Chapter 4
Geochemistry of Natural Gases of the Anadarko Basin

By Geoffrey S. Ellis

Chapter 4 of 13
Petroleum Systems and Assessment of Undiscovered Oil and Gas in the Anadarko Basin Province, Colorado, Kansas, Oklahoma, and Texas—USGS Province 58
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Contents

Figures

Tables

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Abstract

The sources and timing of natural gas generation as well as the migration pathways that lead to the distribution of gas accumulations throughout the Anadarko Basin Province were investigated using a geochemical dataset from more than 400 natural gas wells. The molecular and stable isotopic composition of the hydrocarbon gases indicate that there is no significant contribution of gas from abiogenic sources, and that the majority of the gases are derived from thermal maturation of organic matter. Limited contributions from microbial sources may be possible in localized areas, but this is not thought to be a significant source of gas in the province. The molecular and stable carbon and hydrogen isotopic compositions of the hydrocarbon gases indicate mature (oil window) to post mature (dry gas window) sources for gas generation, which is consistent with the findings of previous studies. Gases produced from the deepest reservoirs in the central Anadarko Basin show evidence for gas contributions from oil cracking. The geochemistry of the gases produced from the giant Panhandle Hugoton fields is remarkably homogeneous and likely reflects a single Early Mississippian or older source in the central Anadarko Basin. Uncommonly high concentrations of nitrogen are encountered in the Panhandle and Hugoton fields, and are derived from a mixture of crustal sources and thermally mature sedimentary organic matter. Gas reservoirs in the central Kansas uplift are also thought to be primarily sourced from lower Paleozoic source rocks in the central Anadarko Basin and charged via long distance migration (several hundred miles). Locally sourced, early thermogenic gas may constitute a small portion of the gas accumulations in the central Kansas uplift and Panhandle Hugoton regions. Sooner trend gas production is associated with Woodford Shale-sourced oil, and these hydrocarbons are not likely to have been generated locally but rather migrated from deeper portions of the central Anadarko Basin.

Introduction

The Anadarko Basin Province covers an area of approximately 58,000 square miles of southwestern Kansas, northwestern Oklahoma, southeastern Colorado, and northern parts of the Texas Panhandle (fig. 1). The province includes the Anadarko Basin which is bounded by the Nemaha ridge to the east, the Amarillo-Wichita uplift to the south, and a broad shallow shelf (Hugoton embayment) to the west and northwest of the basin proper (Higley, 2014). The Anadarko Basin is one of the deepest basins on the North American craton, containing in excess of 40,000 feet of Paleozoic sedimentary rocks (Ham and Wilson, 1967); it is also the setting for the Bertha Rogers 1 well, which at a total depth of 31,441 feet (9,583 meters) is the deepest well ever drilled in the United States (Johnson and others, 1988).

Oil and gas development in the province dates back to the early 1900s. It contains one of the largest commercial accumulations of hydrocarbons in the United States (Petroleum Information Corporation, 1982); as of mid-2011, the Anadarko Basin Province has produced approximately 5 billion barrels of oil and 150 trillion cubic feet of natural gas (IHS Energy, 2011). In 2009, the Hugoton gas field was ranked the 9th largest natural gas accumulation in the United States in terms of proved reserves (Energy Information Administration, 2010). The 2011 U.S. Geological Survey (USGS) assessment of the Anadarko Basin Province estimated the mean undiscovered technically recoverable resource potential to be 495 million barrels of oil, 27.5 trillion cubic feet of gas, and 410 million barrels of natural gas liquids (Higley and others, 2011).

The objectives of this study are to provide a better understanding of (1) the sources and timing of natural gas generation, and (2) the migration pathways that lead to the distribution of gas accumulations throughout the Anadarko Basin Province. To achieve these objectives, a review of the published literature on the geochemistry of natural gases produced from the Anadarko Basin Province was conducted and a suite of gas samples was collected and analyzed to augment existing datasets.

Geologic Setting and Gas Geochemistry

The geologic evolution of the Anadarko Basin Province is described by Higley (2014) and only a brief overview is provided herein. The Anadarko Basin is structurally asymmetric with a deep northwest-southeast trending axis at the south margin that parallels the Amarillo–Wichita Mountain front, and a broad shallow shelf region to the north and west
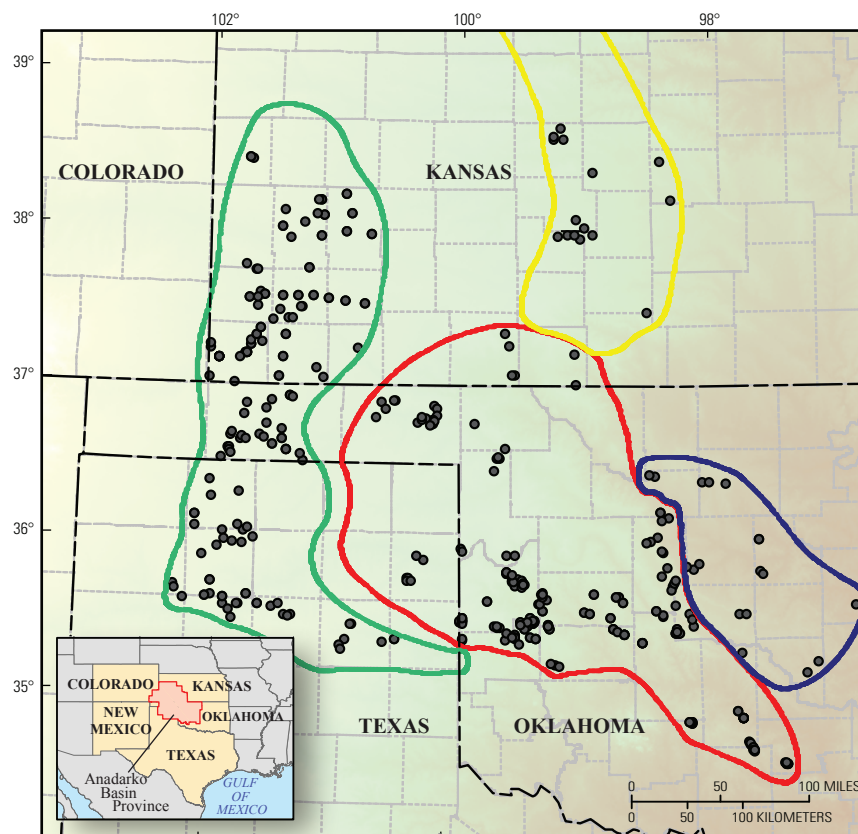
Figure 1.   Map showing the locations of the Anadarko Basin Province (red line on inset map) and the interpretive regions used in this study: central Anadarko Basin (red line), Panhandle-Hugoton field (green line), Sooner trend (blue line), and central Kansas uplift (yellow line). The boundaries of the interpretive regions are modified from Rice and others (1988b) and Jenden and others (1988). The well locations for the gas geochemistry data used in this study are shown as black circles.

