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

Chapter 22

Neogene Gas Total Petroleum System—Neogene Nonassociated Gas Assessment Unit of the San Joaquin Basin Province

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Contents

Summary

Boundaries	Extent of Etchegoin Formation on the north and east; limit of structural deformation or petroleum system on the west; White Wolf Fault on the south; topographic surface to base of Etchegoin Formation.
Source Rocks	Pliocene marine, kerogen-rich, mudstone of the Etchegoin and San Joaquin Formations.
Reservoir Rocks	Pliocene shallow-water marine sandstones of the Etchegoin and San Joaquin Formations and Pleistocene deltaic and nonmarine sandstone lenses of the Tulare Formation.
Traps	Elongate gentle domes and stratigraphic traps.
Migration	Locally from adjacent kerogen-rich mudstone into sandstone lenses.
Timing	Traps formed during Pliocene as gas was forming.
Primary Fields	Bowerbank, Buttonwillow, Coles Levee North, Coles Levee South, Dudley Ridge, Harvester, Paloma, Rio Bravo, Semitropic, Ten Section, Trico, Trico Northwest.
Secondary Fields	Canal, Garrison City, Los Lobos, Semitropic, Shafter Southeast, Strand.
Exploration Status	Moderately explored (0.3 well per square mile and 23 percent of all sections have at least one exploratory well).
Resource Potential	Potential for undiscovered fields in subtle structural and stratigraphic traps.

Description

The Neogene Nonassociated Gas Assessment Unit (AU) of the Neogene Total Petroleum System consists of nonassociated gas accumulations in Pliocene marine and brackish-water sandstone located in the south and central San Joaquin Basin Province (Rudkin, 1968). Traps consist mainly of stratigraphic lenses in low-relief, elongate domes that trend northwest-southeast. Reservoir rocks typically occur as sands that pinch out at shallow depths (1,000 to 7,500 feet) within the Etchegoin and San Joaquin Formations.

Map boundaries of the assessment unit are shown in figures 22.1 and 22.2; this assessment unit replaces the Pliocene

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Nonassociated Gas play 1001 (shown by purple line in fig. 22.1) considered by the U.S. Geological Survey (USGS) in its 1995 National Assessment (Beyer, 1996). The AU is drawn to include all existing fields containing nonassociated gas accumulations in the Pliocene to Pleistocene section, as was done in the 1995 assessment, but it was greatly expanded to include adjacent areas believed to contain similar source and reservoir rock relationships. Stratigraphically, the AU extends from the topographic surface to the base of the Etchegoin Formation (figs. 22.3 and 22.4). The boundaries of the AU explicitly exclude gas accumulations in Neogene rocks on the severely deformed west side of the basin and gas accumulations in underlying Miocene rocks; these resources, which primarily consist of a mixture of mostly thermogenic and some biogenic gas, are included in two other assessment units. Lillis and others (this volume, chapter 10) discuss the geochemical characteristics of biogenic gas in the San Joaquin Basin Province.

Primary fields in the assessment unit are defined as those containing hydrocarbon resources greater than the USGS minimum threshold for assessment—3 billion cubic feet (BCF) of gas; secondary fields contain smaller volumes of gas but constitute a significant show of hydrocarbons. Although 12 fields meet the 3 BCF criterion for inclusion in the AU, only 5 fields were considered at the time of assessment.

Source Rocks

In general, source rock units for natural gas are difficult to identify with confidence, because the composition of natural gas is too simple to correlate with organic matter in the source rock and the carbon isotopic composition of biogenic methane from all source rocks is similar (generally less than -55 per mil; Rice and Claypool, 1981). Geochemical analysis of five gas samples identified as biogenic in origin reveals that gas within the AU contains low carbon dioxide and nitrogen (less than 0.5 and 0.3 percent, respectively) and low d^{13}C methane (–56 to –70 per mil) (Lillis and others, this volume, chapter 10). Thus, nonassociated, biogenic gas in the central and southern San Joaquin Basin is most likely produced from microbial decomposition of marine organic matter within thick, Pliocene marine mudstone and claystone within the boundaries of the AU (fig. 22.5).

Although Rock-Eval pyrolysis and organic carbon (TOC) data are lacking from organic intervals within the Pliocene section, the San Joaquin Formation is the suspected source rock for the biogenic gas in the AU because about 85 percent of the gas in the AU by volume resides in sand lenses that pinch out stratigraphically against mud and claystone of the San Joaquin Formation.

Maturation and Migration

From early Pliocene time, both stratigraphic trap development and gas charge in this AU probably occurred at or about the time of deposition of the reservoir rock. Biogenic gas forms from organic matter at low temperatures by microbial action at the surface to a depth of few thousand feet (Rice and Claypool, 1981). Typically this gas vents to the atmosphere, but under certain conditions it becomes trapped in adjacent sand lenses that are sealed by mudstone and is buried to greater depths. This burial improves seal integrity and increases the pressure of the entrapped gas, setting the stage for a possible commercial accumulation. In this AU, from late Pliocene time, low-relief anticlinal traps formed and regional up-to-the-northeast tilting occurred after burial had already compacted fine-grained capping beds (Bartow, 1991; Beyer, 1996).

Reservoir Rocks

Hydrocarbon reservoir rocks in this AU consist of Pliocene shallow-water marine sandstones of the Etchegoin and San Joaquin Formations that generally unconformably overlie upper Miocene rocks; these are overlain by Pleistocene deltaic and nonmarine sand in the Tulare Formation (figs. 22.4 and 22.5). Quaternary nonmarine deposits overlie the Tulare Formation. Individual reservoir rocks range from about 5 to 30 feet thick (CDOGGR, 1998). Porosities of these poorly compacted reservoir rocks are reported to range from about 20 to 35 percent (CDOGGR, 1998). Detailed depositional histories of these reservoir rocks are discussed by Miller (1999), Reid (1995), and Loomis (1988), among others.

Traps and Seals

Traps of known biogenic gas accumulations are mostly lenses of sandstone encased in a seal rock associated with elongate gentle domes. Seal rocks are fine-grained, low-permeability claystone, mudstone, and tightly cemented sandstone. Depths of the 18 discovered accumulations range from about 1,000 to 7,500 feet, with one accumulation at about 1,000 feet deep (Dudley Ridge field) and two at about 7,500 feet deep (Semitropic and Ten Section fields).

