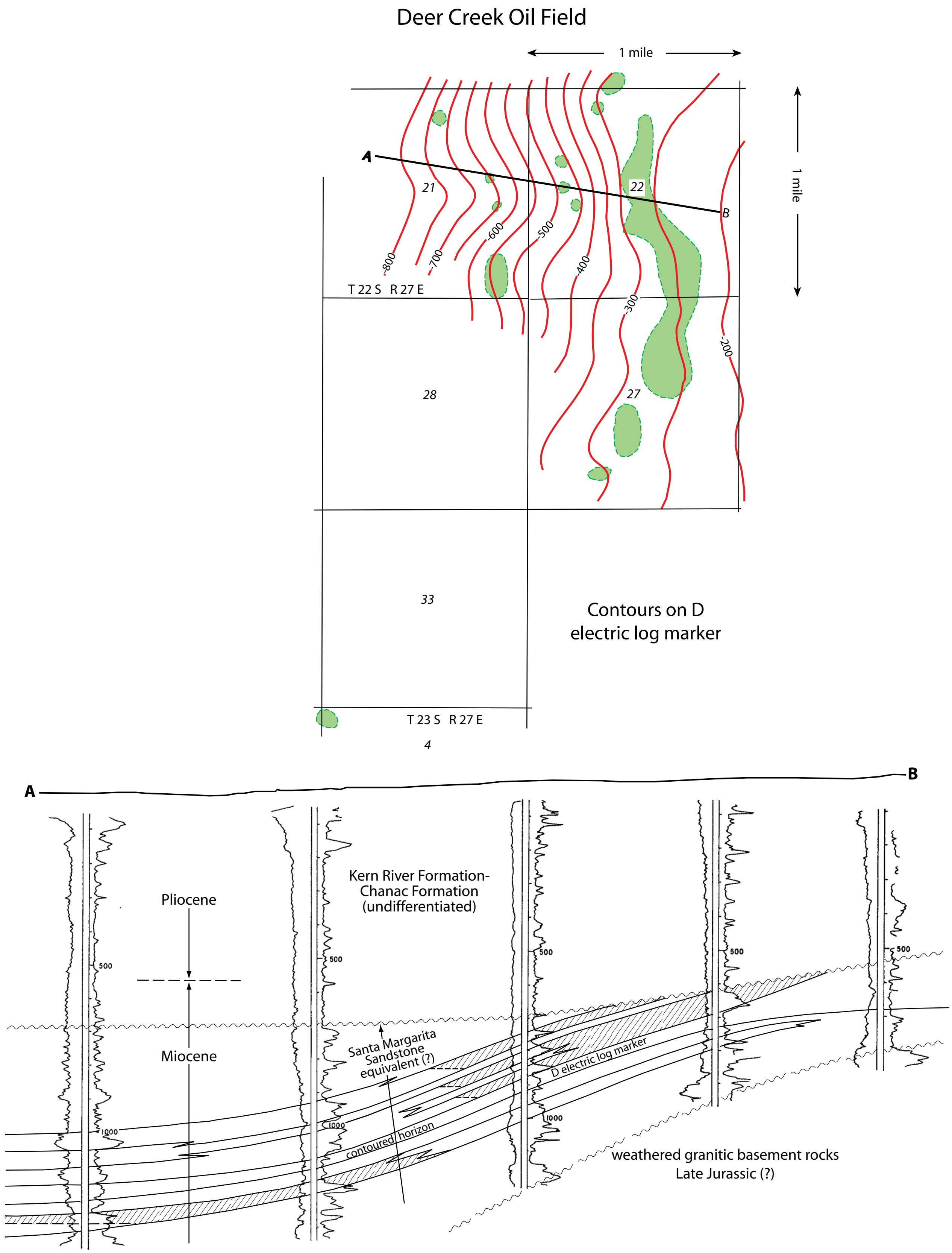

Figure 19.10. Figure of the Deer Creek oil field, illustrating stratigraphic trapping mechanism near the eastern basin margin. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the field. All depths are in feet. See figure 19.2 for location of field. Figure modified from CDOGGR (1998).