(Adler, 1971). From the late Precambrian through the Middle Cambrian, what is now the southern midcontinent of North America, experienced extensive igneous activity and graben formation related to thermally driven rifting (Ham and others, 1964). The present-day Anadarko Basin is thought to have developed on the southern Oklahoma aulacogen that formed during the Middle to Late Cambrian (Shatski, 1946; Burke, 1977; Hoffman and others, 1989). From the Late Cambrian through the Mississippian, this region experienced an epeirogenic phase that was characterized by shallow marine sedimentation in an epicontinental sea (Craig and Varnes, 1979; Frezon and Jordan, 1979; Johnson and others, 1988). Pennsylvanian time brought about dramatic changes to the Anadarko Basin as regional orogenic activity produced significant folding, faulting, and subsidence. Basin fill was initially provided by the uplifting Amarillo-Wichita block to the south, followed later by development of the Nemaha uplift to the east and the Cimarron arch to the northwest, resulting in the deposition of as much as 18,000 feet of

clastic and carbonate sediments (Johnson, 1989). The post-Pennsylvanian sedimentary record within the Anadarko Basin is dominated by Permian red beds, carbonates and evaporites (Jordan and Vosburg, 1963; McKee and others, 1967; Johnson and others, 1988). Sedimentary deposition during the Mesozoic and Cenozoic produced a relatively thin sequence of strata that has been partially or completely eroded throughout extensive parts of the province (Johnson and others, 1988; Johnson, 1989). The generalized stratigraphy of the Anadarko Basin Province is shown in figure 2.

Several organic-rich lithologies have been identified as potential petroleum source rocks in the province (Bartram and others, 1950; Hatch and others, 1986; Johnson and Cardott, 1992; Wang and Philp, 1997), with the Upper Devonian and Lower Mississippian Woodford Shale widely recognized as the most significant source (Hatch and others, 1986; Comer and Hinch, 1987; Rice and others, 1988b; Johnson and Cardott, 1992; Wang and Philp, 1997). The total organic carbon (TOC) content in the Woodford Shale

is reported to range from less than 0.1 weight percent (wt %) to in excess of 25 wt % (Webb, 1976; Comer and Hinch, 1987). Hydrogen index values, determined from Rock Eval pyrolysis of outcrop samples of relatively low thermal maturity, are reported to range from approximately 250 to 850 milligrams of hydrocarbon per gram of total organic carbon (mg HC/g TOC) (Johnson and Cardott, 1992), and the kerogen is predominantly oil-prone Type II (Lewan, 1983; Cardwell, 1985). A number of Pennsylvanian marine shales are also recognized as important petroleum source rocks in the Anadarko Basin, including (1) the Lower Pennsylvanian Morrow Group that has TOC contents ranging from about 0.5 to greater than 10 wt % (average TOC = 1.7 wt %) and hydrogen index values ranging from 15 to 179 mg HC/g TOC (average HI = 46 mg HC/g TOC) (Higley, 2014), which is indicative of a gas-prone source rock; and (2) the Middle and Upper Pennsylvanian shales (Atokan, Desmoinesian, and Virgilian) that are characterized as having good hydrocarbon generation potential (Johnson and Cardott, 1992), with TOC contents ranging from 6 to 18 wt % and kerogen that is predominately Type II (oil prone) (Hatch and others, 1986).

The Ordovician Simpson and Viola Groups and the Sylvan Shale have all been proposed to be potential viable source rocks in the province (Johnson and Cardott, 1992). Burruss and Hatch (1989) studied the Simpson and Viola Groups and reported that, although the TOC contents are generally less than 1 wt %, some samples from the Kansas shelf are as high as 9 wt %, and that Rock-Eval pyrolysis data show the kerogen to be a mixture of Types I and II. Overall, the authors concluded that the source rock potential of the Simpson and Viola Groups is poor to moderate within the Anadarko Basin proper and a little better on the Kansas shelf. Although the Upper Ordovician Sylvan Shale contains oil-prone Type II kerogen, TOC contents are generally less than 1 wt % and the source rock potential is reported to be poor to moderate (Johnson and Cardott, 1992; Wang and Philp, 1997). Early studies of the occurrence of oil and gas in the Upper Cambrian and Lower Ordovician Arbuckle Group indicated a potential indigenous source for the hydrocarbons (Bartram and others, 1950; Webb, 1976); however, subsequent work has shown that these accumulations were sourced from younger strata and the Arbuckle Group is no longer thought to have contributed significant amounts of petroleum to the province (Cardwell, 1985; Jones and Philp, 1990).

Several previous studies have examined the geochemistry of produced natural gases from the Anadarko Basin Province (Moore, 1982; Hatch and others, 1986; Jenden and others, 1988; Rice and others, 1988b, 1988a, 1989; Price, 1995). From 1917 through 1980 the U.S. Bureau of Mines collected more than 10,000 samples of produced natural gases from across the United States and analyzed them for their chemical composition. Of those samples, more than 2,500 were collected from the Anadarko Basin Province (Moore, 1982). Researchers from the USGS examined the molecular and stable isotopic composition (δ^{13}C and δ^2H) of produced gases from the central Anadarko Basin, the Sooner trend, and the Panhandle-Hugoton

fields in efforts to characterize the source, thermal maturity, and migration pathways of the gas accumulations in the Anadarko Basin Province (Hatch and others, 1986; Rice and others, 1988b, 1988a, 1989). Jenden and others (1988) studied the geochemistry of produced natural gas from Kansas, which includes the northeastern portion of the Hugoton field, to determine the mechanisms of formation for the gas accumulations in that state. A subsequent study by Price (1995) of how deep, high-thermal maturity gas accumulations may have formed focused in part on the geochemistry of natural gases from the deep portion of the central Anadarko Basin. The present report provides new geochemical data from producing gas wells in the Anadarko Basin Province and offers an interpretation of their significance in light of these previous studies.

Methods

Gas Sample Collection

A total of 96 produced natural gas samples were collected at or near the individual well heads. Well locations were selected such that only those wells that produce from a single stratigraphic interval were sampled (that is, no commingled gases), and a representative spatial distribution through the central Anadarko Basin was achieved. All gases were collected in Isotubes® following the protocol established by Isotech, Inc. (*http://www.isotechlabs.com/customersupport/samplingprocedures/WellSM.pdf*). Once collected, gas samples were immediately shipped to the USGS Organic Geochemistry Laboratory in Denver, Colorado, for analysis.