Exploration Status and Resource Potential

The AU has been intensely drilled by 1,694 exploratory wells throughout its geographic extent, except for a handful of townships where only a few wells exist (fig. 22.2). However, we believe the number of wells in the AU overstate its exploration maturity; because these wells were drilled at times when natural gas wasn't economic to produce, industry likely drilled for deeper oil targets, bypassing shallower gas sands. Although most of the obvious structures have been drilled in the AU, it seems likely that additional gas deposits in small sand stringers like the ones at Buttonwillow field (fig. 22.6) exist. Future discoveries of stratigraphically trapped biogenic gas likely reside in thin sand lenses that may have already been drilled through on the gentle east flank of the basin, away from already-identified structures to the west. There may also be additional biogenic gas in the Etchegoin and San Joaquin Formations above existing oil fields of the San Joaquin Basin; about half of the gas accumulations assigned to this assessment unit are associated with deeper, prolific oil pools.

Undiscovered gas composition probably is similar to that of 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 most likely in the range of discovered reservoirs (1,000 to 7,000 feet). Undiscovered gas accumulations may exist in stratigraphic traps similar to those already discovered, primarily in the erratic sands in the Mya sand zone of Berryman (1973) of the San Joaquin Formation. To find these, a thorough understanding of reservoir sands and depositional systems, combined with three-dimensional seismic surveys, is essential.

The 12 primary fields larger than 3 BCF and the 5 used in this assessment within the Neogene Nonassociated Gas Assessment Unit, in order of decreasing gas volume, are shown in table 22.1 and figure 22.8; all 18 gas fields are shown in figure 22.2. Trico field (fig. 22.7) accounts for about 50 percent, or 200 billion cubic feet (BCF), of the total biogenic gas produced in the San Joaquin Basin. The remaining population of accumulations ranges from a few to tens of BCF in size. Thus, an additional 200 BCF accumulation is probably unlikely.

All assessment results and supporting documentation for the Neogene Nonassociated Gas Assessment Unit of the San Joaquin Basin Province are available in files c100501.pdf (data form for conventional assessment unit), d100501.pdf (summary of discovery history), em100501.pdf (probabilistic estimates), g100501.pdf (graphs of exploration and discovery data for grown volumes), and k100501.pdf (graphs of exploration and discovery data for known volumes). Klett and Le (this volume, chapter 28) summarize the contents of these files. Using five known accumulations, the November 2003 assessment team estimated that the number of undiscovered accumulations greater than 3 BCF ranges from one to seven, with the likeliest number similar to the number of discovered accumulations. The total estimated gas resource in this assessment unit thus ranges from 4 to 88 BCF, with a mean of 29 BCF.

Since the 2003 assessment, the authors have determined that 12 known accumulations listed in table 22.1 should have been assigned to the AU. Thus, the discovery history of gas accumulations, as illustrated in files d100501.pdf, g100501.pdf, and k100501.pdf, shows fewer accumulations of biogenic gas in the AU.

References Cited

Atwill, E.R., 1935, Oligocene Tumey Formation of California: Bulletin of the American Association of Petroleum Geologists, v. 19, no. 8, p. 1192-1204.

Bartow, J.A., 1991, The Cenozoic evolution of the San Joaquin Valley, California: U.S. Geological Survey Professional Paper 1501, 40 p.

Berryman, W.M., 1973, Lithologic characteristics of Pliocene rocks cored at Elk Hills, Kern County, California: U.S. Geological Survey Bulletin 1332-D, 56 p.

Beyer, L.A., 1996, San Joaquin Basin Province, *in* Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS-30, release 2.

Bishop, C.C., 1970, Upper Cretaceous stratigraphy on the west side of the Northern San Joaquin Valley, Stanislaus and San Joaquin counties, California: California Division of Mines and Geology Special Report 104, 29 p.

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

CDOGGR, 1998, California oil and gas fields: Sacramento, Calif., California Department of Conservation, Division of Oil, Gas, and Geothermal Resources Publication No. CD-1, 1472 p.

CDOGGR, 2003, 2002 Annual Report of the State Oil and Gas Supervisor: California Department of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. PR06, 263 p. [also available at ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/2002/].

Eckis, R., 1940, The Stevens sand, southern San Joaquin Valley, California [abs.]: Bulletin of the American Association of Petroleum Geologists, v. 24, no. 12, p. 2195-2196.

Edwards, E.C., 1943, Kern Front area of the Kern River oil field, *in* Jenkins, O.P., ed., Geologic formations and economic development of the oil and gas fields of California: San Francisco, Calif., State of California, Department of Natural Resources, Division of Mines Bulletin No. 118, p. 571-574.

Goudkoff, P.P., 1943, Correlation of oil field formations on west side of San Joaquin Valley, *in* Jenkins, O.P., ed., Geologic formations and economic development of the oil and gas fields of California: San Francisco, Calif., State of California, Department of Natural Resources, Division of Mines Bulletin No. 118, p. 247-252.

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

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

Kaplow, E.J., 1940, Gas fields of the southern San Joaquin Valley, *in* Summary of operations, California oil fields: San Francisco, Calif., Annual Report of the State Oil and Gas Supervisor, v. 24, no. 1, p. 30-50 [also available in California Division of Oil and Gas, Summary of Operations, 1915-1999: California Division of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. CD-3, and at ftp://ftp.consrv.ca.gov/pub/oil/Summary_of_Operations/1938/].

Kasline, F.E., 1942, Edison oil field, *in* Summary of operations, California oil fields: San Francisco, Calif., Annual Report of the State Oil and Gas Supervisor, v. 26, p. 12-18 [also available *in* California Division of Oil and Gas, Summary of Operations, 1915-1999: California Division of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. CD-3, and at ftp://ftp.consrv.ca.gov/pub/oil/Summary_of_Operations/1940/].

Loken, K.P., 1959, Gill Ranch gas field, *in* Summary of operations, California oil fields: San Francisco, Calif., Annual Report of the State Oil and Gas Supervisor, v. 45, no. 1, p. 27-32 [also available *in* California Division of Oil and Gas, Summary of Operations, 1915-1999: California Division of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. CD-3, and at ftp://ftp.consrv.ca.gov/pub/oil/Summary_of Operations/1959/].

