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

Chapter 10

# Petroleum Systems of the San Joaquin Basin Province—Geochemical Characteristics of Gas Types

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## Contents



## Abstract

The San Joaquin Basin Province is a petroliferous basin filled with predominantly Late Cretaceous to Pliocene-aged sediments, with organic-rich marine rocks of Late Cretaceous, Eocene, and Miocene age providing the source of most of the oil and gas. Previous geochemical studies have focused on the origin of the oil in the province, but the origin of the natural gas has received little attention. To identify and characterize natural gas types in the San Joaquin Basin, 66 gas samples were analyzed and combined with analyses of 15 gas samples from previous studies. For the purpose of this resource assessment, each gas type was assigned to the most likely petroleum system.

Three general gas types are identified on the basis of bulk and stable carbon isotopic composition—thermogenic dry (TD), thermogenic wet (TW) and biogenic (B). The thermogenic gas types are further subdivided on the basis of the $\delta^{13}C$ values of methane and ethane and nitrogen content into TD-1, TD-2, TD-Mixed, TW-1, TW-2, and TW-Mixed. Gas types TD-1 and TD-Mixed, a mixture of biogenic and TD-1 gases, are produced from gas fields in the northern San Joaquin Basin. Type TD-1 gas most likely originated from the Late Cretaceous to Paleocene Moreno Formation, a gas-prone source rock. The biogenic component of the TD-Mixed gas existed in the trap prior to the influx of thermogenic gas. For the assessment, these gas types were assigned to the Winters-Domengine Total Petroleum System, but subsequent to the assessment were reclassified as part of the Moreno-Nortonville gas system. Dry thermogenic gas produced from oil fields in the southern San Joaquin Basin (TD-2 gas) most likely originated from the oil-prone source rock of Miocene age. These samples have low wetness values due to migration fractionation or biodegradation.

The thermogenic wet gas types (TW-1, TW-2, TW-Mixed) are predominantly associated gas produced from oil fields in the southern and central San Joaquin Basin. Type TW-1 gas most likely originates from source rocks within the Eocene Kreyenhagen Formation or the Eocene Tumey formation of Atwill (1935). Type TW-2 gas most likely originates from the Miocene Monterey Formation and equivalents. TW-Mixed gas is likely a mixture of biogenic and wet thermogenic gas (TW-1 or TW-2) derived from source rocks mentioned above. The thermogenic wet gas types are included in the corresponding Eocene or Miocene total petroleum systems.

Type B gas is a dry, nonassociated gas produced from the Pliocene San Joaquin Formation in the central

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and southern San Joaquin Basin. This gas type most likely originated from Pliocene marine source rocks as a product of methanogenesis, and defines the Neogene Nonassociated Gas Total Petroleum System.

# Introduction

The Great Valley of California is a petroleum-productive Cretaceous-Paleogene forearc basin located between the Sierra

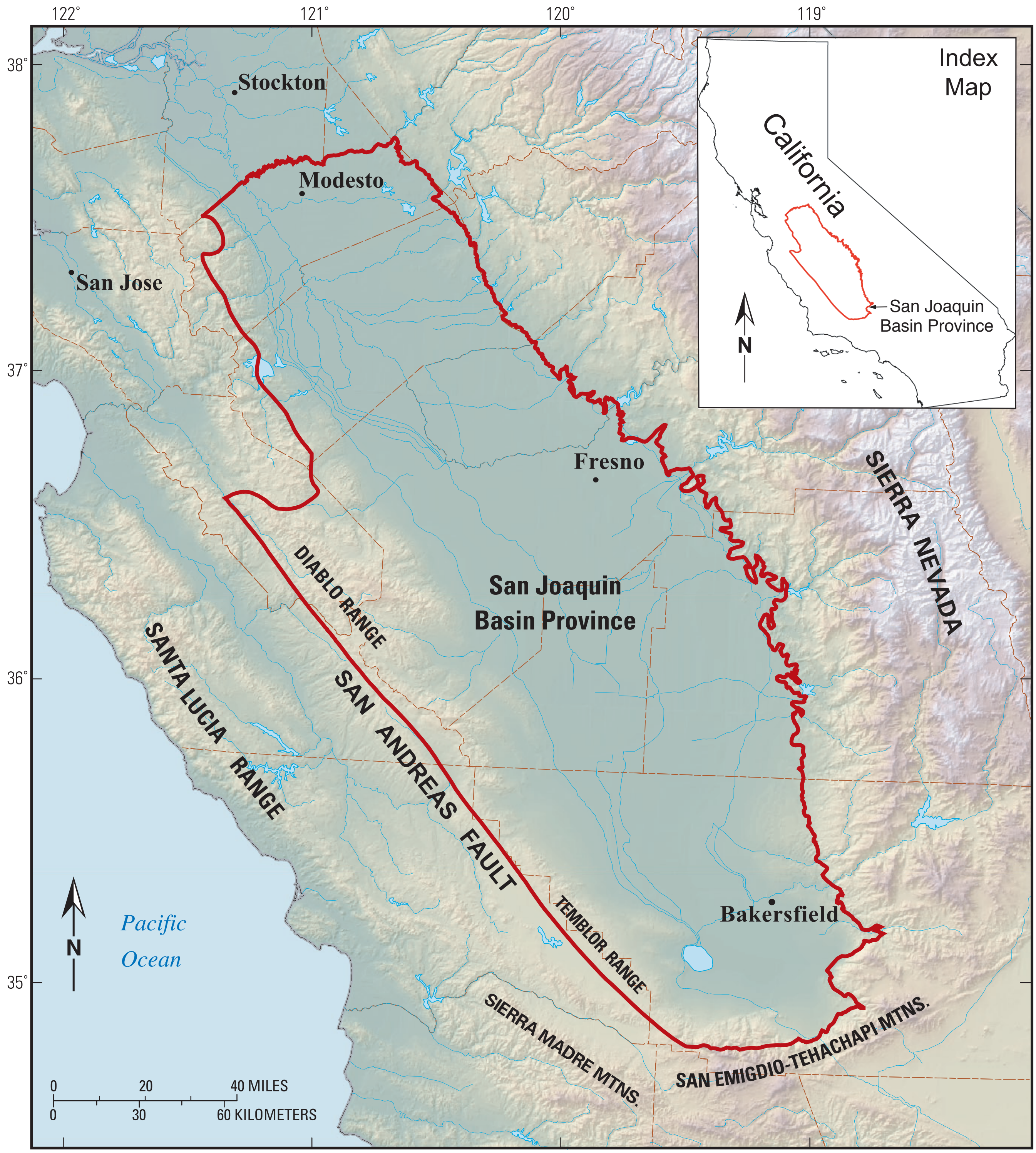


**Figure 10.1.** Location map of San Joaquin Basin Province (red outline) showing topography and location of county lines and some cities. Inset shows location of San Joaquin Basin Province (red outline) within the State of California.

Nevada and Coast Ranges (primarily the Diablo and Temblor Ranges; fig. 10.1). An east-west trending, subsurface structural arch (Stockton Arch) separates the Great Valley into the Sacramento Basin Province to the north and the San Joaquin Basin Province to the south. The Sacramento Basin is primarily a gas province, whereas the San Joaquin Basin produces mostly oil and some gas. The San Joaquin Basin is filled with Late Cretaceous to Pliocene-aged marine sediments (fig. 10.2), and organic-rich marine rocks of Eocene and Miocene age provide the source for most of its petroleum.

Previous geochemical studies in the San Joaquin Basin have focused on the origin of the oil (see discussion in Lillis and Magoon, this volume, chapter 9), but the origin of the natural gas has received little attention. In the Sacramento Basin Province, the natural gas geochemistry was studied by Jenden and Kaplan (1989b) and was reinterpreted in the context of petroleum systems (Magoon and others, 1994; Magoon and others, 1996a; Magoon and others, 1996b; Claypool and others, 2000; Claypool and others, 2001; Hosford Scheirer and others, 2007a; Hosford Scheirer and others, 2007b).

Rudkin (1968) first addressed the gas chemistry in the San Joaquin Basin with discussions of gas wetness, the exceptionally high nitrogen content of gases in Chowchilla field, and the high hydrogen sulfide content of gases at East Coalinga Extension field. Kaplan and others (1988) analyzed 40 gas samples from the San Joaquin Basin and categorized them into four genetic groups on the basis of carbon isotopic composition—two groups of associated thermogenic gases, one group of nonassociated thermogenic gas, and one group of mixed microbial and thermogenic gas. Four gas samples from the northern San Joaquin Basin were included in a study by Jenden and others (1988) on the origin of nitrogen-rich natural gas in the California Great Valley. Eleven gas analyses from the San Joaquin Basin were included in a broad study of more than 800 gas samples from around the United States (Jenden and Kaplan, 1989a). Kamerling and others (1989) recognized Pliocene biogenic gas in the southern San Joaquin Basin. In more recent studies, Claypool and others (2000), Claypool and others (2001), and Lillis and others (2004) assigned the San Joaquin Basin gases to petroleum systems—a mixed biogenic-thermogenic gas attributed to the Winters-Domengine(?) gas system that extends southward from the Sacramento Basin, a Pliocene to Pleistocene biogenic gas system, and two wet thermogenic gas types associated with oils from Eocene and Miocene petroleum systems, respectively. [Note that the formal names for petroleum systems consist of the source rock name, followed by a hyphen, the principal reservoir name, and an indication of the certainty of the correlation (Magoon and Dow, 1994). The symbols (?), (.), and (!) indicate speculative, hypothetical, and known genetic relationships, respectively.]

In this study, 66 gas samples were collected from the San Joaquin Basin Province and analyzed for bulk composition and stable carbon isotope ratios. These analytical results were combined with 15 gas samples from previous studies (Jenden and Kaplan, 1989a; Claypool and others, 2000) to identify and characterize natural gas types, and to assign these types to the most likely petroleum system for the purpose of resource assessment (Magoon and others, this volume, chapter 8).

# Methods

Sixty-six gas samples were analyzed for $C_1$ to $C_7$ hydrocarbons, $CO_2$, CO, $N_2$, $O_2$, Ar, He, $H_2$, and $H_2S$ using a Wasson gas analyzer, a customized Hewlett-Packard gas chromatograph. Oxygen and argon cannot be differentiated by this method, so the concentrations of these gases are reported together ($O_2$+Ar). Because oxygen and argon concentrations are generally very low in natural gas, the measured $O_2$+Ar content in the gas samples is assumed to be air contaminant. Thus, the nitrogen content of the gas samples was corrected by reducing the measured nitrogen by the amount of nitrogen from air contamination using the ratio ($O_2$+Ar)/$N_2$=0.2802 (Mason and Moore, 1982, p. 211). This correction was not applied to the nitrogen data from Jenden and Kaplan (1989a) because their analytical method differentiates oxygen and argon.

Stable carbon isotopes ($\delta^{13}C$) of methane, ethane, propane, butane and carbon dioxide were measured using a Hewlett-Packard gas chromatograph interfaced with a Micromass Optima continuous-flow isotope ratio mass spectrometer (IRMS). The results are expressed in delta (δ) notation, which represents the deviation of the $^{13}C/^{12}C$ ratio in parts per thousand (per mil or ‰) relative to the Peedee belemnite (PDB) standard. Gas wetness is reported as percent $C_{2+}$ hydrocarbon gases relative to total hydrocarbon gases using the expression $[(\Sigma C_2 \text{ to } C_5)/(\Sigma C_1 \text{ to } C_5)] * 100$.

# Results

Gas sample information is listed in table 10.1 and analytical results are listed in table 10.2. About 75 percent of the gas samples in this study were taken from oil fields, with the rest taken from gas fields (fig. 10.3), generally reflecting the dominance of oil and associated gas production over nonassociated gas production in the San Joaquin Basin Province. Natural gases from the San Joaquin Basin Province exhibit a wide range of gas wetness values in percent $C_{2+}$ hydrocarbon gas (zero to 37 percent), and of $\delta^{13}C$ methane composition (–70.2 to –24.2‰; table 10.2, fig. 10.4). Nitrogen content is generally less than 2 percent (fig. 10.5), but many gas samples from the northern San Joaquin Basin (fig. 10.3) have high nitrogen (from 7 to 59 percent; samples 1, 14, 15, 32, 47, 48, 49, 52, 53, and 64; fig. 10.5). The nitrogen correction is substantial in samples with significant air contamination (for example, samples 11, 20, 25, 27, 28, 33, 36, 60, 63, and 75; table 10.2). Gas sample 16 is suspected to have high nitrogen because it came from a treatment vessel rather than from a well.

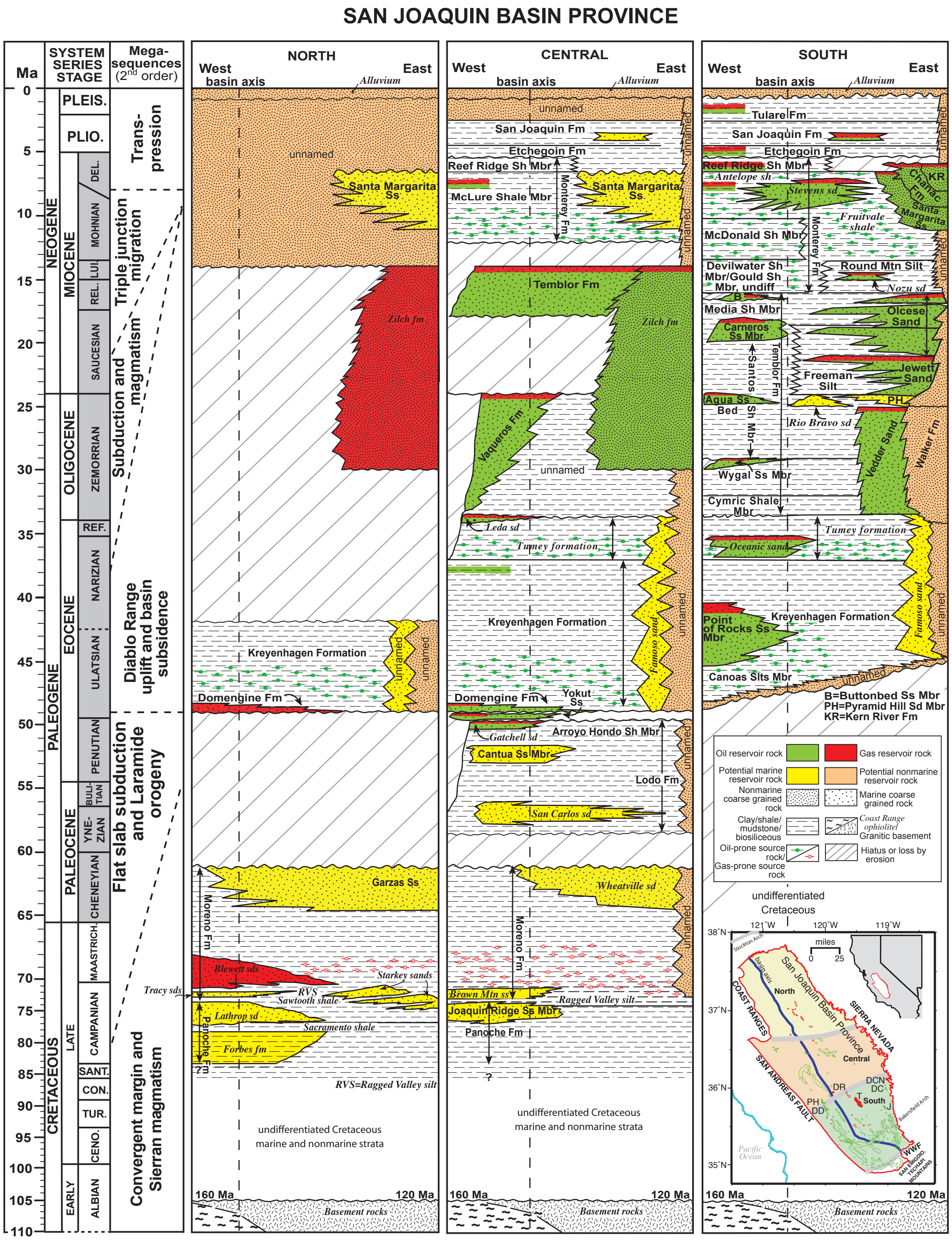


**Figure 10.2.** San Joaquin Basin Province stratigraphy showing hydrocarbon reservoir rocks and potential hydrocarbon source rocks. See Hosford Scheirer and Magoon (this volume, chapter 5) for complete explanation of the figure. Formation names in italics are informal and are defined as follows (in 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).