Analytical Techniques

The molecular composition of the gases was determined using an Agilent 6890 gas chromatograph (GC) (Agilent Technologies) customized for the analysis of light natural gas components (Wasson ECE Instrumentation). The instrument contains eight columns and three detectors [two thermal conductivity detectors (TCD) and one flame ionization detector (FID)], allowing for the analysis of both hydrocarbon and nonhydrocarbon components in a single injection. One TCD uses nitrogen as the carrier gas, and the other TCD and the FID use helium as carrier gas. Analytes that are routinely quantitated include: methane, ethane, ethylene, propane, propylene, n-butane, i-butane, isobutene, 1-butene, cis-2-butene, trans-2-butene, n-pentane, i-pentane, neopentane, n-hexane, benzene, n-heptane, carbon dioxide, carbon monoxide, nitrogen, helium, hydrogen, and hydrogen sulfide. Oxygen and argon are detected but are reported together because of coelution. The minimum reporting level for all analytes is 0.01 mole percent (mol %). Instrument calibration is based on four separate standard reference-gas mixtures and the concentrations of all components are verified to be within 0.6 mol % of the known values. For all analytes of interest in this study, the standard
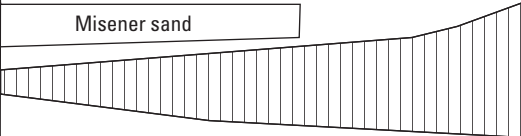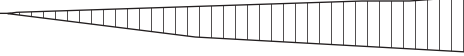
System	Series	Lithostratigraphic Unit (Hydrocarbon Source Rocks in Brown)		Relative Hydrocarbon Source Rock Potential (1-5)	More Oil- or Gas-Prone
Permian (part)	Leonardian	Sumner Gp; Enid Gp.; Hennessey Gp.			
	Wolfcampian	Chase Group Council Grove Group Admire Group	Pontotoc Group		
Pennsylvanian	Virgilian	Wabaunsee Group Shawnee Group	Ada Group		
		Douglas Group			
	Missourian	Lansing Group Kansas City Group	Hoxbar Group	1-2	🔴 Gas 🟢 Oil
	Desmoinesian	Marmaton Group Cherokee Group	Deese Group	1-2	🔴 Gas 🟢 Oil
	Atokan	Atoka Gp.; Thirteen Finger lime		1-2	🔴 Gas 🟢 Oil
	Morrowan	Morrow Gp./Fm.; lower Dornick Hills Gp.		2-3	🔴 Gas 🟢 Oil
Mississippian	Chesterian	Springer Formation Chester Group	Mayes Group	1-2	🔴 Gas 🟢 Oil
	Meramecian	Meramec lime			
	Osagean	Osage lime		2	🔴 Gas 🟢 Oil
	Kinderhookian	Kinderhook Shale			
Devonian	Chautauquan	Woodford Shale, Chattanooga Shale		5 +	🔴 Gas 🟢 Oil
	Senecan Erian Ulsterian	Misener sand			
Silurian	Cayugan Niagaran Alexandrian	Hunton Group			
Ordovician	Cincinnatian	Sylvan Shale; Maquoketa Shale			
		Viola Group/Formation		2	🔴 Gas 🟢 Oil
	Champlainian	Simpson Group		1-2	🔴 Gas 🟢 Oil
	Canadian	Arbuckle Group		?	??
Cambrian (part)	Trempealeauan	Reagan Sandstone			
	Franconian				

Figure 2.   Generalized stratigraphic column for the Anadarko Basin Province with oil and gas source rocks highlighted (red text). Greater source rock potential is indicated by larger numbers. The expected hydrocarbons header indicates whether the source rock is more oil- or gas-prone (Burruss and Hatch, 1989; J. Hatch, oral communication, 2010). Vertical lines show a generalized time range of unconformity from Bebout and others (1993, fig. 5). Gp., Group; Fm., Formation.

deviation of replicate analyses (n=19) of the gas standards ranged from 0.00 to 0.67 mol % and averaged 0.15 mol %.

Where a sufficient quantity of gas was available, the $^{13}C/^{12}C$ ratio of the methane, ethane, and propane of the natural gas samples was determined using a method modeled after Baylis and others (1994). A natural gas sample is introduced from a custom-built autosampler into an Agilent 6890 GC (Agilent Technologies) through a sample-loop injector of variable size. Gas components are chromatographically separated on a 50-meter (m) x 0.32-millimeter (mm) x 5-micrometer (mm) PoraBond-Q column (Agilent Technologies). Typical GC conditions are as follows: helium carrier gas at 1.5 milliliters per minute (mL/min); 40 degrees Celsius (°C) initial temperature; hold for 6 minutes; ramp to 150 °C at 15 degrees Celsius per minute (°C/min); ramp to 250 °C at 30 °C/min; hold for 5 minutes. The individual components are then combusted in the helium stream [with a small addition of (O_2)] at 1,050 °C in an in-line Alsint-99.7 ceramic reactor [0.5-mm inner diameter (I.D.) x 6-mm outer diameter (O.D.) x 500-mm length]. The resulting combustion products [primarily (CO_2) and (H_2O)] are passed through an in-line Nafion® drier to remove H_2O, and the final analyte CO_2 is passively drawn via open split into the source of a GV-Elementar IsoPrime isotope ratio mass spectrometer for subsequent carbon isotope analysis.

Carbon isotope values from the instrument undergo offline isotope corrections for drift from isotopic linearity because of any systematic error in the autosampler, chromatographic, and oxidation processes. Drift-corrected values are then normalized on the Vienna Pee Dee Belemnite (VPDB) scale using two well-calibrated, working laboratory methane standards. On average, for every 6 samples run in replicate (n = 3, 18 total determinations), 6 or more analyses of standards are performed to ensure proper analytical calibration. The final carbon isotope values represent the average of multiple replicate analyses (generally, n=3) with a standard deviation of generally better than 0.2 per mil (‰). All final $\delta^{13}C$ values are reported relative to the international standard VPDB.

The $^2H/^1H$ ratio of methane in the gas samples was determined using a method modeled after Burgøyne and Hayes (1998). A natural gas sample is introduced into an Agilent 6890 GC via an autosampler through a sample-loop injector. Methane is chromatographically separated on a 30-m x 0.32-mm x 1-mm Porplot-Q column (Agilent Technologies). The following GC conditions are used: helium carrier gas at 1 mL/min; 65 °C initial temperature; hold for 12 minutes; ramp to 225 °C at 25 °C/min; hold for 5 minutes. The eluent methane is then pyrolyzed in the helium stream at 1,450 °C in an in-line Alsint-99.7 ceramic reactor (0.5-mm I.D. x 6-mm O.D. x 500-mm length). The resulting H_2 analyte is passively drawn via open split into the source of a GV-Elementar IsoPrime isotope ratio mass spectrometer for subsequent hydrogen isotope analysis.