Loomis, K.B., 1988, Paleoenvironmental and paleoclimatic interpretation of upper Miocene-Pliocene lithofacies and macrobiota of the Etchegoin Group, Jacalitos Canyon, San Joaquin Valley, California, *in* Graham, S.A., and Olson, H.C., eds., Studies of the geology of the San Joaquin Basin: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, book 60, p. 303-318.

McMasters, J.H., 1948, Oceanic sand [abs.]: Bulletin of the American Association of Petroleum Geologists, v. 32, no. 12, p. 2320.

Miller, D.D., 1999, Sequence stratigraphy and controls on deposition of the upper Cenozoic Tulare Formation, San Joaquin Valley, California: Stanford, Calif., Stanford University, Ph.D. dissertation, 179 p.

Miller, R.H., and Bloom, C.V., 1939, Mountain View oil field, *in* Summary of operations, California oil fields: San Francisco, Calif., Annual Report of the State Oil and Gas Supervisor, v. 22, no. 4, p. 5-36 [also available *in* California Division of Oil and Gas, Summary of Operations, 1915-1999: California Division of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. CD-3, and at ftp://ftp.consrv.ca.gov/pub/oil/Summary_of_Operations/1937/].

Noble, E.B., 1940, Rio Bravo oil field, Kern County, California: Bulletin of the American Association of Petroleum Geologists, v. 24, no. 7, p. 1330-1333.

Reid, S.A., 1995, Miocene and Pliocene depositional systems of the southern San Joaquin basin and formation of sandstone reservoirs in the Elk Hills area, California, *in* Fritsche, A.E., ed., Cenozoic paleogeography of the western United States—II: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 131-150.

Rice, D.D., and Claypool, G.E., 1981, Generation, accumulation, and resource potential of biogenic gas: American Association of Petroleum Geologists Bulletin, v. 65, no. 1, p. 5-25.

Rudkin, G.H., 1968, Natural gas in San Joaquin Valley, California, *in* Beebe, B.W., and Curtis, B.F., eds., Natural gases of North America: Tulsa, Okla., American Association of Petroleum Geologists Memoir 9, p. 113-134.

Sullivan, J.C., 1963, Guijarral Hills oil field, *in* Summary of operations, California oil fields: San Francisco, Calif., Annual Report of the State Oil and Gas Supervisor, v. 48, no. 2, p. 37-51 [also available *in* California Division of Oil and Gas, Summary of Operations, 1915-1999: California Division of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. CD-3, and at ftp://ftp.consrv.ca.gov/pub/oil/Summary_of_Operations/1962/].

Wilkinson, E.R., 1960, Vallecitos field, *in* Summary of operations, California oil fields: San Francisco, Calif., Annual Report of the State Oil and Gas Supervisor, v. 45, no. 2, p. 17-33 [also available *in* California Division of Oil and Gas, Summary of Operations, 1915-1999: California Division of Conservation, Division of Oil, Gas, and Geothermal Resources, Publication No. CD-3, and at ftp://ftp.consrv.ca.gov/pub/oil/Summary_of_Operations/1959/].

Figures

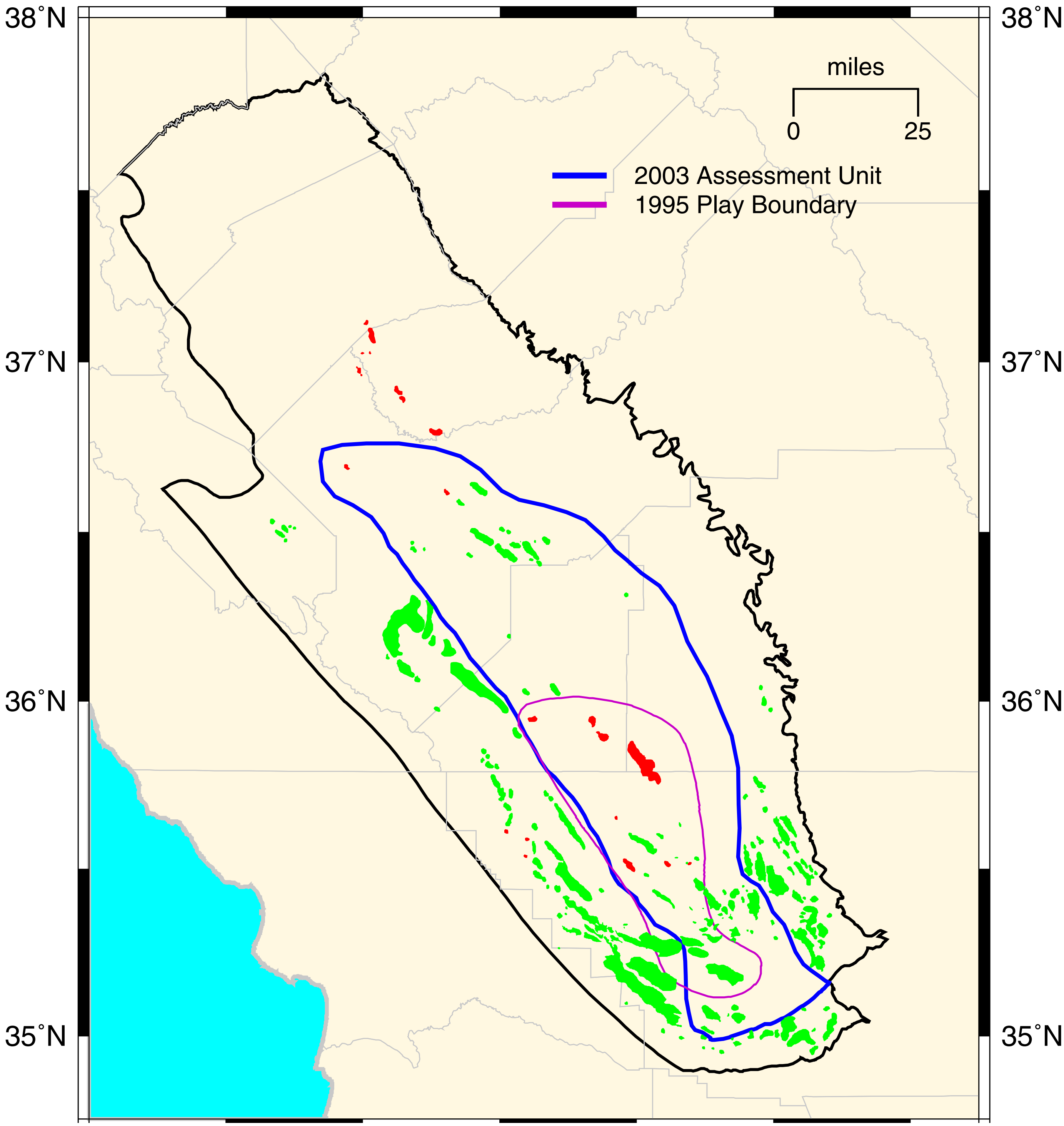

Figure 22.1. Location map of the San Joaquin Valley, illustrating San Joaquin Basin Province boundary (bold black line), county boundaries (thin gray lines), Neogene Nonassociated Gas Assessment Unit boundary (blue line), play boundary from previous USGS assessment (purple line), and oil (green) and gas (red) fields in the province.