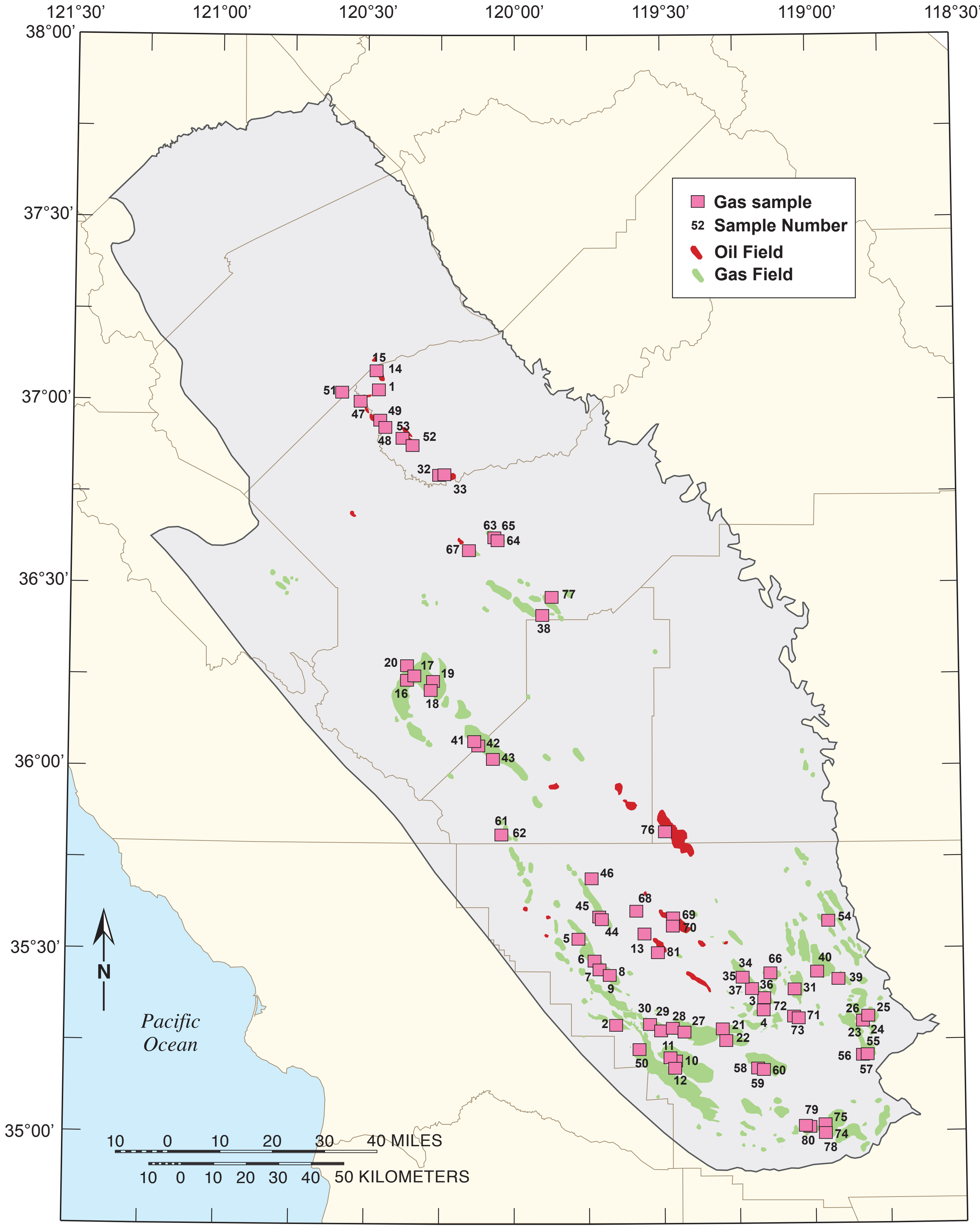


**Figure 10.3.** Locations of the gas samples in the San Joaquin Basin Province (gray shading) used in this study. Sample information is given in table 10.1. County boundaries are shown as thin brown lines.

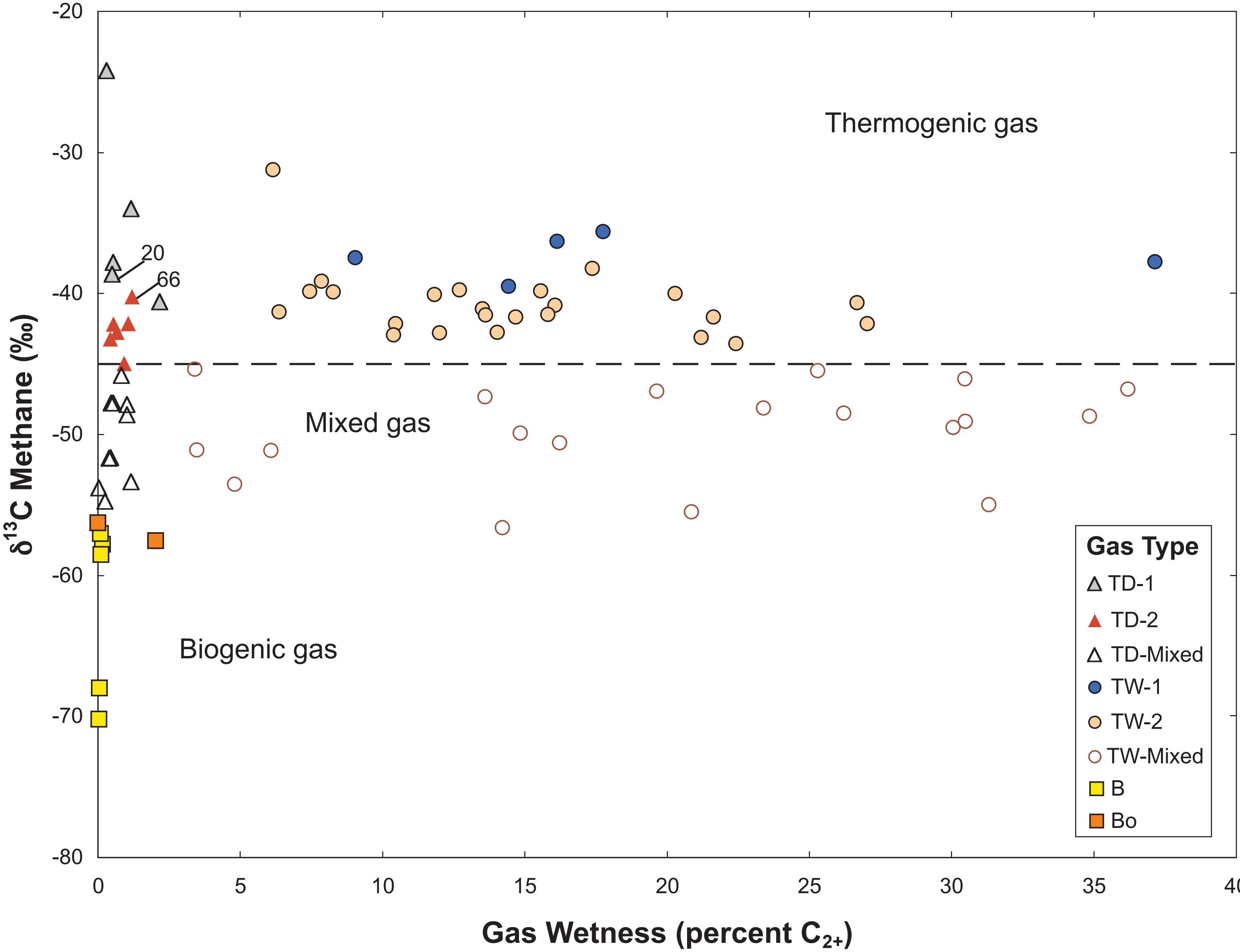


**Figure 10.4.** Plot of gas wetness (percent $C_{2+}$) versus $\delta^{13}C$ of methane for natural gas samples from the San Joaquin Basin Province. Wetness is defined as $[(\Sigma C_2$ to $C_5)/(\Sigma C_1$ to $C_5)] * 100$. Gas types are defined in the text and include thermogenic dry (subtypes TD-1, TD-2), thermogenic wet (subtypes TW-1, TW-2), mixed thermogenic-biogenic (subtypes TD-Mixed, TW-Mixed), biogenic (B), and biogenic outlier (Bo).

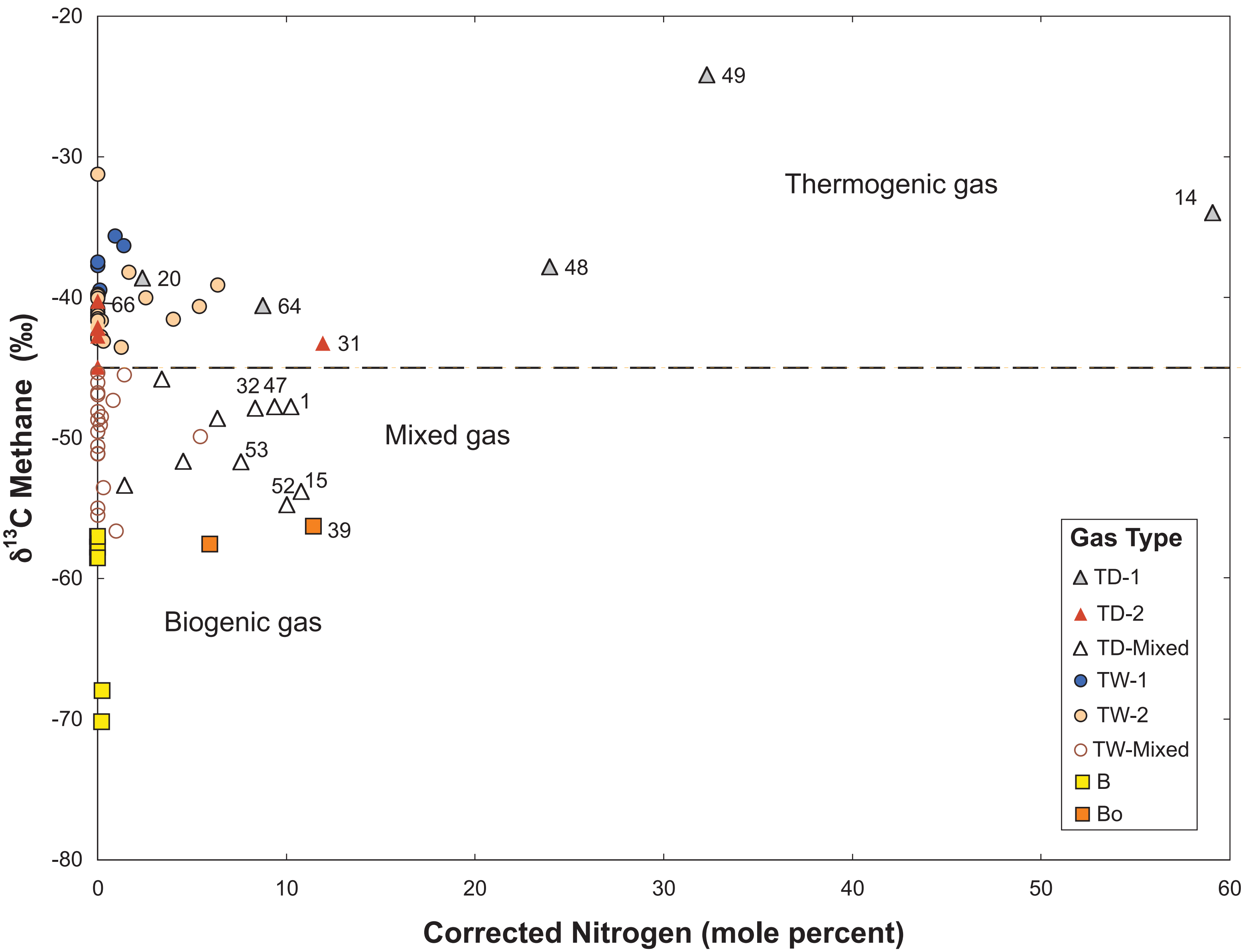


**Figure 10.5.** Plot of percent nitrogen (corrected) versus $\delta^{13}C$ of methane for natural gas samples from the San Joaquin Basin Province. See text for explanation of nitrogen correction.