Raw delta values from the instrument were drift corrected for isotopic nonlinearity because of temporal variations in the autosampler, the GC, and the physical chemistry of the ceramic pyrolysis reactor, and then were normalized to the internationally accepted standard mean ocean water-standard light arctic precipitation (SMOW-SLAP) hydrogen isotope scale using two calibrated, working laboratory methane standards. On average, for every 5 replicate analyses of 5 samples (n = 5, 25 total determinations), 50 analyses of standards were performed to ensure proper analytical calibration. The final hydrogen isotope values represent the average of multiple replicate analyses (n=5) with a standard deviation of better than 1 ‰. All final δ^2H values are presented relative to the international standard, Vienna Standard Mean Ocean Water (VSMOW).

Results

For the purposes of this study, natural gas production from the Anadarko Basin Province is considered in four separate regions within the province. Rice and others (1988b) suggested that, on the basis of the age of the reservoir rocks, type of trap, and the composition and origin of the gases, three distinct areas of the Anadarko Basin Province can be defined as: the central Anadarko Basin, the Panhandle-Hugoton field, and the Sooner trend. In their study of the gases of Kansas, Jenden and others (1988) distinguished between the gases of the Hugoton embayment and the central Kansas uplift on the basis of the regional geology and their interpreted origin of the gases in each region. In the present study, the Hugoton embayment gases are included with the Panhandle-Hugoton field gases and the central Kansas uplift constitutes the fourth region (in addition to the 3 regions identified by Rice and others, 1988b). The spatial distribution of these four regions is shown in figure 1.

Gas Molecular Composition

The U.S. Bureau of Mines natural gas study (Moore, 1982) contains approximately 2,300 gas wells from within the four regions of the Anadarko Basin Province (the central Anadarko Basin, the Panhandle-Hugoton field, the Sooner trend, and the central Kansas uplift). Because this dataset is too extensive to include here, the results from these samples are summarized (minimum, maximum, and average values) in table 1.

Of the 96 gas samples that were collected and sent to the laboratory for this study, 10 contained an insufficient amount of gas to allow for accurate molecular compositional analysis and no data were generated. Two additional samples contained greater than 10 mol % air and were deemed too contaminated to be useful; the associated data for these two wells are not included in this report. Of the remaining 84 samples, 11 contained oxygen plus argon concentrations that indicated levels of air contamination that were less than 10 mol % but were higher than the expected "background" concentration of oxygen plus argon in produced natural gases from the Anadarko

Basin Province. The "background" concentration of oxygen plus argon in Anadarko Basin Province gases was determined by examining natural gas compositional data from 4,117 wells within the Anadarko Basin and surrounding provinces (Moore, 1982). The sum of the mean oxygen (0.10 ± 0.34 mol %) and argon (0.02 ± 0.10 mol %) concentrations plus one standard deviation (0.55 mol %) was taken to be the maximum expected "background" oxygen-plus-argon concentration. For the samples that contained oxygen-plus-argon concentrations that exceeded the maximum "background" level, the "background" concentration (0.55 mol %) was subtracted and the remainder was assumed to be because of air contamination. The nitrogen concentration was then corrected for the assumed air contamination based on the atmospheric abundances of nitrogen (78.08 volume %) and oxygen plus argon (21.88 volume %). The concentrations of all of the gas components were then renormalized to 100 percent using the "air-free" nitrogen value. The gas wetness was calculated on an "air-free" basis using the following equation:

$$Wetness = \frac{C_2 + C_3 + nC_4 + iC_4 + nC_5 + iC_5}{C_1 + C_2 + C_3 + nC_4 + iC_4 + nC_5 + iC_5}$$

where C_1 = mol % methane, C_2 = mol % ethane, C_3 = mol % propane, nC_4 = mol % normal butane, iC_4 = mol % isobutane, nC_5 = mol % normal pentane, and iC_5 = mol % isopentane. The molecular compositional data for the gas samples collected for this study are shown in table 2.

In addition to the data generated from the samples collected for this study, published data from producing gas wells in the central Anadarko Basin are included in table 2. These include 49 wells from Jenden and Kaplan (1989a),

6 wells from Jenden and others (1988), and 89 wells from Rice and others (1988a). To fully characterize the geochemistry of produced gases from the Anadarko Basin Province additional published data from other parts of the province are included in this report. Table 3 contains molecular compositional data for gases produced from the Panhandle-Hugoton field in the Texas and Oklahoma panhandles and southwestern Kansas. These include 31 wells from Ballentine and Sherwood Lollar (2002), 72 wells from Jenden and Kaplan (1989a), 27 wells from Jenden and others (1988), and 36 wells from Rice and others (1988a). Table 4 contains molecular compositional data for 18 gases produced from the Sooner trend on the eastern flank of the Anadarko Basin (Rice and others, 1988a). Table 5 contains molecular compositional data for produced gases from 15 wells in the central Kansas uplift at the north end of the Anadarko Basin Province (Jenden and others, 1988). Four wells identified by Jenden and others (1988) as being part of the Hugoton field (Dutton 1-17, Embry Lease, Chalk A 1-18, and Enlow-Miller #1) are considered here to be part of the central Kansas uplift given their proximity to other wells in this region (about 5 miles to the nearest central Kansas uplift well and about 80 miles to the nearest Hugoton well).

Stable Isotopic Composition

Of the 84 samples analyzed for molecular composition, 9 did not contain a sufficient quantity of gas to allow for determination of the $\delta^{13}C$ composition of methane, ethane, or propane. One of the remaining 75 samples contained concentrations of ethane and propane that were too low to allow

Table 1.   Molecular compositional data (in mole percent) for natural gases from the Anadarko Basin Province by region.