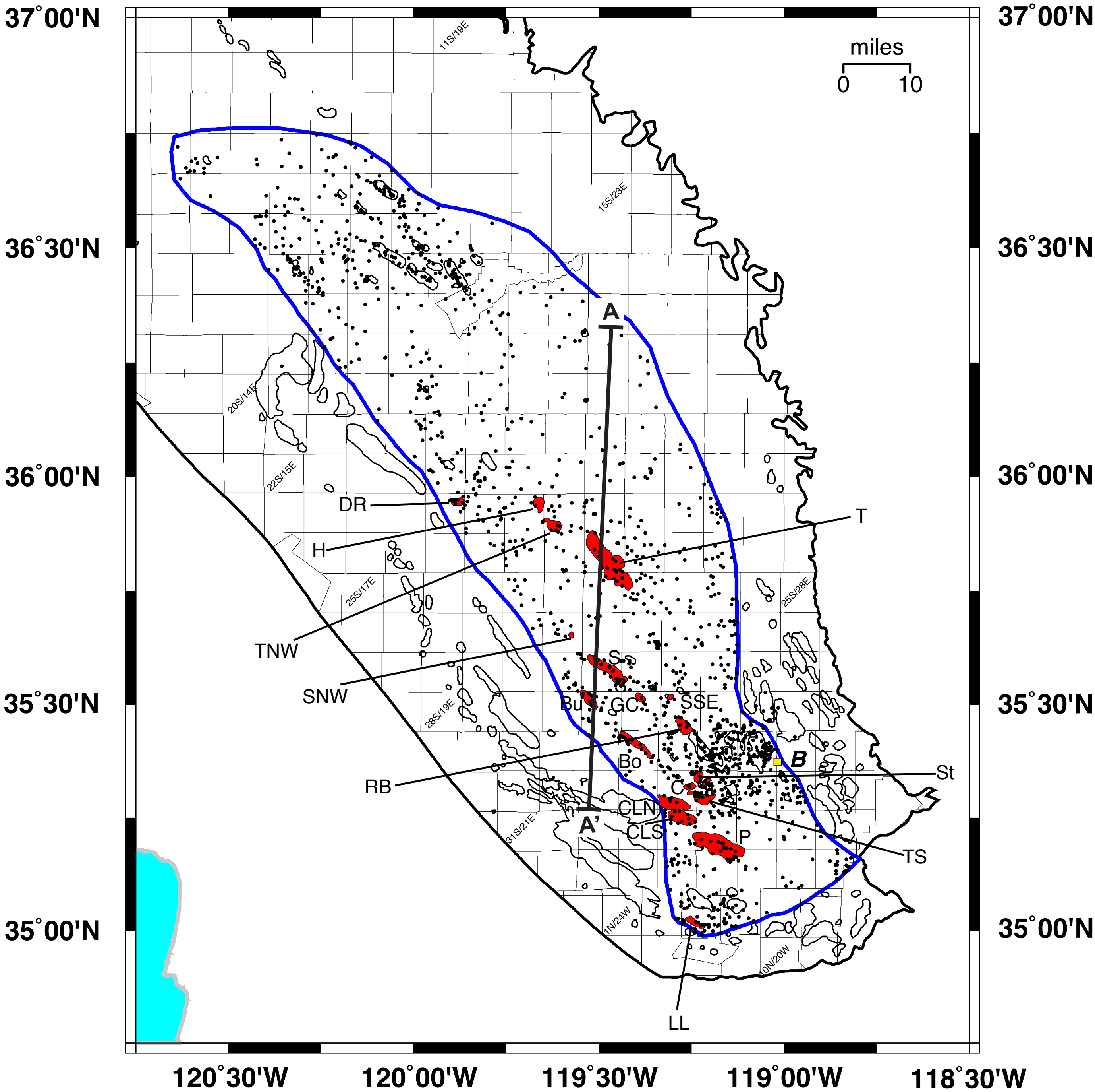

Figure 22.2. Detailed map of Neogene Nonassociated Gas Assessment Unit (AU). The blue line indicates the geographic limit of the AU. The 18 gas fields and pools in this AU are colored red. Fields outside the AU, or within the map boundaries of the AU but assigned to a different assessment unit, are outlined in black. Black dots represent 1,694 exploratory wells drilled for petroleum within the AU between 1916 and 2001. Well locations are from the California Department of Conservation, Division of Oil, Gas, and Geothermal Resources and are available at ftp://ftp.conserv.ca.gov/pub/oil/maps/dist4 and at ftp://ftp.conserv.ca.gov/pub/oil/maps/dist5. Cross-section A-A′ is shown in figure 22.5. Township and range grid is indicated for scale and location; scattered labels are relative to the Mount Diablo baseline and meridian. City of Bakersfield (B) denoted with yellow square. Gas field labels are (* fields used in the assessment, ** secondary fields smaller than 3 BCF): Bo=Bowerbank; Bu=Buttonwillow; C=Canal**; CLN=Coles Levee North; CLS=Coles Levee South; DR=Dudley Ridge*; GC=Garrison City**; H=Harvester*; LL=Los Lobos**; P=Paloma; RB=Rio Bravo*; S=Semitropic; SNW=Semitropic Northwest**; SSE=Shafter Southeast**; St=Strand**; T=Trico*; TNW=Trico Northwest*; TS=Ten Section.