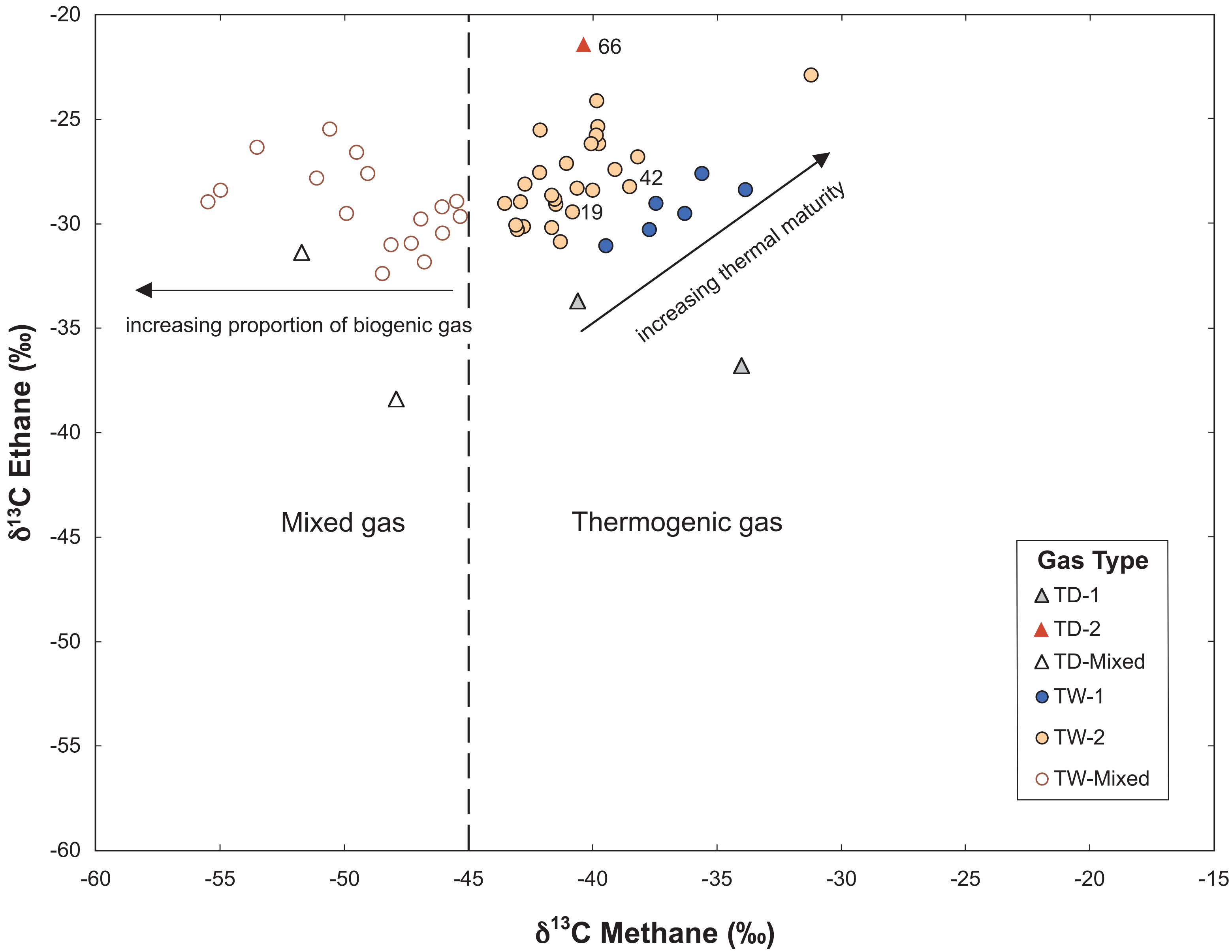


**Figure 10.6.** Plot of $\delta^{13}C$ of methane versus $\delta^{13}C$ of ethane for natural gas samples from the San Joaquin Basin Province. Trend arrows show increasing proportion of biogenic methane mixed with thermogenic gas, as well as change in isotopic composition with increasing thermal maturity.

$\delta^{13}C$ ethane values range from –38.4 to –21.5‰ (fig. 10.6), and $\delta^{13}C$ propane values range from –31.5 to –20.0‰ (table 10.2). The $\delta^{13}C$ *i*-butane values range from –31.9 to –20.3‰, and the $\delta^{13}C$ *n*-butane values range from –28.5 to –9.4‰ (table 10.2). Carbon dioxide content is generally less than 1 percent, but ranges from 0 to 92 percent (table 10.2). However, the sample with 92 percent $CO_2$ (sample 40) may be discounted, because the sample was taken from the surface casing of a producing oil well. The $\delta^{13}C$ carbon dioxide values of the gas samples range from –13.1 to +32.7‰ (table 10.2).

# Natural Gas Types

Natural gas forms by either biogenic (B) or thermogenic (T) processes (Bernard and others, 1977; Fuex, 1977; Schoell, 1980; Rice and Claypool, 1981). Biogenic gas (also called microbial gas) is generated in anaerobic, sulfate-free sediments at temperatures less than 75°C by communities of microbes that include fermentative bacteria, acetogenic bacteria, and a group of Archaea called methanogens. Thermogenic gas, in contrast, is generated by the cracking of kerogen or oil at higher temperatures with increasing burial. The main stage of thermogenic gas generation from kerogen occurs within the oil window, that is, at the same thermal maturity as oil generation. This is equivalent to a vitrinite reflectance range of 0.6 to 1.2 percent.

Biogenic gas is composed of isotopically light methane ($\delta^{13}C$ generally less than –55‰; Rice and Claypool, 1981), whereas thermogenic gas is composed of isotopically heavier methane and varying amounts of higher hydrocarbon gases (measured as gas wetness). On the basis of stable carbon isotopic composition and gas wetness, the gas samples analyzed can be grouped into three gas types—thermogenic dry (TD), thermogenic wet (TW), and biogenic (B). The boundary between TD and TW gas is empirically placed at a wetness value of 2.5 percent $C_{2+}$. This wetness boundary is consistent with the definition of Tissot and Welte (1984)—dry gas has a methane to total hydrocarbon gas ratio greater than 0.97 (wetness less than 3 percent $C_{2+}$). On the basis of a natural break in the data (figs. 10.4 and 10.6) thermogenic gas samples with $\delta^{13}C$ methane values less than –45‰ are interpreted to be a mixture of biogenic and thermogenic gas (TD-Mixed and TW-Mixed). The boundary between TD-Mixed and biogenic (B) gas is placed at a $\delta^{13}C$ methane value of -55‰ on the basis of Rice and Claypool (1981), although there is a natural break in the data at -60‰. All wet gases (greater than 2.5 percent $C_{2+}$) with $\delta^{13}C$ methane values less than -45‰ are classified as TW-Mixed (table 10.3).

The thermogenic dry and wet gas types are further subdivided. Thermogenic dry (TD) gas is subdivided into two subtypes on the basis of $\delta^{13}C$ methane values (fig. 10.4) and nitrogen content (fig. 10.5). Type TD-1 gas has higher $\delta^{13}C$ methane (greater than –41‰, except for sample 66) and higher nitrogen (greater than 8 percent, except for samples 20 and 31) than Type TD-2 gases. Thermogenic wet (TW) gas is subdivided into two subtypes on the basis of $\delta^{13}C$ methane and $\delta^{13}C$ ethane values (fig. 10.6), with TW-1 gases showing a distinct thermal maturity trend, and TW-2 gases showing a weak thermal maturity trend. Two biogenic gas samples (Bo) are distinguished from the biogenic gas type (B) on the basis of nitrogen content (fig. 10.5).

## Thermogenic Dry (TD)

Type TD-1 gas is produced from Cretaceous-aged reservoir rocks in gas fields of the northern San Joaquin Basin Province (grey triangles, fig. 10.7), including Raisin City, Chowchilla, and Merrill Avenue Southeast fields. Claypool and others (2000) suggested that these gas accumulations may be an extension of the Winters-Domengine(?) gas system of Magoon and others (1994) in the Sacramento Basin on the basis of similar $\delta^{13}C$ methane values and high nitrogen content. However, high nitrogen content is not a distinctive characteristic of the Winters-Domengine(?) system; the nitrogen may be derived from metasedimentary basement rocks (Jenden and others, 1988) rather than the Cretaceous Winters formation of Edmondson (1962; hereafter referred to as Winters formation). Furthermore, a Winters formation source for TD-1 gas is problematic because the Stockton Arch separates thermally mature Winters formation in the Sacramento Basin Province from the northern San Joaquin Basin Province (see Hosford Scheirer and Magoon, this volume, chapter 21, for a detailed discussion).

A more likely source for the TD-1 gas is the Cretaceous to Paleocene Moreno Formation in the San Joaquin Basin Province, which has good source rock characteristics (McGuire, 1988; Peters, Magoon, Valin, and others, this volume, chapter 11), and is thermally mature down-dip from these gas fields that contain TD-1 gas. Unfortunately, we lack a gas sample to analyze from the Moreno Formation reservoir rock, such as Cheney Ranch field, that may derive from the Moreno Formation source rock. A gas seep from the Oil City pool at Coalinga field (sample 20), which may derive from the Moreno Formation, matches TD-1 gas on the basis of $\delta^{13}C$ methane and wetness values (fig. 10.4). However, on the basis of evidence of air contamination (high $O_2$+Ar), the quality of the sample is in question.

The TD-Mixed gas is a mixture of thermogenic dry and biogenic gases found in Cretaceous, Eocene, and Miocene reservoir rocks in gas fields of the northern San Joaquin Basin (open triangles, fig. 10.7). The geographic distribution, reservoir rock age, and elevated nitrogen content (as much as 11 percent) of this gas type is similar to TD-1 gas and is considered genetically related. The biogenic gas component of TD-Mixed gas most likely originated from the microbial decomposition of organic matter in the Cretaceous (and possibly Eocene) aged sediments. Two gases assigned to the TD-Mixed gas (samples 15 and 52) are interpreted

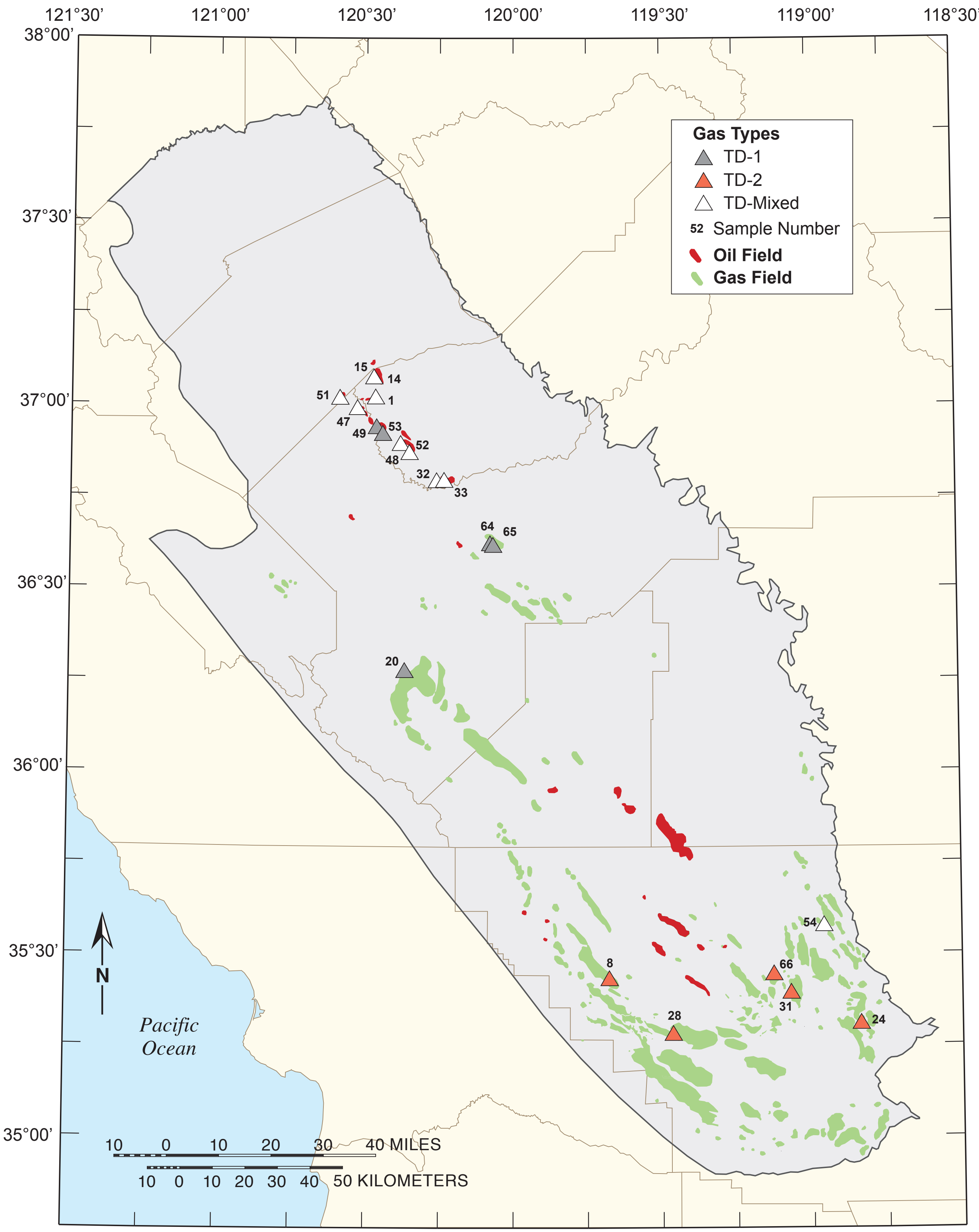


**Figure 10.7.** Sample locations for thermogenic dry gas in the San Joaquin Basin Province (gray shading).

to be predominantly biogenic on the basis of light (low) $\delta^{13}C$ methane values (–53.8 to –54.75‰) but have elevated nitrogen similar to other TD-Mixed gas. Although typed as TD-Mixed, the gas sample from Mount Poso field (sample 54) is probably unrelated to other TD-Mixed or TD-1 gases, because it is produced from an oil field in the southern San Joaquin Basin (fig. 10.7). Slightly elevated propane and butane (table 10.2) in the sample suggests a small component of wet thermogenic gas mixed with a biogenic gas. Type TD-2 gas is discussed below with thermogenic wet gases.

### Thermogenic Wet (TW)

The thermogenic wet (TW) gas of the San Joaquin Basin Province is generally produced from oil fields (fig. 10.8), and most likely originates from the same source rocks as the coproduced oil. The TW-1 gas is produced from Eocene and Oligocene-aged reservoir rocks, and most likely originated from source rocks within the Eocene Kreyenhagen Formation or Tumey formation of Atwill (1935; hereafter referred to as Tumey formation).

Most TW-2 gas is produced from Miocene reservoir rocks, but it also occurs in Jurassic, Eocene, Oligocene and Pliocene-aged reservoir rocks. The most likely source rock for TW-2 gas is the Miocene Monterey Formation and equivalents. Two exceptions in the samples classified as TW-2 gas are samples 19 and 42, which come from fields producing TW-1 gas (fig. 10.8) and oil sourced from the Eocene Kreyenhagen Formation (Lillis and Magoon, this volume, chapter 9, their samples 26 and 179). Further, these two samples are located more than 30 miles north of other TW-2 gas.  On figure 10.6 they plot close to the TW-1 gas samples suggesting that they may be genetically related to the latter.

TW-Mixed gas is a mixture of biogenetic gas and wet thermogenic gas (TW-1 or TW-2) most likely derived from Eocene or Miocene source rocks. The biogenic gas component of TW-Mixed gas most likely originated from the microbial decomposition of organic matter in Eocene or Miocene aged sediments.