[N$_2$, nitrogen; CO$_2$, carbon dioxide; H$_2$, hydrogen; He, helium; C$_1$, methane; C$_2$, ethane; C$_3$, propane; n-C$_4$, n-butane; i-C$_4$, i-butane; n-C$_5$, n-pentane; i-C$_5$, = i-pentane; CYC 5, cyclopentane; CYC 6, cyclohexane; Wet, gas wetness; Min, minimum; Max, maximum; Avg, arithmetic mean. Data are from Moore (1982)]

Region	Number of samples		N$_2$	CO$_2$	H$_2$	He	C$_1$	C$_2$	C$_3$	n-C$_4$	i-C$_4$	n-C$_5$	i-C$_5$	CYC 5	CYC 6	Wet
Central Anadarko Basin	1282	Min	0.00	0.00	0.00	0.00	22.90	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
		Max	27.40	10.90	6.60	0.97	98.10	26.50	27.00	14.60	6.70	3.80	9.30	1.50	0.00	77.01
		Avg	1.73	0.78	0.04	0.07	88.25	5.09	2.22	0.64	0.34	0.18	0.23	0.08	0.00	9.28
Panhandle Hugoton Fields	848	Min	0.40	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Max	99.00	11.60	0.90	2.82	96.50	29.40	19.50	6.90	3.30	6.50	4.40	1.00	0.00	98.39
		Avg	14.62	0.24	0.03	0.50	72.59	6.68	3.08	0.93	0.44	0.23	0.24	0.06	0.00	14.23
Sooner Trend	122	Min	0.00	0.00	0.00	0.00	41.10	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.82
		Max	16.20	3.50	0.10	0.57	96.50	26.80	18.40	8.50	2.90	3.40	2.20	0.70	0.00	58.69
		Avg	2.28	0.32	0.02	0.06	84.10	7.12	3.35	1.09	0.47	0.36	0.28	0.11	0.00	13.49
Central Kansas Uplift	57	Min	1.30	0.00	0.00	0.10	34.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
		Max	50.20	4.10	0.60	4.66	94.60	24.60	5.10	3.60	0.90	1.20	0.60	0.20	0.00	29.50
		Avg	11.71	0.32	0.05	0.74	79.78	4.48	1.35	0.52	0.24	0.17	0.14	0.06	0.00	8.61

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1+C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Cattle #1-34	Atoka	95.80	1.64	0.32	0.12	0.14	ND	ND	ND	1.24	1.08	2.26%	–42.90	–32.20	ND	–139	1
Welks #1-17	Red Fork	87.80	3.04	0.59	0.07	0.14	ND	ND	ND	1.07	1.69	4.18%	–43.20	–32.50	ND	–136	1
Allison #1-3	L. Atoka	95.00	1.98	0.26	0.03	0.04	ND	ND	0.00	0.88	1.07	2.38%	–42.80	–34.30	ND	–147	1
Allison #1-3	L. Atoka	95.00	2.01	0.32	0.04	0.05	ND	ND	0.00	1.70	0.90	2.48%	–42.70	–34.40	ND	ND	1
Allison #1-3	L. Atoka	96.30	2.10	0.98	ND	ND	ND	ND	0.00	0.86	0.42	3.10%	ND	ND	ND	ND	1
Ashby #1-36	L & M Atoka	78.00	8.80	3.60	0.64	0.46	ND	ND	0.00	0.66	1.97	14.75%	–48.10	–34.30	ND	–162	1
Baker #1-20	Red Fork	91.00	4.19	0.63	0.08	0.13	ND	ND	0.00	1.06	1.34	5.24%	–42.30	–32.90	ND	–133	1
Barham #1-32	Morrow	94.00	0.46	0.04	0.00	ND	ND	ND	0.00	1.41	1.76	0.53%	–38.50	ND	ND	–135	1
Berry #1-8	U. Morrow	93.00	0.56	0.56	ND	ND	ND	ND	0.00	1.58	1.32	1.19%	–38.30	ND	ND	–139	1
Bull Elk #1	L. Springer	94.10	0.95	0.12	0.01	0.00	ND	ND	0.00	0.96	1.76	1.14%	–41.40	–35.90	ND	–145	1
Canyon Camp #1	Red Fork	84.50	8.30	2.80	0.49	0.39	ND	ND	0.00	0.82	1.15	12.42%	–46.70	–33.30	ND	–152	1
Clark #1-33	Morrow	95.90	0.45	0.04	0.01	0.00	ND	ND	0.00	1.41	1.34	0.51%	–38.20	–36.10	ND	–147	1
Cornstalk #1	Springer	87.10	2.67	0.75	0.10	0.12	ND	ND	0.00	1.04	1.94	4.01%	–41.90	–34.60	ND	–142	1
Coulson #5-1	L. & M. Atoka	91.10	2.30	0.45	0.04	0.08	ND	ND	0.00	1.12	2.44	3.06%	–43.00	–31.30	ND	–151	1
Dugger #1-18	Morrow	89.90	0.30	0.01	ND	ND	ND	ND	0.00	2.45	1.71	0.35%	–38.10	ND	ND	–140	1
Farrar #2-22	Puryear	93.20	0.50	0.04	0.00	ND	ND	ND	0.00	1.25	1.86	0.58%	–38.20	ND	ND	–133	1
Flaming #1-20	Springer	88.90	2.17	0.97	0.18	0.13	ND	ND	0.00	1.29	1.83	3.73%	–40.70	–36.50	ND	–149	1
Flaming #1-20	Springer	92.90	0.62	0.08	0.01	0.01	ND	ND	0.00	1.63	0.92	0.76%	–38.90	–35.70	ND	–148	1
Foundation #1-16	Springer	89.00	0.52	0.07	ND	0.00	ND	ND	0.00	1.25	0.83	0.66%	–39.40	ND	ND	–139	1
Gregory #1-12	L. & M. Atoka	93.00	1.59	0.35	0.08	0.18	ND	ND	0.00	1.13	1.00	2.31%	–43.90	–31.20	ND	–145	1
Gregory #2-27	Morrow	91.20	0.52	0.04	0.00	0.00	ND	ND	0.00	1.49	1.52	0.62%	–38.20	–36.60	ND	–133	1
Hamberger #1-9	Springer	96.60	0.76	0.12	ND	0.01	ND	ND	0.00	1.38	1.65	0.91%	–39.00	–35.50	ND	–142	1
Harris #2	Bromide 3	83.60	8.50	3.81	0.87	0.56	ND	ND	0.00	0.67	1.86	14.11%	–46.90	–34.70	ND	–161	1
Hazlett #1-21	Red Fork	82.00	9.13	3.20	0.59	0.46	ND	ND	0.00	0.71	1.46	14.03%	–46.90	–32.80	ND	–158	1
Hintchel #1	Springer	87.50	2.34	0.57	0.06	0.06	ND	ND	0.00	1.03	2.24	3.35%	–40.30	–34.50	ND	–146	1
Holder #1A	Bromide A	82.00	9.13	3.20	0.66	0.46	ND	ND	0.00	0.44	0.89	14.09%	–47.00	–34.80	ND	–158	1
Holder #1A	Arbuckle	85.60	4.13	1.90	0.67	0.31	ND	ND	0.00	0.33	1.02	7.57%	–45.40	–34.90	ND	–156	1