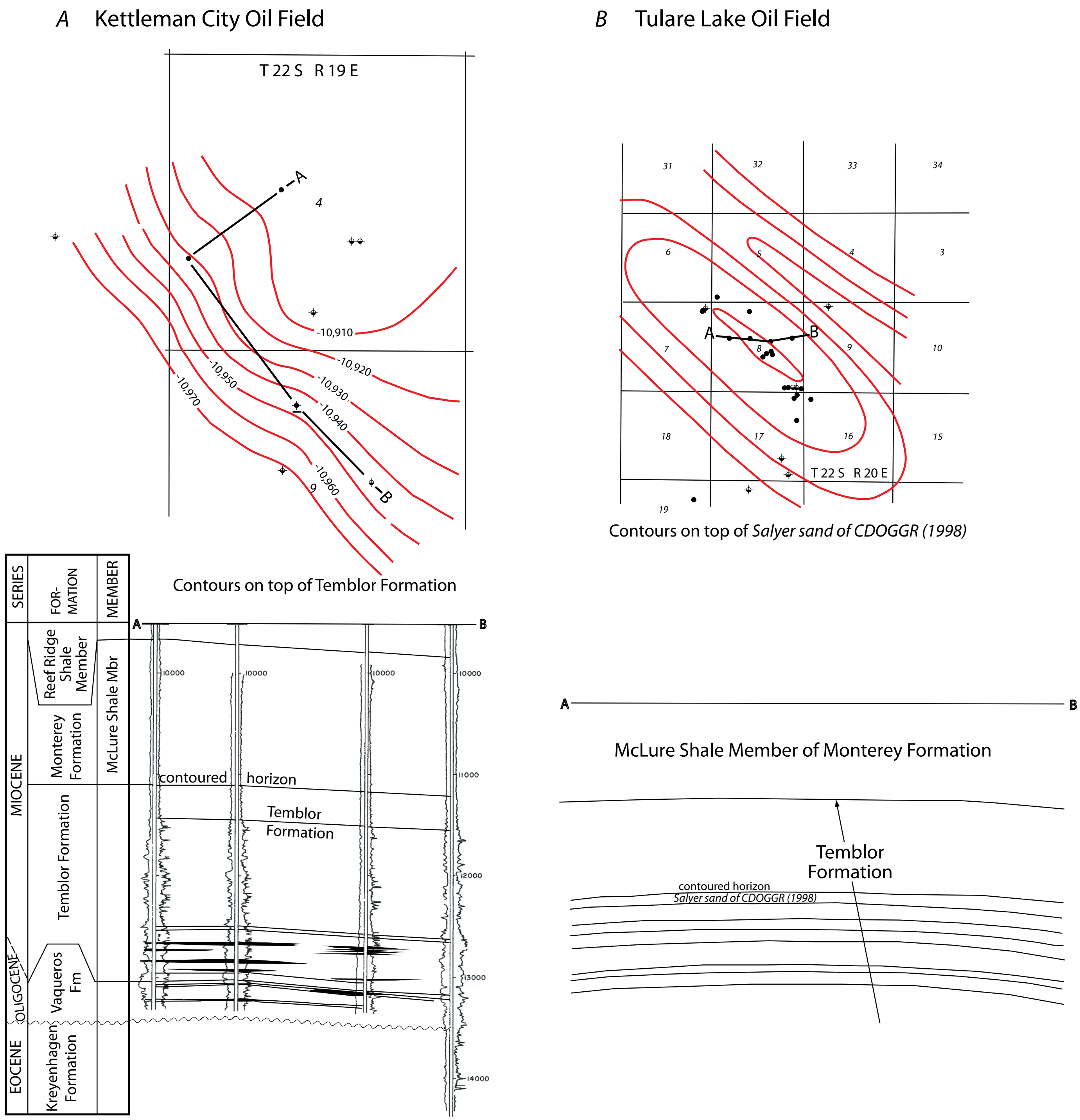

Figure 19.11. Figure of the Kettleman City (*A*) and Tulare Lake (*B*) oil fields, illustrating characteristics of two of the most recently discovered fields within the southwest portion of the assessment unit. All depths are in feet. Formations in italics denote informal geologic names. Informal units not previously defined include the Salyer sand of CDOGGR (1998). See figure 19.2 for location of fields. Figure modified from CDOGGR (1998). Fm, Formation; Mbr, Member.

Table 19.1. Production statistics for primary fields in the North and East of Eocene West Side Fold Belt 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. Fields with zero producing wells are abandoned. Largest pool is cumulative production only. Pool designations follow naming conventions of the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources]

Field	Recoverable Oil through 2002 (MMB)	Percent of Total	Number of Producing Wells in 2002	Largest Pool (MMB)
Rio Bravo	117.0	47.7	14	Rio Bravo-Main Vedder-Osborn (109.6)
Raisin City	43.6	17.8	45	Zilch (38.7)
Helm	32.4	13.2	18	Miocene (Zilch) (20.3)
Riverdale	22.1	9.0	11	Miocene (Zilch) (14.9)
Tulare Lake	7.1	2.9	4	Boswell (1.9)
Vallecitos	5.5	2.2	19	Domengine-Yokut (3.6)
Wasco	5.1	2.1	1	unspecified (5.1)
Jasmin	4.0	1.6	35	Cantleberry (3.8)
Deer Creek	3.3	1.4	59	Santa Margarita (2.6)
Burrel	1.8	0.7	1	Miocene (Zilch) (1.8)
San Joaquin	1.2	0.5	2	Eocene (1.2)
Burrel, SE	1.2	0.5	0	Miocene (Zilch) (1.2)
Van Ness Slough	0.7	0.3	3	Miocene (Zilch) (0.6)
Total	245.0	99.9	212	