The TD-2 gas is produced with oils from Miocene to Pliocene (Fruitvale, Elk Hills, Edison, Rosedale Ranch, and South Belridge fields) and Jurassic-aged (Edison field) reservoir rocks in the southern San Joaquin Basin (fig. 10.7).  The TD-2 gas appears to be genetically related to the thermogenic wet gas (TW-2) and oils produced from the same fields, but is drier due to migration fractionation or biodegradation of ethane and higher hydrocarbons (James and Burns, 1984). For example, the gas sample produced from Rosedale Ranch field (sample 66) has a distinctly high (heavy) $\delta^{13}C$ ethane value (fig. 10.6) due to bacterial consumption of ethane and higher hydrocarbons. Two TW-2 gas samples from Edison field (samples 25 and 26) appear to have biodegraded propane on the basis of higher (heavier) $\delta^{13}C$ values than normally expected (James, 1983; James and Burns, 1984).

### Biogenic

The biogenic (B) gas is a dry, nonassociated gas produced in the central and southern San Joaquin Basin (fig. 10.9) from shallow (less than 5,000 feet) reservoir rocks within the Pliocene San Joaquin Formation.  The gas is characterized by low (light) $\delta^{13}C$ methane values (–56 to –70‰), low carbon dioxide (less than 0.5 percent), and low nitrogen (less than 0.3 percent). The B gas most likely originated from the microbial decomposition (methanogenesis) of marine organic matter in the Pliocene San Joaquin Formation during and soon after deposition. This gas type defines the Neogene Nonassociated Gas Total Petroleum System (Magoon and others, this volume, chapter 8).

Two outlier gas samples (Bo) have isotopically light $\delta^{13}C$ methane values, typically characteristic of biogenic gas, but appear to be unrelated to the B gas type (fig. 10.5).  Gas sample 39 from Kern Bluff field is distinct because it is an associated gas with high nitrogen produced from the Miocene Santa Margarita Sandstone. Gas sample 50 from Midway-Sunset field is distinct because it contains elevated nitrogen and carbon dioxide and is associated with oil produced from the Miocene Reef Ridge Shale Member of the Monterey Formation. The origin of these two gases is unknown but the anomalous composition may be an artifact of sampling or field production practice (table 10.1).

## Origin of Carbon Dioxide

Carbon dioxide in the San Joaquin Basin Province has at least two possible origins. For gas samples that have less than 2 percent carbon dioxide and negative $\delta^{13}C$ carbon dioxide values, the carbon dioxide is likely a minor byproduct of the thermal degradation of organic matter (Hunt, 1996).  For gas samples with a carbon dioxide content greater than 2 percent and isotopic $\delta^{13}C$ values between +2 and +24‰, the carbon dioxide may be the residual gas from methanogenesis produced during petroleum biodegradation. Most of these gas samples (samples 6, 7, 8, 9, 10, 17, 23, 24, 25, 26, 50, 62, and 66) are produced from shallow reservoir rocks (less than 5,000 feet depth) that contain biodegraded oil. A similar process has been suggested for the origin of isotopically heavy carbon dioxide in some Los Angeles Basin oil fields (Jeffrey and others, 1991).

## Petroleum Systems

For the purpose of resource assessment, the gas types characterized above were assigned to petroleum systems.  The TD-1 and TD-Mixed gas types were assigned to the Winters-Domengine Total Petroleum System. Subsequent to the assessment, these gas types were reclassified to form the basis of the Moreno-Nortonville(.) gas system (fig. 10.10). The TW-1, TW-2, TW-Mixed and TD-2 gas types are considered to be associated gases that are included in the corresponding Eocene or Miocene total petroleum systems (Magoon and others, this

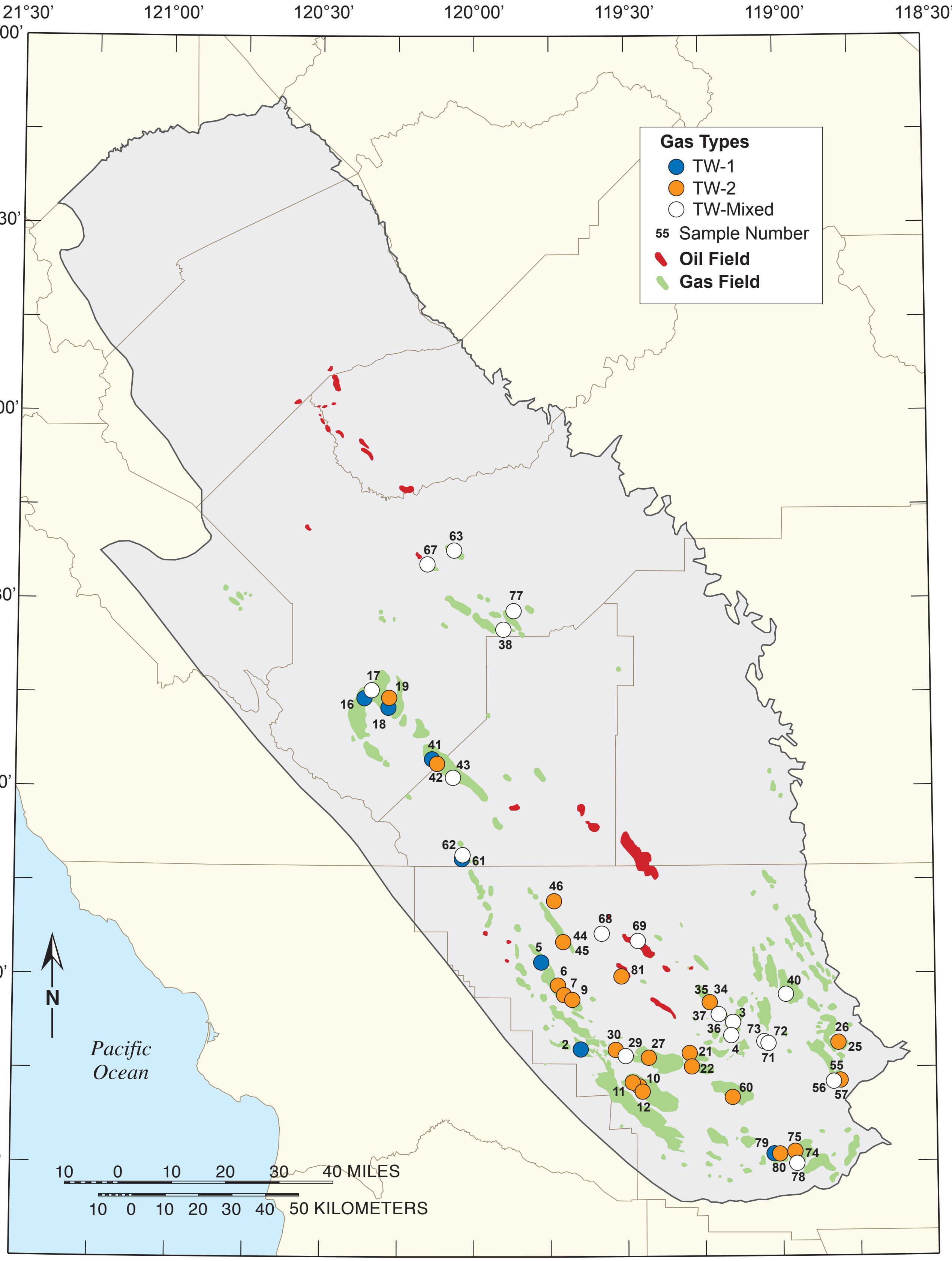


**Figure 10.8.** Sample locations for thermogenic wet gas in the San Joaquin Basin Province (gray shading).

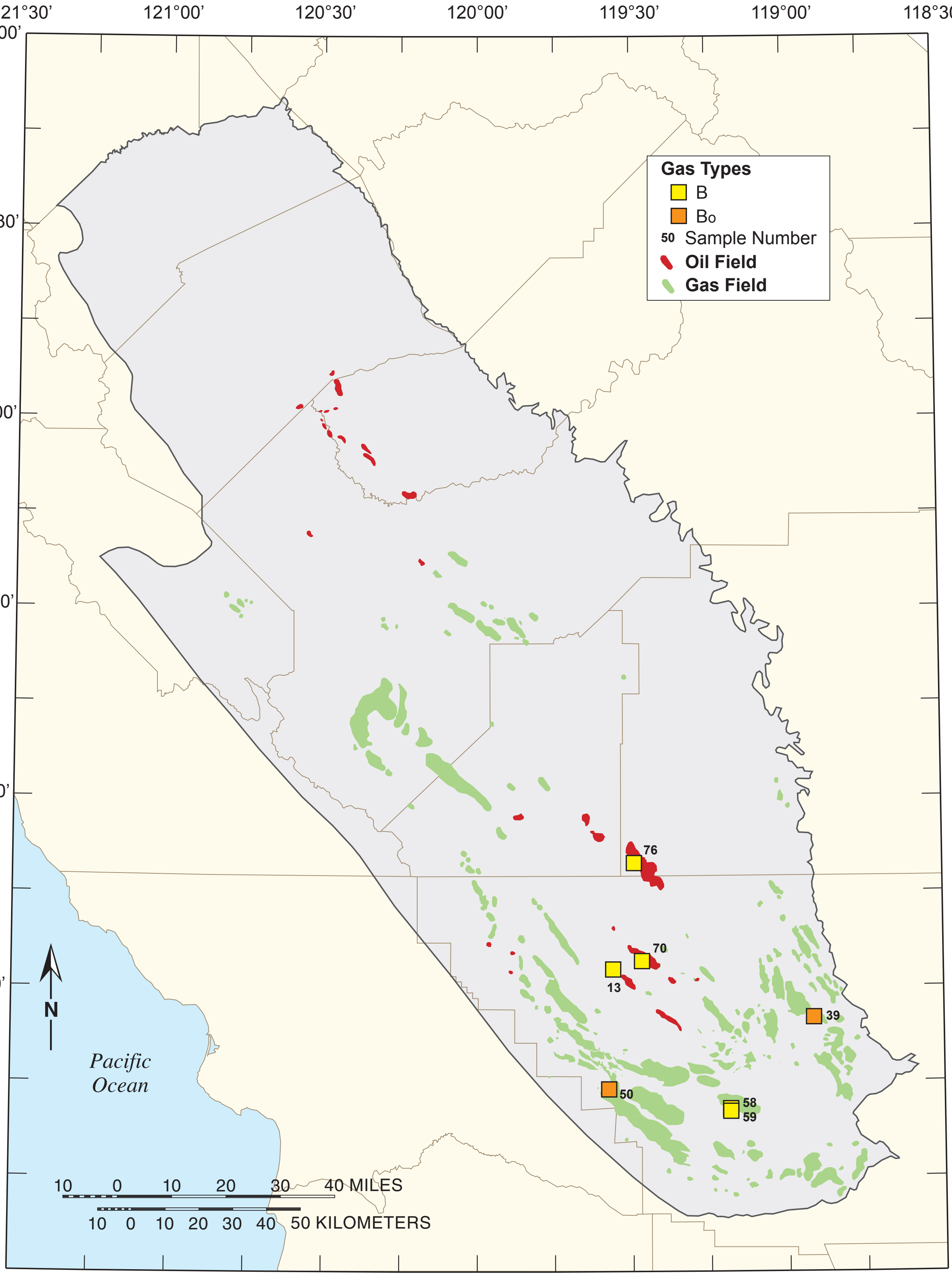


**Figure 10.9.** Sample locations for biogenic gas in the San Joaquin Basin Province (gray shading).

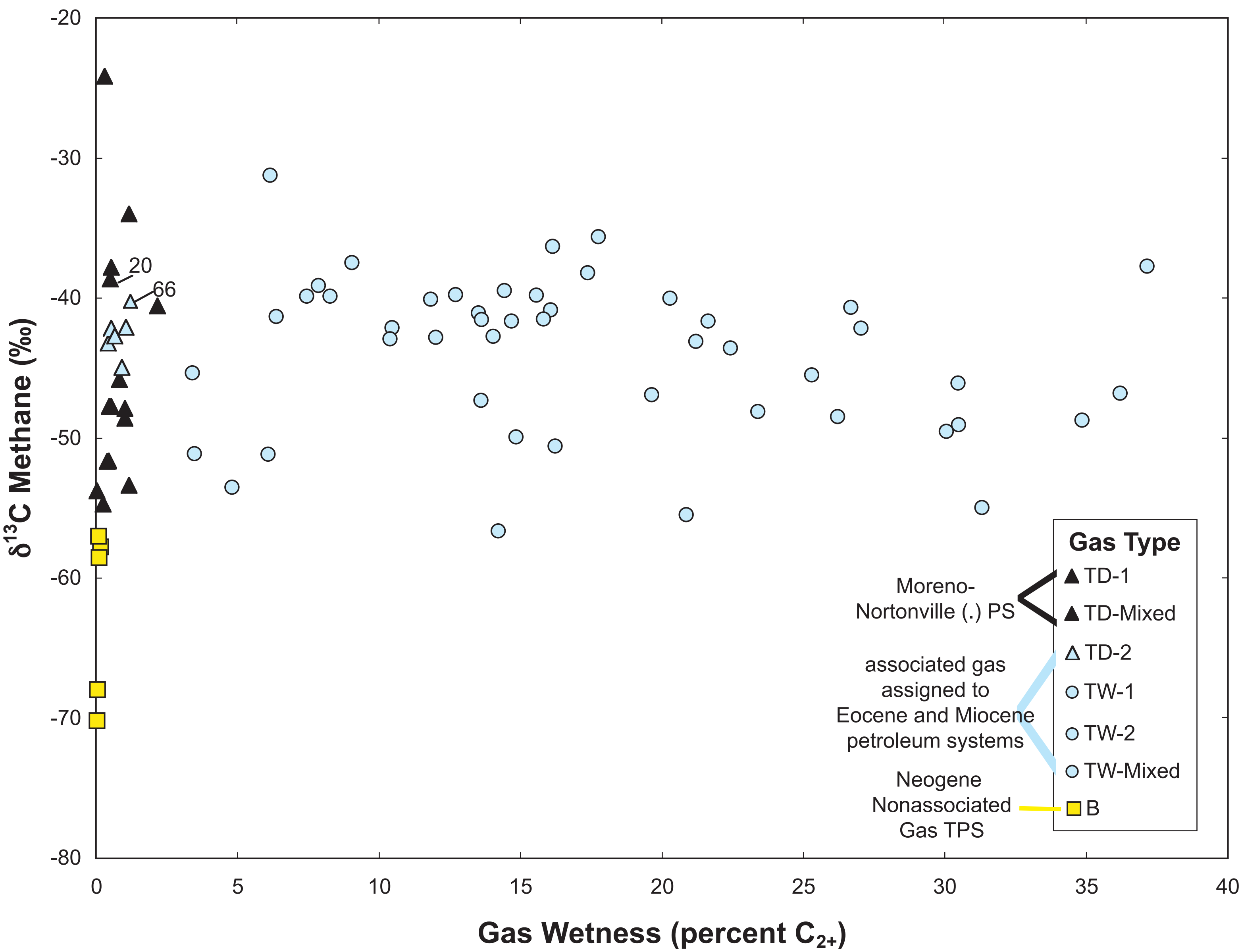


**Figure 10.10.** Plot of gas wetness versus $\delta^{13}C$ of methane for natural gas samples from San Joaquin Basin Province with symbol color representing petroleum system assignment. Type TD-1 and Type TD-Mixed gases are assigned to the Moreno-Nortonville(.) gas system (black triangles). Type TW-1, TW-2, TW-Mixed, and TD-2 gases are assigned to Eocene and Miocene petroleum systems (blue circles and triangless). Type B gas defines the Neogene Nonassociated gas system (yellow squares). PS, petroleum system; TPS, total petroleum system.

volume, chapter 8). The B gas defines the Neogene Nonassociated Gas Total Petroleum System (Magoon and others, this volume, chapter 8).