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and $\delta^{2}H$ values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_{1}+C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. $\delta^{2}HC_1$ is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	$\delta^{2}HC_1$	S
Jones #1-17	Boatwright	92.00	2.20	0.77	0.13	0.11	ND	ND	0.00	0.87	1.25	3.37%	−39.50	−34.30	ND	−143	1
Kardokys #10-1	Morrow	95.10	0.71	0.14	0.02	0.01	ND	ND	0.00	1.68	0.84	0.92%	−38.70	−35.10	ND	−148	1
Kardokys #10-1	Permian Lm	96.50	0.69	0.13	0.02	0.01	ND	ND	0.00	1.52	0.88	0.87%	−38.80	−34.90	ND	−147	1
Marik #1-11	L. Desmoinesian	84.70	5.90	2.10	0.41	0.34	ND	ND	0.00	0.93	4.35	9.36%	−46.40	−34.80	ND	−150	1
McConnel #1-34	L. & M. Atoka	92.00	1.55	0.27	0.08	0.04	ND	ND	0.00	0.95	0.87	2.07%	−42.30	−34.30	ND	−149	1
McKay #1	Red Fork	83.00	9.48	2.29	0.42	0.34	ND	ND	0.00	1.77	1.33	13.12%	−46.70	−32.80	ND	−159	1
Palmer #1-17	Red Fork	83.50	6.70	2.90	0.57	0.43	ND	ND	0.00	0.76	1.35	11.26%	−45.90	−35.10	ND	−153	1
Parker #1	Springer	89.90	1.08	0.16	0.01	0.01	ND	ND	0.00	1.02	2.11	1.37%	−43.00	−36.30	ND	−136	1
Partain #1-6	Red Fork	82.10	4.56	0.96	0.13	0.20	ND	ND	0.00	1.35	7.10	6.66%	−45.00	−30.90	ND	−152	1
Ranch #1-15	Morrow	85.50	6.50	2.80	0.57	0.36	ND	ND	0.00	0.68	1.64	10.69%	−49.20	−38.30	ND	−154	1
Rayner #1	Springer	93.00	1.61	0.57	0.10	0.08	ND	ND	0.00	1.05	1.34	2.47%	−39.90	−34.90	ND	−144	1
Rice #1-35	Springer	94.00	0.17	0.01	ND	ND	ND	ND	0.00	2.89	1.90	0.19%	−33.20	ND	ND	−154	1
Rice #1-35	Morrow	93.80	1.87	0.01	ND	ND	ND	ND	0.00	3.50	1.00	1.96%	−33.20	ND	ND	ND	1
Rymer #1	Morrow	87.20	5.04	1.32	0.24	0.29	ND	ND	0.00	0.78	1.17	7.32%	−43.00	−32.70	ND	−149	1
Ten Bears #1	Springer	95.10	0.91	0.11	0.01	ND	ND	ND	0.00	1.04	0.71	1.07%	−40.00	−34.40	ND	−144	1
Thornton #2-30	Morrow	93.00	0.43	0.04	ND	ND	ND	ND	0.00	1.52	0.88	0.50%	−37.80	ND	ND	−131	1
Thurmond #1-27	Atoka	91.40	1.67	0.32	0.07	0.13	ND	ND	0.00	1.14	1.26	2.33%	−43.10	−31.90	ND	−137	1
Thurmond #1-32	Red Fork	86.90	4.90	1.50	0.22	0.25	ND	ND	0.00	0.94	1.76	7.33%	−44.50	−34.10	ND	−145	1
Washita #1	Springer	94.20	1.12	0.10	0.01	ND	ND	ND	0.00	1.24	1.16	1.28%	−39.00	−34.00	ND	−140	1
Watkins #2-21	Red Fork	92.00	5.10	0.73	0.09	0.14	ND	ND	0.00	0.96	1.09	6.18%	−44.10	−32.30	ND	−145	1
Webb #2-1	L. & M. Atoka	87.90	2.68	0.41	0.03	0.04	ND	ND	0.00	1.01	1.01	3.47%	−43.70	−30.70	ND	−150	1
West #1-7	Morrow	90.00	2.66	0.64	0.07	0.08	ND	ND	0.00	0.87	1.10	3.69%	−41.40	−34.00	ND	−150	1
Seacat 1,2,3-19	Chat	81.4	7.19	3.00	1.200	0.700	0.385	0.486	ND	0.217	4.63	13.74%	−41.0	−34.9	−29.4	−158	2
Harden 7-17	Viola	59.0	8.25	8.04	3.570	1.440	1.020	0.761	ND	0.117	12.30	28.12%	−39.4	−37.6	−31.2	−179	2
McAninch Gregg 4	Chat	92.2	3.34	1.06	0.267	0.139	0.072	0.073	ND	0.088	1.12	5.10%	−40.9	−34.6	−30.8	−148	2
Barby 5-23	Morrow	91.7	3.41	1.41	0.170	0.385	0.121	0.107	ND	0.193	3.27	5.76%	−39.3	−33.3	−28.6	−179	2
Barby-Harper 1-22A	Topeka	56.7	13.50	13.70	4.440	2.420	1.190	1.540	ND	0.309	6.71	39.35%	−47.9	−37.3	−32.3	−192	2