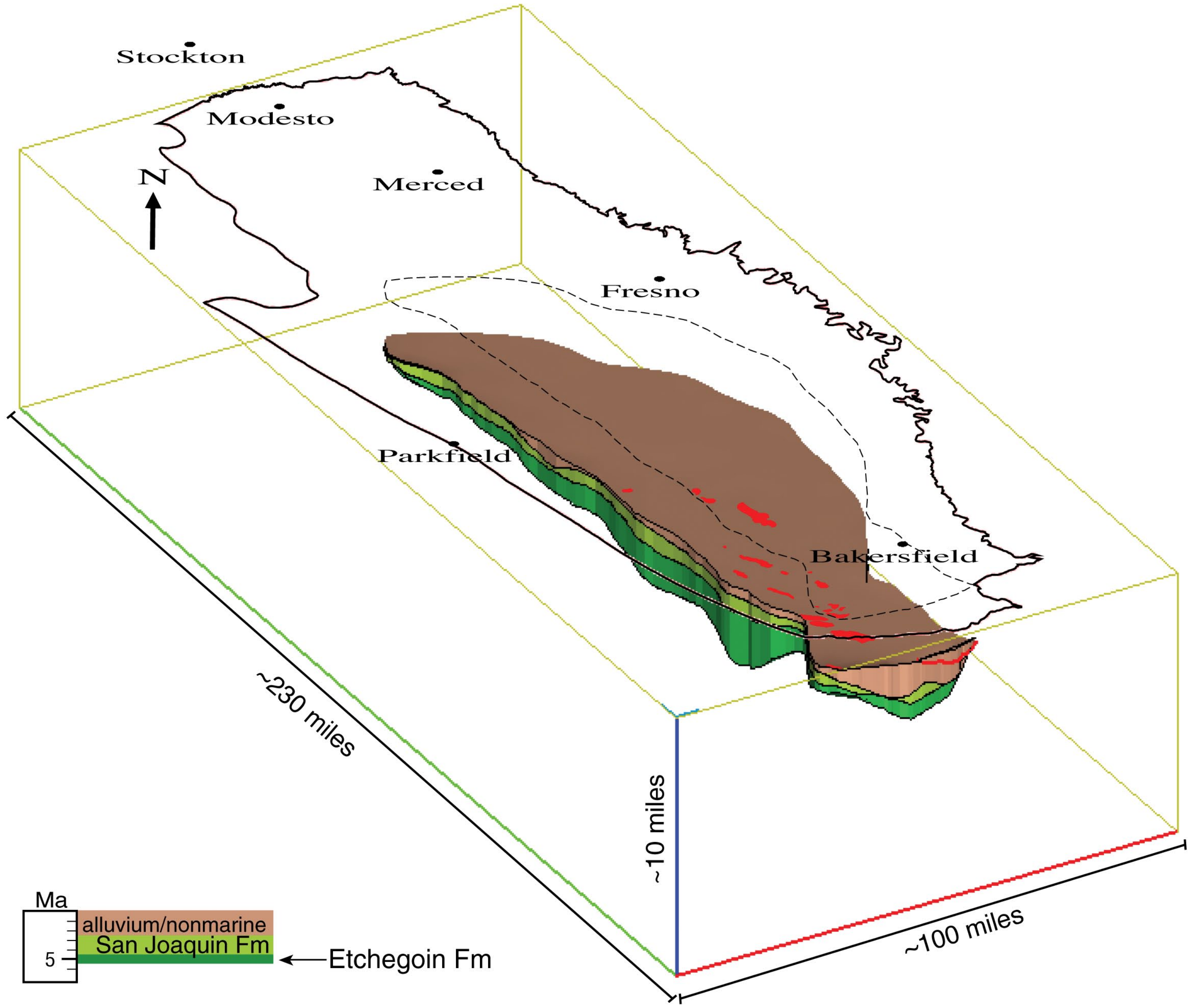

Figure 22.3. Three-dimensional stratigraphy model of the Neogene Nonassociated Gas AU extracted from the EarthVision® model of the basin by Hosford Scheirer (this volume, chapter 7). The major stratigraphic units within the AU are shown by colors; see figure 22.4 for stratigraphic relations among the units. Gas fields and pools (red) in the AU 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 x4. EarthVision is a registered trademark (Marca Registrada) of Dynamic Graphics, Inc., Alameda, Calif.