## Conclusions

Natural gases in the San Joaquin Basin Province can be grouped into three general types on the basis of bulk and stable carbon isotopic composition—thermogenic dry, thermogenic wet, and biogenic. The thermogenic gas types can be further subdivided on the basis of $\delta^{13}C$ values of methane and ethane and nitrogen content into TD-1, TD-2, TD-Mixed, TW-1, TW-2, and TW-Mixed.

The dry thermogenic gas TD-1 is produced from gas fields in the northern San Joaquin Basin Province, and most likely originated from gas-prone source rocks of Cretaceous age. The TD-Mixed gas is a mixture of dry thermogenic and biogenic gases produced from Cretaceous, Eocene, and Miocene reservoir rocks in the northern San Joaquin Basin Province. These two gas types are assigned to the Moreno-Nortonville(.) gas system, but, alternatively, may be part of the Winters-Domengine Total Petroleum System of the Sacramento Basin. The dry thermogenic gas TD-2 is produced from oil fields in the southern San Joaquin Basin, and most likely originated from an oil-prone source rock of Miocene age. Low wetness values in this gas type likely results from migration fractionation or biodegradation.

The three wet thermogenic gases, or TW-1, TW-2, and TW-Mixed, are predominantly gases associated with produced oil from fields in the southern and central San Joaquin Basin. The TW-1 gas is produced from Eocene and Oligocene-aged reservoir rocks, and most likely originates from source rocks within the Eocene Kreyenhagen Formation or Tumey formation. The TW-2 gas is produced from Jurassic, Eocene, Miocene, and Pliocene reservoir rocks, and most likely originates from a source rock in the Miocene Monterey Formation and equivalents. The TW-Mixed gas is likely a mixture of wet thermogenic (TW-1 or TW-2) gases derived from Eocene or Miocene source rocks and biogenic gas. These three gas types are included in the resource assessments of the corresponding oil systems (Magoon and others, this volume, chapter 8).

The biogenic gas (type B) is a dry, nonassociated gas produced from the Pliocene San Joaquin Formation in the central and southern San Joaquin Basin. The B gas most likely originated from Pliocene marine source rocks as a product of methanogenesis and defines the Neogene Nonassociated Total Petroleum System.

## Acknowledgments

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# Tables

**Table 10.1.** Sample information for natural gas samples from the San Joaquin Basin Province, California.

[Gas types are based on gas composition (table 10.2) and are designated as thermogenic dry (TD-1, TD-2), thermogenic wet (TW-1, TW-2), biogenic (B), thermogenic mixed with biogenic (TW-Mixed, TD-Mixed), and biogenic outlier (Bo). Field names are designated by the State of California, Division of Oil, Gas, and Geothermal Resources (CDOGGR, 1998). Formation name and reservoir rock are modified to comply with USGS geologic name standards. Sec-Twn-Rng, location of sample in notation of public land survey system. Fm, Formation; Mbr, Member; Sh, Shale. See appendix for more information on each sample]

| Gas Sample Number | Field Name | Formation Name | Reservoir Rock | Gas Type | Comments | Well Name | Depth Interval (feet) | Sec-Twn-Rng |
|---|---|---|---|---|---|---|---|---|
| 1 | Ash Slough | Blewett sands of Hoffman (1964) | Blewett sands of Hoffman (1964) | TD-Mixed | gas well just south of Ash Slough gas field | Redman-Roduner 1-32 | 5,441 - 5,594 | 32-10S-14E |
| 2 | Belgian Anticline | Kreyenhagen Shale | Kreyenhagen Shale | TW-1 | oil well | Midway-McKittrick 21A | 6,550 - 6,550 | 30-30S-22E |
| 3 | Bellevue | Fruitvale shale of Miller and Bloom (1939) | Stevens sand of Eckis (1940) | TW-Mixed | oil well | Argonaut 1 | 8,200 - 8,500 | 34-29S-26E |
| 4 | Bellevue | Fruitvale shale of Miller and Bloom (1939) | Stevens sand of Eckis (1940) | TW-Mixed | oil well | KCL 61 52X-10 | 7,530 - 7,572 | 10-30S-26E |
| 5 | Belridge North | Temblor Formation | Belridge 64 sand of Foss and Blaisdell (1968) | TW-1 | oil well | 63-35 | 7,820 - 7,867 | 35-27S-20E |
| 6 | Belridge South | Etchegoin Fm/Reef Ridge Sh Mbr of Monterey Fm | Etchegoin Fm/Reef Ridge Sh Mbr of Monterey Fm | TW-2 | oil well | 29 573-29 | 1,490 - 2,390 | 29-28S-21E |
| 7 | Belridge South | Etchegoin Fm/Reef Ridge Sh Mbr of Monterey Fm | Etchegoin Fm/Reef Ridge Sh Mbr of Monterey Fm | TW-2 | oil well | 33 577CR-33 | 775 - 2,615 | 33-28S-21E |
| 8 | Belridge South | Monterey Fm/Reef Ridge Sh Mbr of Monterey Fm/Etchegoin Fm | Monterey Fm/Reef Ridge Sh Mbr of Monterey Fm/Etchegoin Fm | TD-2 | oil well | Sebu T 7624-1 | 1,195 - 3,020 | 1-29S-21E |
| 9 | Belridge South | Reef Ridge Sh Mbr of Monterey Fm | Reef Ridge Sh Mbr of Monterey Fm | TW-2 | oil well | Belridge V 7384B-2 | 1,420 - 2,700 | 2-29S-21E |
| 10 | Buena Vista | Etchegoin Formation | Etchegoin Formation | TW-2 | oil well | Crimson Sec 25B 1-7A | 2,900 - 3,390 | 25-31S-23E |
| 11 | Buena Vista | Monterey Formation | Monterey Formation | TW-2 | oil well | Crimson 523 | 4,000 - 5,000 | 26 31S-23E |
| 12 | Buena Vista | San Joaquin Formation | Mya sand zone of Berryman (1973) | TW-2 | shallow gas well | 36 B McNee 5-8 | 2,070 - 2,300 | 36-31S-23E |
| 13 | Buttonwillow | San Joaquin Formation | San Joaquin Formation | B | gas well | Buttonwillow 1 | 4,000 - 4,000 | 25-27S-22E |
| 14 | Chowchilla | Panoche Formation | Starkey sands of Hoffman (1964) (third) | TD-1 | gas well | Chowchilla 3 | 7,924 - 7,924 | 8-10S-14E |
| 15 | Chowchilla | Zilch formation of Loken (1959) | Zilch formation of Loken (1959) | TD-Mixed | gas well | Chowchilla 5 | 2,605 - 2,605 | 8-10S-14E |
| 16 | Coalinga | --- | --- | TW-1 [a] | from oil treater (no. 3) for many wells, suspect sample | plant treater | --- | 32-19S-15E |
| 17 | Coalinga | Temblor Formation | Temblor Formation | TW-Mixed | oil well | Coalinga 45-27 | 1,122 - 1,724 | 27-19S-15E |
| 18 | Coalinga East Extension | Lodo Formation | Gatchell sand of Goudkoff (1943) | TW-1 | well produces only gas but was oil producer | Coalinga Nose Unit 3-7F | 6,666 - 6,973 | 7-20S-16E |
| 19 | Coalinga East Extension | Lodo Formation | Gatchell sand of Goudkoff (1943) | TW-2 [b] | from oil and gas separator | Coalinga Nose Unit 26-31B | 7,695 - 8,040 | 31-19S-16E |

**Table 10.1.** Sample information for natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | Formation Name | Reservoir Rock | Gas Type | Comments | Well Name | Depth Interval (feet) | Sec-Twn-Rng |
|---|---|---|---|---|---|---|---|---|
| 20 | Coalinga, Oil City area | Moreno (?) Formation | Moreno (?) Formation | TD-1 [c] | from seep in water tank near abandoned well | gas seep in water tank | --- | 17-19S-15E |
| 21 | Coles Levee, North | Monterey Formation | Antelope shale of Graham and Williams (1985) | TW-2 | oil well | North Coles Levee Unit 76-32 | 8,814 - 9,187 | 32-30S-25E |
| 22 | Coles Levee, South | Monterey Formation | Antelope shale of Graham and Williams (1985) | TW-2 | oil well | South Coles Levee Unit 72-9 | 8,245 - 8,584 | 9-31S-25E |
| 23 | Edison | Kern River Formation | Kern River Formation | TD-2 | from tank battery of oil well | Young Fee Dos Tres 72 | 1,961 - 2,192 | 23-30S-29E |
| 24 | Edison | schist | schist | TD-2 | oil well | Young Fee 13 | 2,050 - 2,200 | 23-30S-29E |
| 25 | Edison | schist | schist | TW-2 | oil well | Corp Fee 35 | 1,336 - 1,833 | 13-30S-29E |
| 26 | Edison | schist | schist | TW-2 | oil well | Corp. Fee S 2 | 1,740 - 1,740 | 13-30S-29E |
| 27 | Elk Hills | Monterey Formation | Antelope shale of Graham and Williams (1985) | TW-2 | from tank for several oil wells | 358-31S | 6,036 - 7,008 | 31-30S 24E |
| 28 | Elk Hills | San Joaquin Formation | San Joaquin Formation | TD-2 | gas well | DZG 405X-36R | 1,781 - 1,896 | 36-30S-23E |
| 29 | Elk Hills | San Joaquin Formation | San Joaquin Formation | TW-Mixed | well produces only gas but was oil producer | 4-242-33R | 2,110 - 2,205 | 33-30S-23E |
| 30 | Elk Hills | Temblor Formation | Carneros Ss Mbr of Temblor Fm | TW-2 | oil well | 542-30R | 9,485 - 9,850 | 30-30S-23E |
| 31 | Fruitvale | Chanac Formation | Chanac Formation | TD-2 | from separator for several oil wells | separator 3F | approx. 4,300 | 22-29S-27E |
| 32 | Gill Ranch | Panoche Formation | Panoche Formation | TD-Mixed | gas well | Gill 38-16 | 5,750 - 5,750 | 16-13S-16E |
| 33 | Gill Ranch | Panoche Formation | Panoche Formation | TD-Mixed | gas well | Gill 38X-17 | 5,000 - 7,000 | 20-13S-16E |
| 34 | Greeley | Freeman Silt-Jewett Sand | Freeman Silt-Jewett Sand | TW-2 | oil well | KCL 12-8 | 11,234 - 11,327 | 7-29S-26E |
| 35 | Greeley | Freeman Silt-Jewett Sand | Freeman Silt-Jewett Sand | TW-Mixed | oil well | KCL 51 114-7 | 10,260 - 10,652 | 7-29S-26E |
| 36 | Greeley | Fruitvale shale of Miller and Bloom (1939) | Fruitvale shale of Miller and Bloom (1939) | TW-Mixed | oil well | KCL 63 43-20 | 8,677 - 9,143 | 20-29S-26E |
| 37 | Greeley | Vedder Sand | Vedder Sand | TW-2 | from well casing of oil well | KCL 12-9 | 11,292 - 11,332 | 7-29S-26E |
| 38 | Helm | Zilch formation of Loken (1959) | Zilch formation of Loken (1959) | TW-Mixed | oil well, southeast area of field | Covey 3X | 7,057 - 7,061 | 33-17S-19E |
| 39 | Kern Bluff | Santa Margarita Sandstone | Santa Margarita Sandstone | Bo [d] | from separator for several oil wells | separator | 1,066 - 1,109 | 12-29S-28E |
| 40 | Kern River | Kern River Formation | Kern River Formation | TW-Mixed | from shut-in oil well casing | San Joaquin Fee 769 | 380 - 750 | 5-29S-28E |
| 41 | Kettleman North Dome | Lodo Formation | lower McAdams sandstone of Sullivan (1963) | TW-1 | oil well, total depth = 10,060 ft | E 72-33 | approx. 10,000 | 33-21S-17E |
| 42 | Kettleman North Dome | Lodo Formation | upper McAdams sandstone of Sullivan (1963) | TW-2 [e] | oil well | E 423-34 J | 9,680 - 9,910 | 34-21S-17E |
| 43 | Kettleman North Dome | Temblor Formation | Temblor Formation | TW-Mixed | Total depth = 6326 ft, originally a gas well (now oil and gas) | 31-18 Q | approx. 6,000 | 18-22S-18E |