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
McMoran 2	Kansas City	90.2	3.72	1.59	0.034	0.058	0.007	0.010	ND	0.007	2.00	5.67%	–41.8	–36.7	–33.3	–150	2
Coldwater No. 213	Council Grove	76.93	3.41	0.71	0.00	0.08	0.00	0.00	0.00	0.00	18.90	5.18%	–42.60	ND	ND	ND	3
Angleton No. B-2	Council Grove	82.39	4.84	1.50	0.16	0.15	0.00	0.00	0.00	0.00	10.96	7.47%	–43.40	ND	ND	ND	3
Barby No. A-1	Council Grove	81.32	4.59	1.62	0.20	0.20	0.00	0.00	0.00	0.00	12.07	7.52%	–44.10	ND	ND	ND	3
Follett Beard No. A-1	Council Grove	81.54	5.47	2.93	0.30	0.39	0.00	0.00	0.00	0.00	9.37	10.03%	–41.90	–29.60	ND	ND	3
O'Neill Barby No. 1	Virgilian	81.52	5.33	3.15	0.47	0.41	0.00	0.08	0.00	0.28	8.76	10.38%	–42.40	ND	ND	ND	3
O'Neil Barby Estate No. 1	Council Grove	74.74	4.98	1.92	0.16	0.19	0.00	0.00	0.00	0.14	17.87	8.84%	–45.40	ND	ND	ND	3
Barby No. 1-35	Chester B	62.80	12.52	8.33	0.62	0.72	0.00	0.00	0.00	0.00	15.00	26.11%	–48.60	–36.40	ND	ND	3
Muehlebach No. 1	Tonkawa	82.90	5.62	1.79	0.20	0.17	0.00	0.00	0.00	0.19	9.06	8.58%	–44.30	ND	ND	ND	3
Verna Roberts	Tonkawa	80.01	7.30	2.62	0.22	0.31	0.00	0.00	0.00	0.31	9.21	11.55%	–47.30	–28.60	ND	ND	3
Ira E. Northrup No. 1-21	Tonkawa	79.84	7.88	2.66	0.20	0.31	0.00	0.00	0.00	0.36	8.73	12.16%	–47.30	–30.00	ND	ND	3
Berryman No. 1	Tonkawa	81.41	5.60	1.82	0.20	0.20	0.00	0.00	0.00	0.11	10.74	8.76%	–46.80	ND	ND	ND	3
Nuttall No.1-32	Tonkawa	80.42	5.63	1.99	0.29	0.34	0.00	0.00	0.00	0.18	11.16	9.30%	–47.00	ND	ND	ND	3
Dunaway No.2-4	Hoover	86.19	5.51	2.28	0.47	0.31	0.09	0.13	0.00	0.19	4.83	9.25%	–44.20	ND	ND	ND	3
Shaller No. 1	Douglas	79.37	7.59	4.27	1.17	0.62	0.31	0.35	0.00	0.52	5.80	15.28%	–49.80	ND	ND	ND	3
Texas Wildlife and Parks No. 2	Douglas	78.05	7.36	4.46	1.21	0.64	0.33	0.38	0.00	0.30	7.27	15.56%	–49.60	ND	ND	ND	3
Baker No. 1-20	Cherokee	92.49	4.01	0.67	0.09	0.14	ND	ND	0.00	1.20	1.30	5.04%	–42.30	–32.90	ND	–133	3
Watkins No. 2-21	Red Fork	92.30	4.26	0.82	0.10	0.16	ND	ND	0.00	1.10	1.20	5.47%	–44.10	–32.30	ND	–145	3
Wilks No. 1-17	Red Fork	93.36	3.40	0.66	0.08	0.16	ND	ND	0.00	1.12	1.20	4.40%	–43.20	–32.50	ND	–136	3
Thurmond No. 1-32	Red Fork	89.58	5.57	1.56	0.22	0.26	ND	ND	0.00	0.90	1.90	7.83%	–44.50	–34.10	ND	–145	3
Marik No. 1-11	L. Desmoinesian	83.09	7.20	2.36	0.43	0.38	ND	ND	0.00	1.00	5.60	11.10%	–46.40	–43.80	ND	–150	3
Partain No. 1-6	Red Fork	90.57	5.52	1.04	0.14	0.22	ND	ND	0.00	1.30	1.20	7.10%	–45.00	–31.00	ND	–152	3
Flaming No. 1-20	Springer	94.28	1.80	1.06	0.20	0.14	ND	ND	0.00	1.43	1.09	3.28%	–40.70	–36.50	ND	–149	3
Palmer No. 1-17	Red Fork	85.79	6.95	3.76	0.70	0.55	ND	ND	0.00	0.82	1.43	12.24%	–45.90	–35.10	ND	–153	3
Canyon Camp Unit No. I	Red Fork	86.51	7.36	2.94	0.50	0.41	ND	ND	0.00	0.92	1.37	11.47%	–46.70	–33.30	ND	–152	3

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1+C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Rickenberg McKay No. 1	Red Fork	86.57	6.26	2.67	0.48	0.40	ND	ND	0.00	2.10	1.51	10.18%	–46.70	–32.80	ND	–159	3
Hazlett No. 1	Red Fork	80.19	11.51	4.47	0.75	0.64	ND	ND	0.00	0.77	1.65	17.80%	–46.90	–32.80	ND	–158	3
Worley Unit No. I	Cherokee	83.74	4.19	1.61	0.36	0.20	0.05	0.09	0.00	0.47	9.10	7.20%	–42.60	ND	ND	ND	3
Brown No. 1 H	Red Fork	75.11	2.65	0.66	0.09	0.06	0.01	0.02	0.00	0.33	21.07	4.44%	–41.60	ND	ND	ND	3
Outhier No. I	Big Lime	78.08	2.96	0.96	0.10	0.11	0.02	0.02	0.00	0.20	17.55	5.07%	–40.70	ND	ND	ND	3
Carl No. 1-35	Red Fork	73.82	6.64	1.99	0.15	0.24	0.00	0.02	0.00	0.41	16.73	10.91%	–43.70	ND	ND	ND	3
Thurmond No. 1-27	Atoka	94.65	2.04	0.36	0.07	0.15	ND	ND	0.00	1.20	1.50	2.69%	–43.10	–32.00	ND	–137	3
McConnell	L. & M. Atoka	95.72	1.87	0.29	0.04	0.04	ND	ND	0.00	1.10	1.00	2.29%	–42.30	–34.30	ND	–149	3
K.C. Cattle No. 1-34	Atoka	95.20	1.48	0.35	0.08	0.17	ND	ND	0.00	1.30	1.40	2.14%	–42.90	–32.20	ND	–139	3
Gregory No. 1-12	L. & M. Atoka	95.20	1.74	0.38	0.09	0.13	ND	ND	0.00	1.20	1.20	2.40%	–43.90	–31.20	ND	–145	3
Ashby No. 1-36	L. & M. Atoka	82.00	9.64	4.20	0.73	0.61	ND	ND	0.00	0.07	2.10	15.62%	–48.10	–34.30	ND	–162	3
Coulson No. 5-1	L. & M. Atoka	95.06	1.91	0.48	0.04	0.09	ND	ND	0.00	1.10	1.40	2.58%	–43.00	–31.30	ND	–151	3
Webb No. 2-1	L. & M. Atoka	95.23	2.08	0.44	0.03	0.04	ND	ND	0.00	1.10	1.10	2.65%	–43.70	–30.70	ND	–150	3
Allison No. 103	L. Atoka	95.72	1.77	0.28	0.03	0.04	ND	ND	0.00	1.01	1.20	2.17%	–42.80	–34.30	ND	–147	3
Risley No. 4	Granite Wash	81.84	8.67	3.65	0.90	0.47	0.25	0.28	0.00	0.77	3.16	14.80%	–45.60	ND	ND	ND	3
Risley No. 3	Granite Wash	79.00	8.56	3.70	0.97	0.50	0.30	0.30	0.00	0.68	5.99	15.35%	–45.70	ND	ND	ND	3
Ross No. 2-71	Granite Wash	70.75	8.06	3.59	0.87	0.47	0.22	0.24	0.00	0.32	15.47	15.97%	–46.20	ND	ND	ND	3
Hobart No. 8-70	Granite Wash	78.02	10.45	4.83	1.28	0.69	0.30	0.34	0.00	0.69	3.42	18.65%	–48.30	ND	ND	ND	3
Long "A" No. 2	Morrow	79.61	5.39	2.81	0.26	0.27	0.00	0.00	0.00	0.25	11.34	9.88%	–43.10	ND	ND	ND	3
Barby No. 1-36	Morrow	79.39	5.53	3.45	0.30	0.23	0.00	0.00	0.00	0.32	10.76	10.70%	–44.40	–33.80	ND	ND	3
Barby No. 1-29	Chester	83.48	3.81	1.64	0.15	0.16	0.00	0.00	0.00	0.20	10.49	6.45%	–42.10	ND	ND	ND	3
Boatman No. 1-23	Morrow	83.30	4.12	1.18	0.08	0.11	0.00	0.00	0.00	0.46	10.73	6.18%	–40.20	ND	ND	ND	3
Elliot No. 1-24	Morrow	77.98	3.58	1.13	0.08	0.13	0.00	0.00	0.00	0.10	17.00	5.93%	–40.40	ND	ND	ND	3
Frisby No. 1-29	Morrow	82.55	4.47	1.53	0.10	8.18	0.00	0.00	0.00	0.26	10.91	14.75%	–37.70	ND	ND	ND	3
Harrison No. 1-19	Chester	86.34	2.13	0.40	0.00	0.00	0.00	0.00	0.00	0.32	10.78	2.85%	–38.00	ND	ND	ND	3
Hudson No. 1-35	Morrow	86.94	5.12	2.30	0.50	0.33	0.08	0.14	0.00	0.29	4.20	8.88%	–41.90	ND	ND	ND	3
Conley No. 1	L. Morrow	80.62	2.61	0.67	0.06	0.07	0.01	0.02	0.00	0.28	15.66	4.09%	–39.60	ND	ND	ND	3