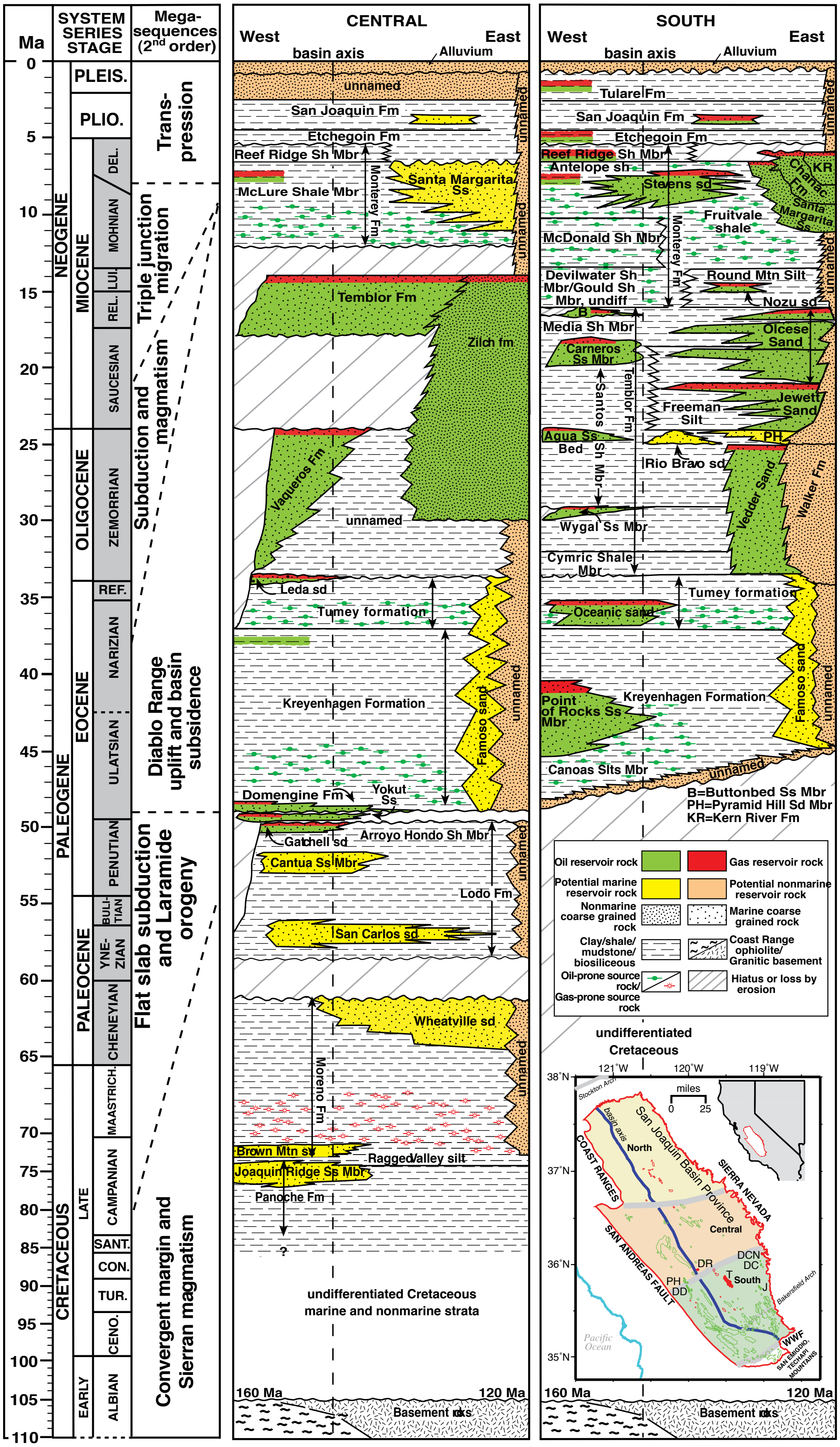

Figure 22.4. Generalized stratigraphic column for the southern and central San Joaquin Basin Province, showing hydrocarbon reservoir rocks and potential hydrocarbon source rocks. See Hosford Scheirer and Magoon (this volume, chapter 5) for complete explanation of the figure. Formation names in italics 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), Zilch formation of Loken (1959), Rio Bravo sand of Noble (1940), Oceanic sand of McMasters (1948), Tumey formation of Atwill (1935), Leda sand of Sullivan (1963), Famoso sand of Edwards (1943), Gatchell sand of Goudkoff (1943), San Carlos sand of Wilkinson (1960), Wheatville sand of Callaway (1964), Brown Mountain sandstone of Bishop (1970), and Ragged Valley silt of Hoffman (1964).

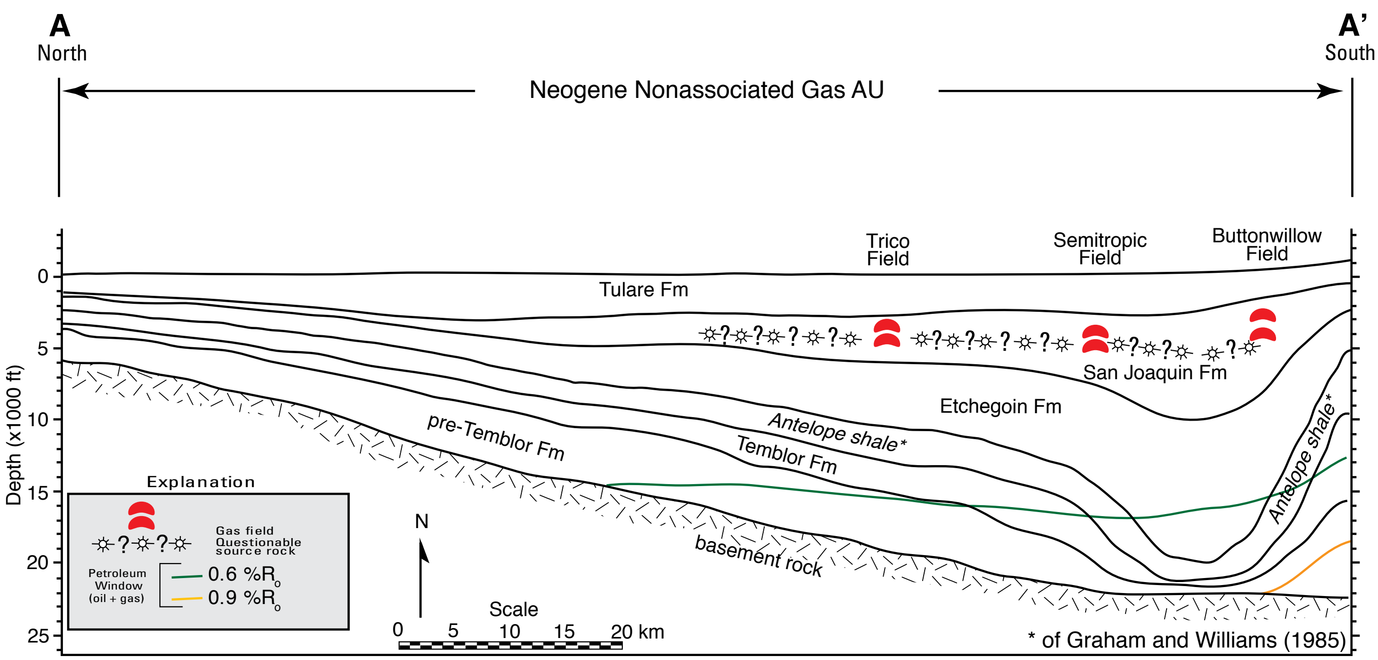

Figure 22.5. Cross section A-A' through biogenic gas fields of the southern San Joaquin Basin. Location of cross-section is shown on figure 22.2. Stratigraphically, the AU extends from the ground surface down to the base of the Etchegoin Formation. Fm, Formation; % R_o, percent vitrinite reflectance. Modified from Magoon and others (this volume, chapter 8).