**Table 10.1.** Sample information for natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | Formation Name | Reservoir Rock | Gas Type | Comments | Well Name | Depth Interval (feet) | Sec-Twn-Rng |
|---|---|---|---|---|---|---|---|---|
| 44 | Lost Hills | Monterey Formation | Monterey Formation | TW-2 | oil well | Monte Cristo 16 1741 | 4,546 - 4,782 | 16-27S-21E |
| 45 | Lost Hills | Reef Ridge Sh Mbr of Monterey Fm | Reef Ridge Sh Mbr of Monterey Fm | TW-2 | from separator of oil well | Monte Cristo Fee 41 | 2,300 - 2,700 | 16-27S-21E |
| 46 | Lost Hills, East | Temblor Formation | Gibson sand of Williams (1938) | TW-2 | gas well with condensate | Berkeley 1 | 19,370 - 19,698 | 6-26S-21E |
| 47 | Merrill Avenue | Blewett sands of Hoffman (1964) | Blewett sands of Hoffman (1964) | TD-Mixed | gas well | Wolfson 1-10 | 6,102 - 6,286 | 10-11S-13E |
| 48 | Merrill Avenue, SE | Blewett sands of Hoffman (1964) | Blewett sands of Hoffman (1964) | TD-1 | gas well | Triangle-T 1-33 | 6,220 - 6,243 | 33-11S-14E |
| 49 | Merrill Avenue, SE | Panoche Formation | Ragged Valley silt of Hoffman (1964) | TD-1 | gas well | Triangle-T 1-29 | 6,377 - 6,756 | 29-11S-14E |
| 50 | Midway-Sunset | Reef Ridge Sh Mbr of Monterey Fm | Reef Ridge Sh Mbr of Monterey Fm | Bo [f] | oil well, steam (from field injection) mixed with gas sample | Shale 284-D | 1,516 - 1,690 | 14-31S-22E |
| 51 | Mint Road | Blewett sands of Hoffman (1964) | Blewett sands of Hoffman (1964) | TD-Mixed | gas well | Bertao 1-31 | 6,344 - 6,371 | 31-10S-13E |
| 52 | Moffat Ranch | Kreyenhagen Shale | Kreyenhagen Shale | TD-Mixed | gas well | Columbia Ranch 2-2 | 3,974 - 3,985 | 20-12S-15E |
| 53 | Moffat Ranch | Kreyenhagen Shale | Nortonville sand of Frame (1950) | TD-Mixed | gas well | N.M.R. 8-12 | 4,087 - 4,087 | 12 12S-14E |
| 54 | Mount Poso | Vedder Sand | Vedder Sand | TD-Mixed [g] | from tank for several oil wells | Glide 15-5 | approx. 1,600 | 15 27S-28E |
| 55 | Mountain View | Chanac Formation | Chanac Formation | TW-2 | from oil and gas separator | Jewett 1-23 | 5,696 - 6,418 | 23-31S-29E |
| 56 | Mountain View | Chanac Formation | Chanac Formation | TW-Mixed | oil well | Simpson 1 | 6,930 - 7,013 | 26-31S-29E |
| 57 | Mountain View | schist | schist | TW-2 | oil well | Stockton 3 | 5,605 - 6,140 | 25-31S-29E |
| 58 | Paloma | San Joaquin Formation | San Joaquin Formation | B | gas well | Paloma 43X-4 | 5,672 - 5,676 | 4-32S-26E |
| 59 | Paloma | San Joaquin Formation | San Joaquin Formation | B | gas well | Paloma 44-4 | 4,385 - 5,465 | 4-32S-26E |
| 60 | Paloma | Temblor Formation | Carneros Ss Mbr of Temblor Fm | TW-2 | oil/condensate well | Paloma 28X-2 | approx. 18,300 | 2-32S-26E |
| 61 | Pyramid Hills | Kreyenhagen Shale | Kreyenhagen Shale | TW-1 | oil well | Norris-Drilexico-Hand 15 | 3,542 - 3,600 | 28-24S-18E |
| 62 | Pyramid Hills | Kreyenhagen Shale | Kreyenhagen Shale | TW-Mixed | oil well | Norris/Baylis 2-9 | 737 - 857 | 29-24S-18E |
| 63 | Raisin City | Kreyenhagen Shale | Kreyenhagen Shale | TW-Mixed | oil well | Ripperdan 56-13 | 6,174 - 6,300 | 13-15S-17E |
| 64 | Raisin City | Panoche Formation | Panoche Formation | TD-1 | gas well | Ripperdan 501-13 | 7,574 - 7,584 | 13-15S-17E |
| 65 | Raisin City | Zilch formation of Loken (1959) | Zilch formation of Loken (1959) | TD-Mixed | oil well | B 22X-19 | 4,500 - 5,000 | 19-15S-18E |
| 66 | Rosedale Ranch | Etchegoin Formation | Etchegoin Formation | TD-2 | oil well with high water production | KCL 31 16-1 | 4,190 - 4,328 | 1-29S-26E |
| 67 | San Joaquin | Domengine Formation | Domengine Formation | TW-Mixed | oil well | Schramm 71 | approx. 7,800 | 31-15S-17E |
| 68 | Semitropic | --- | --- | TW-Mixed | gas and condensate well | EKHO 1 | gt 17,000 | 3-27S-22E |

**Table 10.1.** Sample information for natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | Formation Name | Reservoir Rock | Gas Type | Comments | Well Name | Depth Interval (feet) | Sec-Twn-Rng |
|---|---|---|---|---|---|---|---|---|
| 69 | Semitropic | Etchegoin Formation | Randolph sand of Mitchell and Chamberlain (1983) | TW-Mixed | dual completion - oil zone, from separator | Community 1 | 7,500 - 8,000 | 14-27S-23E |
| 70 | Semitropic | San Joaquin Formation | San Joaquin Formation | B | dual completion - gas zone, from separator | Community 1 | 3,000 - 4,000 | 14-27S-23E |
| 71 | Stockdale | Round Mountain Silt | Round Mountain Silt | TW-Mixed | oil well | Panama 2-14 | 11,073 - 11,140 | 14-30S-27E |
| 72 | Stockdale | Round Mountain Silt | Round Mountain Silt | TW-Mixed | oil well | Panama 2-15 | 11,150 - 11,250 | 15-30S-27E |
| 73 | Stockdale | Round Mountain Silt | Round Mountain Silt | TW-Mixed | oil well | Panama 3-15 | 11,035 - 11,170 | 15-30S-27E |
| 74 | Tejon, North | Vedder Sand | Vedder Sand | TW-2 | oil well | KCL "L" 67-25 | 8,710 - 8,710 | 25-11N-20W |
| 75 | Tejon, North | Vedder Sand-Tejon Formation | Vedder Sand-Tejon Formation | TW-2 | from separator of oil well | KCL-G North 65-24 | 8,475 - 10,695 | 24-11N-20W |
| 76 | Trico | San Joaquin Formation | Mya sand zone of Berryman (1973) | B | gas well | Trico-Newland 12 | 2,427 - 2,427 | 21-24S-23E |
| 77 | Van Ness Slough | Zilch formation of Loken (1959) | Zilch formation of Loken (1959) | TW-Mixed | oil well | Kleinhammer 1 | approx. 6,900 | 11-17S-19E |
| 78 | Wheeler Ridge | Olcese Sand (lower) | Olcese Sand (lower) | TW-Mixed | oil well | KCL "L" So. 56-36 | 7,460 - 7,460 | 36-11N-20W |
| 79 | Wheeler Ridge | Tejon Formation | Tejon Formation | TW-1 | oil well | WRU 312-28 | 10,140 - 10,552 | 28-11N-20W |
| 80 | Wheeler Ridge | Vedder Sand | Vedder Sand | TW-2 | oil well | KCL G 34-27 | 8,880 - 8,880 | 27-11N-20W |
| 81 | wildcat well | --- | --- | TW-2 | from oil and gas drill stem test | Bravo 1 | approx. 14,300 | 17-28S-23E |

[a] Probably Type TW-1 gas but has high nitrogen and lacks $\delta^{13}C$ ethane data to confirm.
[b] Possibly Type TW-1 gas on the basis of location, association with Eocene oil and TW-1 gas, and location as shown on figure 10.6.
[c] Has low, corrected nitrogen compared with other TD-1 gases, and sample quality is in question due to air contamination.
[d] Different origin from Type B gas because it has high nitrogen and is associated gas.
[e] Possibly Type TW-1 gas on the basis of location, association with Eocene oil and TW-1 gas, and location as shown on figure 10.6.
[f] Different origin from Type B gas because it has high nitrogen and carbon dioxide and is associated gas.
[g] Different origin than other TD-Mixed or TD-1 gases because it is produced in southern San Joaquin Basin from an oil field (see text).

**Table 10.2 *A*.** Geochemical data of natural gas samples from the San Joaquin Basin Province, California.

[Sample information is given in table 10.1. Lab No., analysis number for U.S. Geological Survey Organic Geochemistry Laboratory, Denver, Colo., except numbers starting with GGC- (Jenden and Kaplan, 1989a) and M- (Claypool and others, 2000). Gas compositions are in mole percent. $N_2$corr, corrected nitrogen content, using the expression $N_2$-($O_2$+Ar)/0.2802. $N_2$, nitrogen; $O_2$+Ar, oxygen plus argon; $O_2$, oxygen; Ar, argon; $CO_2$, carbon dioxide; $H_2S$, hydrogen sulfide; $H_2$, hydrogen; He, helium; $C_1$, methane; $C_2$, ethane; $C_3$, propane; *i*-$C_4$, isobutane]

| Gas Sample Number | Field Name | Lab No. | $N_2$corr % | $N_2$ % | $O_2$+Ar % | $O_2$ % | Ar % | $CO_2$ % | $H_2S$ % | $H_2$ % | He % | $C_1$ % | $C_2$ % | $C_3$ % | *i* -$C_4$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Ash Slough | 99003023 | 10.25 | 12.28 | 0.57 | --- | --- | 0.13 | --- | --- | --- | 86.62 | 0.33 | 0.06 | 0.02 |
| 2 | Belgian Anticline | GGC-1180 | --- | 1.38 | --- | 0.13 | 0.027 | 0.90 | --- | --- | 0.001 | 79.50 | 6.61 | 4.74 | 0.937 |
| 3 | Bellevue | 99003005 | 0 | 3.42 | 1.11 | --- | --- | 0.95 | --- | --- | --- | 75.96 | 6.88 | 7.66 | 1.14 |
| 4 | Bellevue | 02025012 | 0 | 1.28 | 0.51 | --- | --- | 0.53 | --- | --- | --- | 67.67 | 10.33 | 12.39 | 1.49 |
| 5 | Belridge North | 02025040 | 0 | 1.76 | 0.59 | --- | --- | 1.26 | --- | --- | --- | 87.65 | 4.98 | 2.13 | 0.5 |
| 6 | Belridge South | 02025039 | 0 | 2.28 | 0.95 | --- | --- | 17.51 | --- | --- | --- | 74.16 | 1.05 | 1.72 | 0.49 |
| 7 | Belridge South | 02025038 | 0 | 1.72 | 0.69 | --- | --- | 23.98 | --- | --- | --- | 57.46 | 2.73 | 5.36 | 1.38 |
| 8 | Belridge South | 02025036 | 0 | 1.64 | 0.72 | --- | --- | 15.35 | --- | --- | --- | 81.55 | 0.25 | 0.07 | 0.19 |
| 9 | Belridge South | 02025037 | 0 | 1.32 | 0.52 | --- | --- | 15.58 | --- | --- | --- | 60.09 | 9.61 | 7.06 | 1.23 |
| 10 | Buena Vista | 02025035 | 0 | 1.49 | 0.72 | --- | --- | 10.10 | --- | --- | --- | 75.73 | 4.94 | 3.5 | 0.85 |
| 11 | Buena Vista | 02025034 | 0 | 10.67 | 3.27 | --- | --- | 3.85 | --- | --- | --- | 73.67 | 3.52 | 2.97 | 0.52 |
| 12 | Buena Vista | 02025033 | 0 | 1.51 | 0.61 | --- | --- | 6.45 | --- | --- | --- | 84.56 | 3.46 | 1.76 | 0.46 |
| 13 | Buttonwillow | 99003006 | 0 | 1.67 | 0.64 | --- | --- | 0.00 | --- | --- | --- | 97.53 | 0.06 | 0.06 | 0.04 |
| 14 | Chowchilla | GGC-1146 | --- | 59.10 | --- | 0.04 | 0.016 | 0.01 | --- | --- | 0.01 | 40.70 | 0.374 | 0.078 | 0.01 |
| 15 | Chowchilla | GGC-1148 | --- | 10.80 | --- | 0.013 | 0.015 | 0.19 | --- | --- | 0.013 | 88.20 | 0.027 | 0.001 | --- |
| 16 | Coalinga | 02025003 | 34.34 | 35.98 | 0.46 | --- | --- | 11.63 | --- | --- | --- | 48.91 | 1.18 | 0.62 | 0.44 |
| 17 | Coalinga | 02025002 | 0.19 | 2.90 | 0.76 | --- | --- | 13.60 | 0.03 | --- | --- | 60.90 | 6.76 | 7.99 | 1.56 |
| 18 | Coalinga East Extension | 02025004 | 0.12 | 1.12 | 0.28 | --- | --- | 1.09 | --- | --- | --- | 83.38 | 11.17 | 2.53 | 0.15 |
| 19 | Coalinga East Extension | 02025005 | 0 | 1.11 | 0.43 | --- | --- | 2.49 | --- | --- | --- | 80.25 | 6.6 | 4.74 | 0.84 |
| 20 | Coalinga, Oil City area | 02025001 | 2.39 | 31.41 | 8.13 | --- | --- | 4.22 | --- | --- | --- | 55.96 | 0.2 | 0.04 | 0.02 |
| 21 | Coles Levee, North | 99003004 | 0 | 2.25 | 0.77 | --- | --- | 1.01 | --- | --- | --- | 82.51 | 6.21 | 5.07 | 0.55 |
| 22 | Coles Levee, South | 99003003 | 0 | 3.80 | 1.32 | --- | --- | 1.53 | --- | --- | --- | 82.31 | 6.75 | 3 | 0.41 |
| 23 | Edison | 02025020 | 0 | 1.65 | 0.53 | --- | --- | 2.69 | --- | --- | --- | 94.51 | 0.63 | --- | --- |
| 24 | Edison | 02025019 | 0 | 2.77 | 0.90 | --- | --- | 3.31 | --- | --- | --- | 92.51 | 0.45 | --- | 0.03 |
| 25 | Edison | 02025018 | 4 | 20.95 | 4.75 | --- | --- | 5.12 | 0.02 | --- | --- | 59.74 | 2.51 | 4.07 | 1.58 |
| 26 | Edison | GGC-1181 | --- | 6.37 | --- | 0.418 | 0.069 | 4.92 | --- | --- | --- | 81.00 | 1.64 | 2.48 | 1.31 |