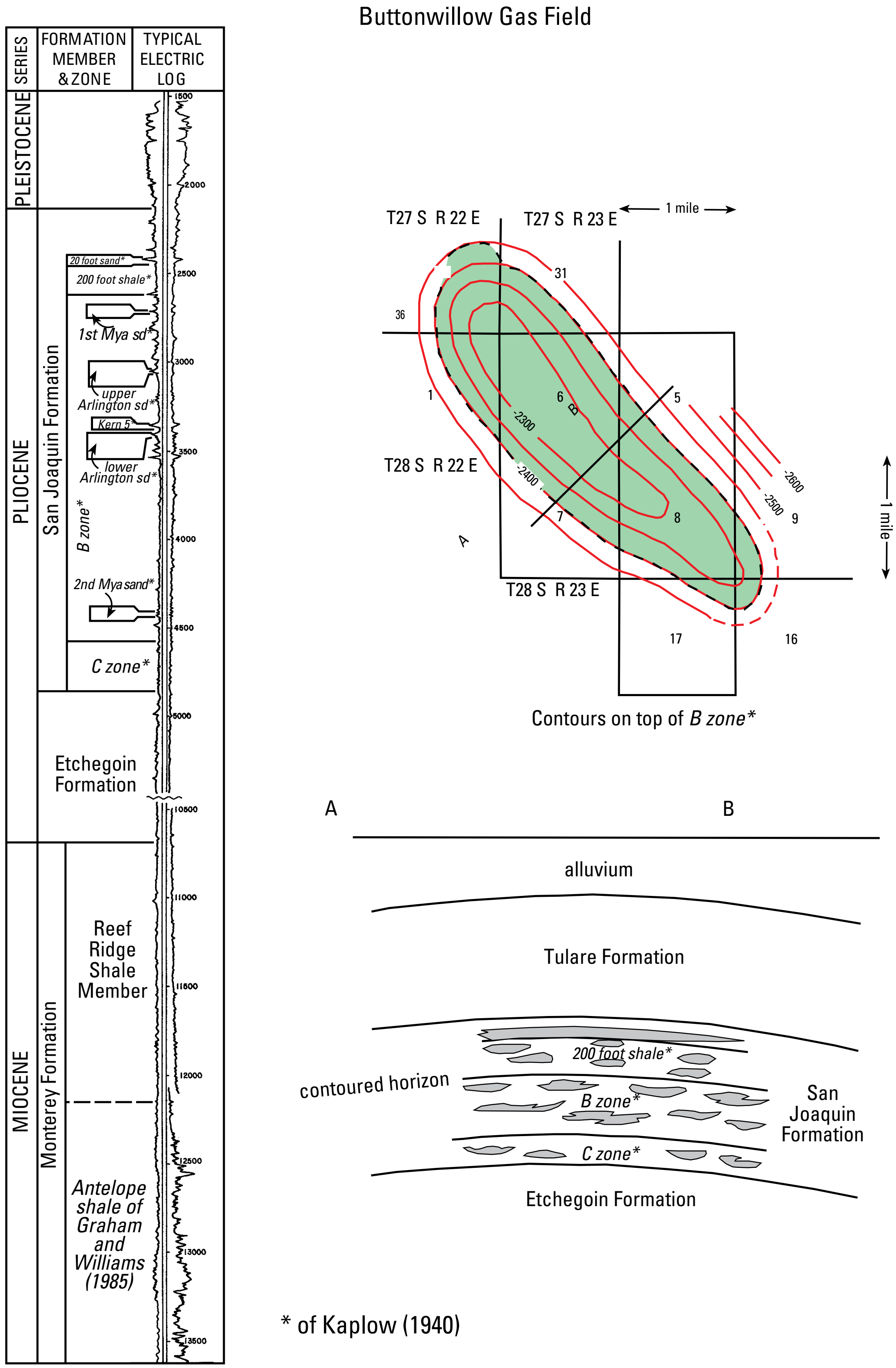

Figure 22.6. Map, cross-section, and stratigraphic column of Buttonwillow gas field, illustrating typical stratigraphic sand lenses in the Neogene Nonassociated Gas AU. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the fields. All depths are in feet. Formations in italics denote informal geologic names. Informal names not previously defined are the 20 foot sand, Arlington sand, Kern 5, first Mya sand, second Mya sand, B zone, C zone, and 200 foot shale, all of Kaplow (1940). See figure 22.2 for location of field. Figure redrafted from CDOGGR (1998). sd, sand.

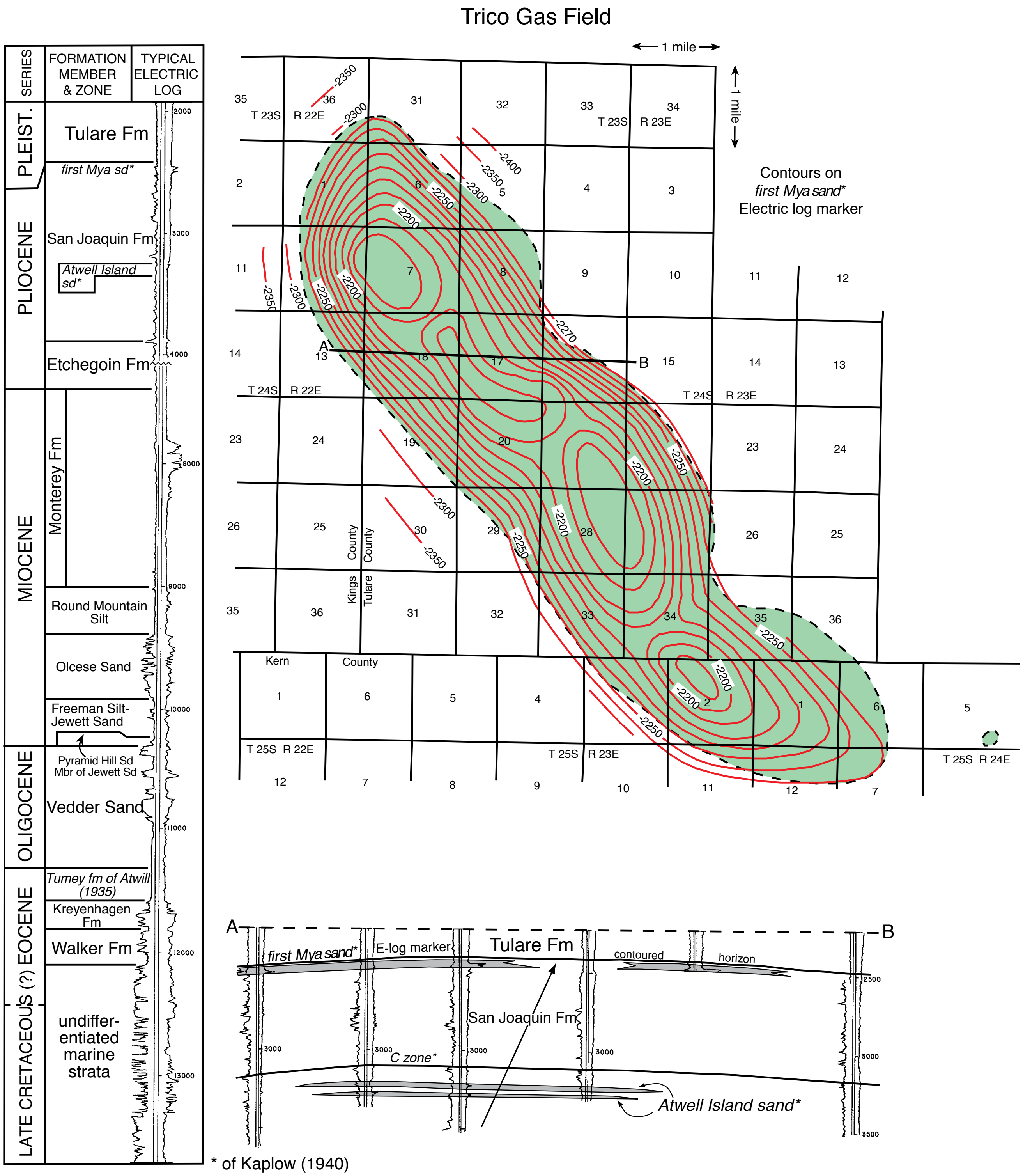

Figure 22.7. Map, cross-section, and stratigraphic column of Trico gas field, illustrating typical asymmetrical, anticlinal trap in the Neogene Nonassociated Gas AU. Green shading (underlying township-range grid) denotes reported 1998 limits of productive sand units within the fields. All depths are in feet. Formations in italics denote informal geologic names. Informal names not previously defined are Tumey formation of Atwill (1935) and Atwill Island sand of Kaplow (1940). See figure 22.2 for location of field. Figure redrafted from CDOGGR (1998). Fm, Formation; fm, formation; Mbr, Member; Pleist., Pleistocene; Sd, Sand; sd, sand.

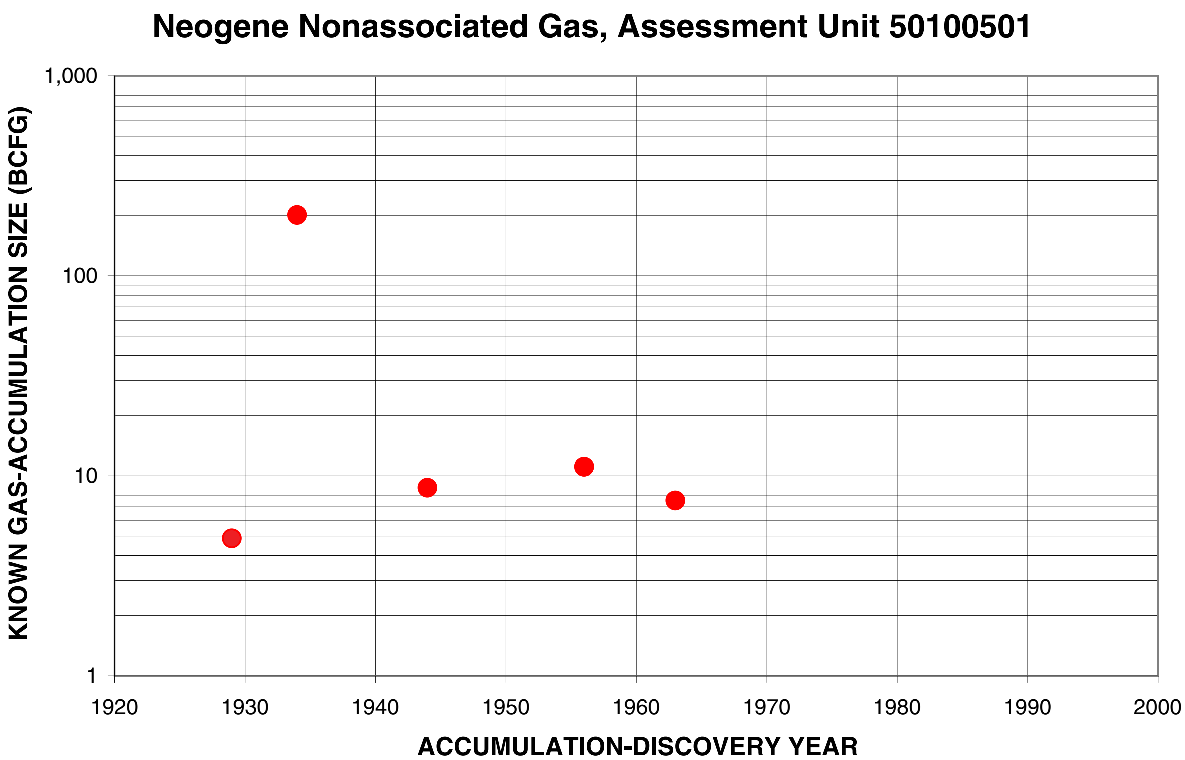

Figure 22.8. Gas-accumulation size versus year of accumulation discovery in the Neogene Nonassociated Gas AU. Figure is excerpted from data file k100501.pdf (see Klett and Le, this volume, chapter 28, for explanation of data file).

Table 22.1. Production statistics for primary fields in the Neogene Nonassociated Gas Assessment Unit.

[Recoverable gas is the sum of cumulative production and estimated proved reserves. Data source is CDOGGR (2003). BCF, billion cubic feet. Primary fields are defined as those with recoverable gas equal to or greater than 3 BCF. Six additional fields have recoverable gas of less than 3 BCF. Five fields (*) were analyzed for assessment purposes. Fields with zero producing wells are abandoned]

Field	Estimated Ultimate Recoverable Gas through 2002 (BCF)	Percent of Total	Number of Producing Wells in 2002
Trico*	201.4	48.6	5
Coles Levee South	43.9	10.6	2
Buttonwillow	38.4	9.3	0
Paloma	26.0	6.3	2
Bowerbank	24.9	6.0	7
Semitropic	23.9	5.8	3
Coles Levee North	13.0	3.1	2
Rio Bravo*	11.1	2.7	0
Ten Section	9.1	2.2	0
Trico Northwest*	9.1	2.2	0
Harvester*	8.9	2.2	0
Dudley Ridge*	4.9	1.2	0
Total	414.6	100.0	21