**Table 10.2 *A*.** Geochemical data of natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | Lab No. | $N_2$corr % | $N_2$ % | $O_2$+Ar % | $O_2$ % | Ar % | $CO_2$ % | $H_2S$ % | $H_2$ % | He % | $C_1$ % | $C_2$ % | $C_3$ % | *i* -$C_4$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | Elk Hills | 99003002 | 0 | 7.89 | 3.47 | --- | --- | 0.64 | --- | --- | --- | 80.73 | 5.52 | 1.49 | 0.17 |
| 28 | Elk Hills | 99003001 | 0 | 8.76 | 2.54 | --- | --- | 2.90 | --- | --- | --- | 84.89 | 0.68 | 0.17 | 0.02 |
| 29 | Elk Hills | 02025032 | 0 | 2.27 | 0.95 | --- | --- | 0.47 | --- | --- | --- | 92.97 | 1.82 | 1 | 0.2 |
| 30 | Elk Hills | 02025031 | 0.04 | 0.93 | 0.25 | --- | --- | 4.25 | --- | --- | --- | 79.52 | 8.03 | 3.56 | 0.8 |
| 31 | Fruitvale | 99003011 | 11.94 | 14.76 | 0.79 | --- | --- | 0.51 | --- | --- | --- | 83.59 | 0.33 | 0.03 | --- |
| 32 | Gill Ranch | GGC-1151 | --- | 8.35 | --- | 0.014 | 0.012 | 0.01 | --- | --- | 0.01 | 90.30 | 0.796 | 0.115 | 0.007 |
| 33 | Gill Ranch | 99003019 | 3.4 | 12.79 | 2.63 | --- | --- | 0.10 | --- | --- | --- | 83.78 | 0.62 | 0.08 | --- |
| 34 | Greeley | 02025016 | 0.29 | 1.79 | 0.42 | --- | --- | 1.06 | --- | --- | --- | 75.74 | 10.37 | 6.51 | 0.71 |
| 35 | Greeley | 02025015 | 0.13 | 2.45 | 0.65 | --- | --- | 1.05 | --- | --- | --- | 66.48 | 4.69 | 11.09 | 3.74 |
| 36 | Greeley | 02025013 | 0 | 6.84 | 2.05 | --- | --- | 2.36 | --- | --- | --- | 74.14 | 2.23 | 4.79 | 2.05 |
| 37 | Greeley | 02025014 | 0.15 | 1.97 | 0.51 | --- | --- | 3.41 | --- | --- | --- | 82.75 | 7.28 | 3.81 | --- |
| 38 | Helm | 99003015 | 0.82 | 1.07 | 0.07 | --- | --- | 0.80 | --- | --- | --- | 84.70 | 7.48 | 3.96 | 0.54 |
| 39 | Kern Bluff | 02025021 | 11.45 | 14.73 | 0.92 | --- | --- | 0.42 | --- | --- | --- | 83.93 | --- | --- | --- |
| 40 | Kern River | 02025026 | 0 | 3.52 | 1.60 | --- | --- | 92.24 | --- | --- | --- | 1.72 | --- | 0.39 | 0.17 |
| 41 | Kettleman North Dome | M-1 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 42 | Kettleman North Dome | M-2 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 43 | Kettleman North Dome | M-3 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 44 | Lost Hills | 02025042 | 0 | 2.88 | 1.02 | --- | --- | 0.70 | --- | --- | --- | 80.28 | 8.27 | 4.39 | 0.72 |
| 45 | Lost Hills | 99003012 | 0.19 | 2.01 | 0.51 | --- | --- | 0.68 | --- | --- | --- | 82.58 | 7.28 | 4.22 | 0.59 |
| 46 | Lost Hills, East | 02025041 | 0 | 0.46 | 0.13 | --- | --- | 5.65 | --- | --- | --- | 83.84 | 6.55 | 1.74 | 0.54 |
| 47 | Merrill Avenue | 99003025 | 9.4 | 12.36 | 0.83 | --- | --- | 0.16 | --- | --- | --- | 86.20 | 0.36 | 0.07 | 0.03 |
| 48 | Merrill Avenue, SE | 99003022 | 23.96 | 27.99 | 1.13 | --- | --- | 0.00 | --- | --- | 0.11 | 70.39 | 0.31 | 0.05 | 0.02 |
| 49 | Merrill Avenue, SE | 99003021 | 32.29 | 39.21 | 1.94 | --- | --- | 0.13 | --- | --- | --- | 58.55 | 0.15 | 0.03 | --- |
| 50 | Midway-Sunset | 02025030 | 5.94 | 7.23 | 0.36 | --- | --- | 43.24 | 0.04 | 4.1 | --- | 44.08 | 0.24 | 0.15 | 0.2 |
| 51 | Mint Road | 99003024 | 4.54 | 4.79 | 0.07 | --- | --- | 0.18 | --- | --- | --- | 94.55 | 0.33 | 0.06 | 0.03 |
| 52 | Moffat Ranch | 99003020 | 10.03 | 13.10 | 0.86 | --- | --- | 0.37 | --- | --- | --- | 85.41 | 0.21 | --- | --- |
| 53 | Moffat Ranch | GGC-1150 | --- | 7.61 | --- | 0.021 | 0.012 | 0.06 | --- | --- | 0.01 | 91.40 | 0.289 | 0.049 | 0.005 |
| 54 | Mount Poso | 02025025 | 6.36 | 9.43 | 0.86 | --- | --- | 0.32 | --- | --- | --- | 88.48 | 0.17 | 0.36 | 0.18 |
| 55 | Mountain View | 02025023 | 1.24 | 4.17 | 0.82 | --- | --- | 0.00 | --- | --- | --- | 73.68 | 8.69 | 7.91 | 1.4 |
| 56 | Mountain View | 02025024 | 1.41 | 4.09 | 0.75 | --- | --- | 0.00 | --- | --- | --- | 71.03 | 9.43 | 8.29 | 1.78 |
| 57 | Mountain View | 02025022 | 5.39 | 7.28 | 0.53 | --- | --- | 0.00 | --- | --- | --- | 67.55 | 10.05 | 9.13 | 1.54 |
| 58 | Paloma | 99003008 | 0 | 1.58 | 0.54 | --- | --- | 0.49 | --- | --- | --- | 97.27 | 0.05 | 0.04 | 0.02 |

**Table 10.2 *A*.** Geochemical data of natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | Lab No. | $N_2$corr % | $N_2$ % | $O_2$+Ar % | $O_2$ % | Ar % | $CO_2$ % | $H_2S$ % | $H_2$ % | He % | $C_1$ % | $C_2$ % | $C_3$ % | *i* -$C_4$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | Paloma | 99003009 | 0 | 1.71 | 0.53 | --- | --- | 0.35 | --- | --- | --- | 97.33 | 0.05 | 0.03 | --- |
| 60 | Paloma | 99003010 | 0 | 5.93 | 2.69 | --- | --- | 0.16 | --- | --- | --- | 79.64 | 7.42 | 3.27 | 0.51 |
| 61 | Pyramid Hills | 02025006 | 0 | 0.67 | 0.37 | --- | --- | 0.12 | --- | --- | --- | 61.85 | 14.17 | 13.1 | 2.33 |
| 62 | Pyramid Hills | 02025007 | 0 | 0.23 | 0.26 | --- | --- | 7.39 | --- | --- | --- | 88.99 | 2.04 | 0.85 | 0.17 |
| 63 | Raisin City | 02025029 | 0.29 | 7.93 | 2.14 | --- | --- | 0.56 | --- | --- | --- | 85.06 | 1.21 | 1.14 | 0.81 |
| 64 | Raisin City | 02025028 | 8.77 | 11.84 | 0.86 | --- | --- | 0.07 | --- | --- | --- | 85.35 | 1.03 | 0.44 | 0.19 |
| 65 | Raisin City | 99003017 | 1.43 | 6.14 | 1.32 | --- | --- | 2.85 | --- | --- | --- | 88.65 | 0.79 | 0.13 | 0.12 |
| 66 | Rosedale Ranch | 02025017 | 0 | 1.51 | 0.74 | --- | --- | 15.92 | --- | --- | --- | 80.86 | 0.93 | 0.02 | 0.02 |
| 67 | San Joaquin | 99003018 | 0.96 | 1.25 | 0.08 | --- | --- | 0.68 | --- | --- | --- | 83.95 | 4.13 | 4.72 | 1.62 |
| 68 | Semitropic | 02025008 | 0 | 0.48 | 0.27 | --- | --- | 0.98 | --- | --- | --- | 62.57 | 16.03 | 12.33 | 1.84 |
| 69 | Semitropic | 99003014 | 0 | 4.07 | 1.98 | --- | --- | 0.30 | --- | --- | --- | 87.97 | 1.92 | 3.05 | 0.34 |
| 70 | Semitropic | 99003013 | 0.23 | 3.23 | 0.84 | --- | --- | 0.14 | --- | --- | --- | 95.73 | 0.04 | 0.02 | --- |
| 71 | Stockdale | 02025011 | 0 | 2.00 | 0.88 | --- | --- | 0.91 | --- | --- | --- | 67.23 | 7.05 | 12.14 | 2.5 |
| 72 | Stockdale | 02025010 | 0 | 1.94 | 0.70 | --- | --- | 1.32 | --- | --- | --- | 75.90 | 3.79 | 8.6 | 1.81 |
| 73 | Stockdale | 02025009 | 0 | 3.29 | 0.99 | --- | --- | 1.50 | --- | --- | --- | 64.71 | 3.97 | 11.11 | 2.69 |
| 74 | Tejon, North | GGC-1176 | --- | 1.65 | --- | 0.129 | 0.012 | 0.08 | --- | --- | 0.001 | 76.20 | 7.57 | 4.77 | 0.986 |
| 75 | Tejon, North | 99003007 | 0 | 8.68 | 3.94 | --- | --- | 0.03 | --- | --- | --- | 81.99 | 4.01 | 1.15 | 0.16 |
| 76 | Trico | GGC-1153 | --- | 0.22 | --- | 0.02 | 0.003 | 0.50 | --- | --- | 0.001 | 99.00 | 0.033 | 0.002 | --- |
| 77 | Van Ness Slough | 99003016 | 0 | 2.93 | 0.94 | --- | --- | 0.85 | --- | --- | --- | 73.01 | 10.11 | 7.76 | 1.21 |
| 78 | Wheeler Ridge | GGC-1177 | --- | 5.43 | --- | 0.346 | 0.025 | 0.11 | --- | --- | 0.003 | 77.50 | 5.01 | 4.18 | 1.12 |
| 79 | Wheeler Ridge | GGC-1178 | --- | 0.93 | --- | 0.274 | 0.013 | 0.04 | --- | --- | --- | 79.20 | 8.76 | 5.15 | 0.863 |
| 80 | Wheeler Ridge | GGC-1179 | --- | 2.54 | --- | 0.291 | 0.022 | 0.02 | --- | 0.005 | 0.001 | 75.50 | 7.93 | 6.58 | 1.21 |
| 81 | wildcat well | M-4 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |

**Table 10.2 *B*.** Additional geochemical data of natural gas samples from the San Joaquin Basin Province, California.

[Sample information is given in table 10.1. Lab No., analysis number for U.S. Geological Survey Organic Geochemistry Laboratory, Denver, Colo., except numbers starting with GGC- (Jenden and Kaplan, 1989a) and M- (Claypool and others, 2000). Gas compositions are in mole percent. *n*-$C_4$, normal butane; *i*-$C_5$, isopentane (2-methyl butane); *n*-$C_5$, normal pentane; *neo*-$C_5$, neopentane (2,2-dimethyl propane); n-$C_6$, normal hexane; n-$C_7$, normal heptane; Wetness, percent $C_2$+, using the expression [($\Sigma C_2$ to C5)/($\Sigma$C1 to C5)]*100. $\delta^{13}C$ in per mil relative to Peedee belemnite standard; $\delta D$ in per mil relative to Standard Mean Ocean Water standard]

| Gas Sample Number | Field Name | *n* -$C_4$ % | *i* -$C_5$ % | *n* -$C_5$ % | neo-$C_5$ % | *n* -$C_6$ % | *n* -$C_7$ % | benzene % | wetness % | $\delta^{13}C_1$ ‰ | $\delta D$ $C_1$ ‰ | $\delta^{13}C_2$ ‰ | $\delta D$ $C_2$ ‰ | $\delta^{13}C_3$ ‰ | $\delta^{13}$ *i* -$C_4$ ‰ | $\delta^{13}$ *n* -$C_4$ ‰ | $\delta^{13}CO_2$ ‰ | $\delta^{13}C_5$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Ash Slough | --- | --- | --- | --- | --- | --- | --- | 0.47 | -47.78 | --- | --- | --- | --- | --- | --- | --- | --- |
| 2 | Belgian Anticline | 1.92 | 0.685 | 0.39 | --- | --- | --- | --- | 16.12 | -36.30 | -156 | -29.50 | -132 | -28.90 | --- | --- | --- | --- |
| 3 | Bellevue | 2.57 | 0.2 | 0.11 | --- | --- | --- | --- | 19.64 | -46.91 | --- | -29.78 | --- | -27.14 | --- | --- | --- | --- |
| 4 | Bellevue | 4.56 | 0.08 | 0.78 | --- | 0.3 | 0.1 | --- | 30.46 | -46.05 | --- | -30.45 | --- | -27.96 | -26.87 | -24.39 | --- | --- |
| 5 | Belridge North | 0.8 | 0.18 | 0.12 | --- | 0.03 | --- | --- | 9.04 | -37.46 | --- | -29.03 | --- | -27.38 | -25.15 | -24.42 | -0.03 | --- |
| 6 | Belridge South | 1.24 | 0.31 | 0.23 | --- | 0.07 | --- | --- | 6.36 | -41.30 | --- | -30.86 | --- | -29.56 | -28.24 | -25.14 | 9.29 | --- |
| 7 | Belridge South | 4.25 | 1.18 | 0.95 | --- | 0.29 | 0.02 | --- | 21.62 | -41.65 | --- | -28.63 | --- | -26.91 | -26.76 | -23.56 | 19.16 | --- |
| 8 | Belridge South | 0.21 | 0.02 | 0.02 | --- | --- | --- | --- | 0.92 | -44.96 | --- | --- | --- | --- | --- | --- | 20.65 | --- |
| 9 | Belridge South | 2.95 | 0.78 | 0.64 | --- | 0.23 | --- | --- | 27.04 | -42.13 | --- | -27.54 | --- | -27.78 | -28.33 | -25.15 | 8.12 | --- |
| 10 | Buena Vista | 1.68 | 0.49 | 0.36 | --- | 0.14 | --- | --- | 13.50 | -41.07 | --- | -27.12 | --- | -27.16 | -28.40 | -24.85 | 16.13 | --- |
| 11 | Buena Vista | 1.15 | 0.23 | 0.14 | --- | 0.02 | --- | --- | 10.38 | -42.91 | --- | -28.95 | --- | -26.66 | -22.12 | -21.73 | -0.76 | --- |
| 12 | Buena Vista | 0.79 | 0.18 | 0.15 | --- | 0.07 | --- | --- | 7.44 | -39.84 | --- | -24.12 | --- | -23.00 | -22.25 | -18.64 | 18.91 | --- |
| 13 | Buttonwillow | --- | --- | --- | --- | --- | --- | --- | 0.16 | -57.79 | --- | --- | --- | --- | --- | --- | --- | --- |
| 14 | Chowchilla | 0.009 | 0.006 | 0.004 | --- | --- | --- | --- | 1.17 | -34.00 | -143 | -36.80 | --- | --- | --- | --- | --- | --- |
| 15 | Chowchilla | --- | 0.001 | 0.001 | --- | --- | --- | --- | 0.03 | -53.80 | -199 | --- | --- | --- | --- | --- | --- | --- |
| 16 | Coalinga | 0.43 | 0.15 | 0.08 | 0.02 | 0.03 | --- | --- | 5.76 | -43.28 | --- | --- | --- | --- | --- | --- | -11.48 | --- |
| 17 | Coalinga | 3.85 | 0.89 | 0.56 | 0.02 | 0.19 | --- | --- | 26.21 | -48.46 | --- | -32.38 | --- | -31.09 | -31.89 | -28.47 | 13.71 | --- |
| 18 | Coalinga East Extension | 0.11 | 0.02 | 0.08 | --- | 0.04 | 0.02 | --- | 14.43 | -39.47 | --- | -31.06 | --- | -28.93 | --- | --- | -2.72 | --- |
| 19 | Coalinga East Extension | 2.17 | 0.52 | 0.48 | --- | 0.26 | 0.09 | 0.02 | 16.06 | -40.82 | --- | -29.44 | --- | -28.66 | -29.09 | -26.77 | -4.01 | --- |
| 20 | Coalinga, Oil City area | --- | 0.02 | --- | --- | --- | --- | --- | 0.50 | -38.65 | --- | --- | --- | --- | --- | --- | 21.40 | --- |
| 21 | Coles Levee, North | 1.35 | 0.16 | 0.12 | --- | --- | --- | --- | 14.03 | -42.73 | --- | -28.10 | --- | -27.60 | --- | --- | --- | --- |
| 22 | Coles Levee, South | 0.68 | 0.12 | 0.07 | --- | --- | --- | --- | 11.82 | -40.06 | --- | -26.17 | --- | -25.43 | --- | --- | --- | --- |
| 23 | Edison | --- | --- | --- | --- | --- | --- | --- | 0.66 | -42.73 | --- | --- | --- | --- | --- | --- | 16.65 | --- |
| 24 | Edison | --- | --- | --- | 0.02 | --- | --- | --- | 0.54 | -42.18 | --- | --- | --- | --- | --- | --- | 15.52 | --- |
| 25 | Edison | 0.49 | 0.72 | 0.02 | 0.03 | --- | --- | --- | 13.62 | -41.52 | --- | -28.83 | --- | -20.76 | -25.42 | -9.41 | 14.17 | --- |
| 26 | Edison | 0.37 | 1.1 | 0.005 | --- | --- | --- | --- | 7.86 | -39.10 | -255 | -27.40 | --- | -20.00 | --- | --- | 24.00 | --- |

**Table 10.2 *B*.** Additional geochemical data of natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | *n* -$C_4$ % | *i* -$C_5$ % | *n* -$C_5$ % | neo-$C_5$ % | *n* -$C_6$ % | *n* -$C_7$ % | benzene % | wetness % | $\delta^{13}C_1$ ‰ | $\delta D\ C_1$ ‰ | $\delta^{13}C_2$ ‰ | $\delta D\ C_2$ ‰ | $\delta^{13}C_3$ ‰ | $\delta^{13}$ *i* -$C_4$ ‰ | $\delta^{13}$ *n* -$C_4$ ‰ | $\delta^{13}CO_2$ ‰ | $\delta^{13}C_5$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | Elk Hills | 0.09 | --- | --- | --- | --- | --- | --- | 8.26 | -39.87 | --- | -25.75 | --- | -25.96 | --- | --- | --- | --- |
| 28 | Elk Hills | 0.04 | --- | --- | --- | --- | --- | --- | 1.06 | -42.12 | --- | --- | --- | --- | --- | --- | 16.24 | --- |
| 29 | Elk Hills | 0.28 | 0.02 | 0.02 | --- | --- | --- | --- | 3.47 | -51.10 | --- | -27.82 | --- | -24.11 | --- | --- | -4.34 | --- |
| 30 | Elk Hills | 1.45 | 0.43 | 0.37 | --- | 0.27 | 0.1 | 0.06 | 15.55 | -39.79 | --- | -25.34 | --- | -23.61 | -20.34 | -19.93 | -1.07 | --- |
| 31 | Fruitvale | --- | --- | --- | --- | --- | --- | --- | 0.43 | -43.23 | --- | --- | --- | --- | --- | --- | 18.23 | --- |
| 32 | Gill Ranch | 0.006 | 0.003 | 0.001 | --- | --- | --- | --- | 1.02 | -47.90 | -193 | -38.40 | --- | --- | --- | --- | --- | --- |
| 33 | Gill Ranch | --- | --- | --- | --- | --- | --- | --- | 0.83 | -45.83 | --- | --- | --- | --- | --- | --- | --- | --- |
| 34 | Greeley | 2.15 | 0.09 | 0.55 | --- | 0.42 | 0.18 | --- | 21.20 | -43.09 | --- | -30.06 | --- | -28.55 | -25.69 | -24.92 | --- | --- |
| 35 | Greeley | 8.14 | 0.15 | 1.33 | --- | 0.22 | --- | --- | 30.47 | -49.05 | --- | -27.60 | --- | -30.11 | -29.30 | -25.13 | --- | --- |
| 36 | Greeley | 4.34 | 0.07 | 0.87 | --- | 0.26 | --- | --- | 16.22 | -50.58 | --- | -25.46 | --- | -31.50 | -29.04 | -25.60 | 0.37 | --- |
| 37 | Greeley | --- | 0.03 | 0.17 | --- | 0.07 | --- | --- | 12.01 | -42.78 | --- | -30.13 | --- | -26.81 | -28.84 | -25.22 | -5.92 | --- |
| 38 | Helm | 1.16 | 0.18 | --- | --- | --- | 0.02 | 0.02 | 13.59 | -47.31 | --- | -30.92 | --- | -30.54 | --- | --- | --- | --- |
| 39 | Kern Bluff | --- | --- | --- | --- | --- | --- | --- | 0.00 | -56.28 | --- | --- | --- | --- | --- | --- | --- | --- |
| 40 | Kern River | 0.21 | 0.04 | 0.02 | 0.09 | --- | --- | --- | 34.85 | -48.71 | --- | --- | --- | --- | --- | --- | 32.70 | --- |
| 41 | Kettleman North Dome | --- | --- | --- | --- | --- | --- | --- | --- | -33.85 | --- | -28.37 | --- | -27.55 | --- | -27.42 | --- | -28.44 |
| 42 | Kettleman North Dome | --- | --- | --- | --- | --- | --- | --- | --- | -38.52 | --- | -28.22 | --- | -27.62 | --- | -27.46 | --- | -27.85 |
| 43 | Kettleman North Dome | --- | --- | --- | --- | --- | --- | --- | --- | -46.06 | --- | -29.18 | --- | -27.23 | --- | -26.82 | --- | -26.99 |
| 44 | Lost Hills | 1.48 | 0.02 | 0.2 | --- | 0.04 | --- | --- | 15.81 | -41.49 | --- | -29.08 | --- | -27.52 | -25.14 | -21.17 | --- | --- |
| 45 | Lost Hills | 1.53 | 0.27 | 0.31 | --- | 0.03 | --- | --- | 14.67 | -41.64 | --- | -30.19 | --- | -27.98 | --- | --- | --- | --- |
| 46 | Lost Hills, East | 0.63 | 0.21 | 0.12 | --- | 0.08 | 0.02 | 0.03 | 10.46 | -42.12 | --- | -25.51 | --- | -21.91 | -24.64 | -19.19 | -1.20 | --- |
| 47 | Merrill Avenue | --- | --- | --- | --- | --- | --- | --- | 0.53 | -47.78 | --- | --- | --- | --- | --- | --- | --- | --- |
| 48 | Merrill Avenue, SE | --- | --- | --- | --- | --- | --- | --- | 0.54 | -37.82 | --- | --- | --- | --- | --- | --- | --- | --- |
| 49 | Merrill Avenue, SE | --- | --- | --- | --- | --- | --- | --- | 0.31 | -24.19 | --- | --- | --- | --- | --- | --- | --- | --- |
| 50 | Midway-Sunset | 0.25 | 0.04 | 0.03 | --- | 0.03 | 0.02 | --- | 2.02 | -57.56 | --- | --- | --- | --- | --- | --- | 2.11 | --- |
| 51 | Mint Road | --- | --- | --- | --- | --- | --- | --- | 0.44 | -51.66 | --- | --- | --- | --- | --- | --- | --- | --- |
| 52 | Moffat Ranch | --- | --- | --- | --- | --- | --- | 0.04 | 0.25 | -54.75 | --- | --- | --- | --- | --- | --- | --- | --- |
| 53 | Moffat Ranch | 0.012 | 0.006 | 0.009 | --- | --- | --- | --- | 0.40 | -51.70 | -200 | -31.40 | --- | --- | --- | --- | --- | --- |
| 54 | Mount Poso | 0.2 | --- | --- | --- | --- | --- | --- | 1.02 | -48.62 | --- | --- | --- | --- | --- | --- | --- | --- |
| 55 | Mountain View | 2.91 | 0.03 | 0.35 | --- | 0.04 | --- | --- | 22.42 | -43.55 | --- | -29.03 | --- | -28.13 | -28.95 | -24.22 | --- | --- |
| 56 | Mountain View | 3.18 | 0.89 | 0.48 | --- | 0.09 | --- | --- | 25.29 | -45.48 | --- | -28.93 | --- | -27.67 | -27.47 | -22.75 | --- | --- |
| 57 | Mountain View | 3.37 | 0.04 | 0.45 | --- | 0.06 | --- | --- | 26.68 | -40.64 | --- | -28.30 | --- | -26.40 | -26.11 | -22.20 | --- | --- |
| 58 | Paloma | --- | --- | --- | --- | --- | --- | --- | 0.11 | -58.53 | --- | --- | --- | --- | --- | --- | --- | --- |

**Table 10.2 *B*.** Additional geochemical data of natural gas samples from the San Joaquin Basin Province, California—Continued.

| Gas Sample Number | Field Name | *n*-$C_4$ % | *i*-$C_5$ % | *n*-$C_5$ % | neo-$C_5$ % | *n*-$C_6$ % | *n*-$C_7$ % | benzene % | wetness % | $\delta^{13}C_1$ ‰ | $\delta D\ C_1$ ‰ | $\delta^{13}C_2$ ‰ | $\delta D\ C_2$ ‰ | $\delta^{13}C_3$ ‰ | $\delta^{13}$ *i*-$C_4$ ‰ | $\delta^{13}$ *n*-$C_4$ ‰ | $\delta^{13}CO_2$ ‰ | $\delta^{13}C_5$ ‰ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 | Paloma | --- | --- | --- | --- | --- | --- | --- | 0.08 | -57.02 | --- | --- | --- | --- | --- | --- | --- | --- |
| 60 | Paloma | 0.35 | 0.03 | --- | --- | --- | --- | --- | 12.69 | -39.75 | --- | -26.16 | --- | -24.76 | --- | --- | --- | --- |
| 61 | Pyramid Hills | 5.23 | 0.89 | 0.8 | 0.02 | 0.37 | 0.08 | --- | 37.14 | -37.73 | --- | -30.28 | --- | -29.25 | -27.51 | -25.67 | --- | --- |
| 62 | Pyramid Hills | --- | 0.03 | 0.02 | 0.02 | --- | --- | --- | 3.40 | -45.34 | --- | -29.65 | --- | --- | -26.10 | -25.15 | 12.81 | --- |
| 63 | Raisin City | 0.75 | 0.27 | 0.11 | --- | 0.02 | --- | --- | 4.80 | -53.52 | --- | -26.33 | --- | -28.03 | -30.13 | -24.41 | --- | --- |
| 64 | Raisin City | 0.21 | 0.02 | --- | --- | --- | --- | --- | 2.17 | -40.59 | --- | -33.72 | --- | --- | --- | --- | --- | --- |
| 65 | Raisin City | --- | --- | --- | --- | --- | --- | --- | 1.16 | -53.38 | --- | --- | --- | --- | --- | --- | --- | --- |
| 66 | Rosedale Ranch | --- | --- | --- | --- | --- | --- | --- | 1.19 | -40.36 | --- | -21.50 | --- | --- | --- | --- | 15.22 | --- |
| 67 | San Joaquin | 2.4 | 0.56 | 0.47 | --- | 0.05 | 0.03 | 0.05 | 14.21 | -56.62 | --- | --- | --- | --- | --- | --- | --- | --- |
| 68 | Semitropic | 4.08 | 0.71 | 0.51 | --- | 0.17 | 0.04 | --- | 36.20 | -46.77 | --- | -31.82 | --- | -27.98 | -27.61 | -22.92 | --- | --- |
| 69 | Semitropic | 0.36 | 0.02 | --- | --- | --- | --- | --- | 6.08 | -51.13 | --- | --- | --- | --- | --- | --- | --- | --- |
| 70 | Semitropic | --- | --- | --- | --- | --- | --- | --- | 0.06 | -67.99 | --- | --- | --- | --- | --- | --- | --- | --- |
| 71 | Stockdale | 6.41 | 0.06 | 0.73 | --- | 0.09 | --- | --- | 30.06 | -49.51 | --- | -26.57 | --- | -26.13 | -21.75 | -19.80 | --- | --- |
| 72 | Stockdale | 5.06 | 0.05 | 0.68 | --- | 0.16 | --- | --- | 20.86 | -55.48 | --- | -28.96 | --- | -29.78 | -28.09 | -24.40 | --- | --- |
| 73 | Stockdale | 8.39 | 1.97 | 1.36 | --- | --- | --- | --- | 31.31 | -54.97 | --- | -28.38 | --- | -28.87 | -27.44 | -23.21 | -5.92 | --- |
| 74 | Tejon, North | 1.61 | 0.6 | 0.49 | --- | --- | --- | --- | 17.38 | -38.20 | -155 | -26.80 | -134 | -24.70 | -24.80 | -23.30 | --- | --- |
| 75 | Tejon, North | 0.05 | --- | --- | --- | --- | --- | --- | 6.15 | -31.22 | --- | -22.87 | --- | --- | --- | --- | --- | --- |
| 76 | Trico | 0.001 | 0.001 | 0.001 | --- | --- | --- | --- | 0.04 | -70.20 | -203 | --- | --- | --- | --- | --- | -13.10 | --- |
| 77 | Van Ness Slough | 2.56 | 0.38 | 0.27 | --- | --- | --- | --- | 23.39 | -48.11 | --- | -31.01 | --- | -29.98 | --- | --- | --- | --- |
| 78 | Wheeler Ridge | 1.85 | 0.781 | 0.554 | --- | --- | --- | --- | 14.83 | -49.90 | -198 | -29.50 | -128 | -26.70 | --- | --- | --- | --- |
| 79 | Wheeler Ridge | 1.54 | 0.457 | 0.326 | --- | --- | --- | --- | 17.75 | -35.60 | -153 | -27.60 | -126 | -25.50 | --- | --- | --- | --- |
| 80 | Wheeler Ridge | 2.14 | 0.739 | 0.611 | --- | --- | --- | --- | 20.28 | -40.00 | -163 | -28.40 | -133 | -26.20 | -25.00 | -23.20 | --- | --- |
| 81 | wildcat well | --- | --- | --- | --- | --- | --- | --- | --- | -43.04 | --- | -30.29 | --- | -27.02 | --- | -25.32 | -8.73 | -25.14 |

**Table 10.3** Definition of gas types, San Joaquin Basin Province, California

| $C_1$ Stable Carbon Isotopes, ‰ | Wetness 0 to 2.5% | Wetness >2.5% |
|---|---|---|
| $\delta^{13}C$ > –45 | TD | TW |
| $\delta^{13}C$ –55 to –45 | TD-Mixed | TW-Mixed |
| $\delta^{13}C$ <–55 | B | TW-Mixed |

TD = thermogenic dry, TW = thermogenic wet, B = biogenic, mixed = mixture of biogenic and thermogenic gas.
Wetness = percent $C_2$+ or [($\Sigma C_2$ to $C_5$)/($\Sigma C_1$ to $C_5$)] * 100.