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1+C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Bradford No. 1-18	Morrow	78.25	6.24	3.02	0.38	0.36	0.01	0.08	0.00	0.45	11.21	11.42%	–42.40	ND	ND	ND	3
Tomkinson No. 17-1	L. Morrow	78.41	3.52	0.01	0.08	0.19	0.00	0.02	0.00	0.52	17.30	4.65%	–39.90	ND	ND	ND	3
Youngheim No. I	Morrow	84.12	1.09	0.38	0.01	0.01	0.00	0.00	0.00	0.22	14.17	1.74%	–37.80	ND	ND	ND	3
Barnum No. 1-32	Morrow	96.59	0.95	0.04	0.00	0.00	ND	ND	0.00	1.40	0.90	1.01%	–38.50	ND	ND	–135	3
Clark No. 1-33	Puryear	95.81	1.06	0.04	0.00	0.00	ND	ND	0.00	1.50	1.50	1.14%	–38.20	–36.10	ND	–147	3
Gregory No. 2-27	Morrow	96.41	1.08	0.04	0.00	0.00	ND	ND	0.00	1.60	0.80	1.15%	–38.20	–36.60	ND	–133	3
Farrar No. 1-22	Morrow	96.18	0.26	0.04	0.00	0.00	ND	ND	0.00	1.40	1.90	0.31%	–38.20	ND	ND	–133	3
Watkins No. 1-21	Morrow	96.80	0.41	0.03	0.00	0.00	ND	ND	0.00	1.50	1.20	0.45%	–38.20	ND	ND	–135	3
Thornton No.2-30	Morrow	96.75	0.46	0.03	0.00	0.00	ND	ND	0.00	1.70	1.00	0.50%	–37.80	ND	ND	–131	3
Berry No. 1-8	Morrow	96.48	0.52	0.00	0.00	0.00	ND	ND	0.00	1.70	1.30	0.54%	–38.30	ND	ND	–139	3
Dugger No. 1-18	Morrow	95.45	0.30	0.01	0.00	0.00	ND	ND	0.00	2.80	1.60	0.32%	–38.10	ND	ND	–140	3
Rymer No. 1	Morrow	92.28	3.65	1.40	0.25	0.31	ND	ND	0.00	0.90	1.30	5.73%	–43.00	–32.70	ND	–149	3
West No. 1-7	Morrow	94.61	2.36	0.69	0.08	0.08	ND	ND	0.00	0.98	1.19	3.28%	–41.40	–34.00	ND	–150	3
Ranch No. 1-15	Morrow	87.08	6.69	2.90	0.59	0.37	ND	ND	0.00	0.07	1.65	10.81%	–49.20	–38.30	ND	–154	3
Kardokus No. 10-1	Morrow	96.24	1.07	0.14	0.03	0.02	ND	ND	0.00	1.56	0.93	1.29%	–38.80	–34.90	ND	–170	3
Lesperance No. 1-35	Springer	85.05	0.82	0.02	0.00	0.01	0.00	0.01	0.00	0.75	13.16	1.00%	–36.60	ND	ND	ND	3
Rice No. 1-35	Morrow	94.01	0.66	0.00	0.00	0.00	ND	ND	0.00	3.10	2.10	0.70%	–33.20	ND	ND	–154	3
Cornstalk Unit No. 1-8	Springer	ND	2.29	0.81	0.11	0.13	ND	ND	0.00	1.10	1.20	100.00%	–41.90	–34.60	ND	–142	3
Rayner No. 2	Springer	95.60	1.20	0.50	0.09	0.08	ND	ND	0.00	1.10	1.30	1.92%	–39.90	–34.90	ND	–144	3
Hamburger No 1-9	Springer	96.46	0.00	0.13	0.00	0.00	ND	ND	0.00	1.54	1.86	0.13%	–39.00	–35.50	ND	–142	3
Brown Foundation No. 1-16	Springer	97.23	0.16	0.07	0.00	0.00	ND	ND	0.00	1.45	1.00	0.24%	–39.40	ND	ND	–139	3
Flaming No. 1-20	Springer	96.30	0.98	0.08	0.01	0.01	ND	ND	0.00	1.67	0.94	1.11%	–38.90	–35.70	ND	–148	3
Hintchel Unit No. 1	Springer	94.99	2.17	0.62	0.07	0.07	ND	ND	0.00	0.98	1.09	2.99%	–40.30	–34.50	ND	–146	3
Jones No. 1-17	Boatwright	93.92	2.19	1.03	0.18	0.16	ND	ND	0.00	1.03	0.48	3.65%	–39.50	–34.30	ND	–143	3
Bull Elk No. 1	L. Springer	97.02	0.55	0.14	0.00	0.00	ND	ND	0.00	0.96	1.32	0.71%	–41.40	–35.90	ND	–145	3
Ten Bears No.1	Springer	96.36	1.50	0.12	0.00	0.00	ND	ND	0.00	1.18	0.82	1.65%	–40.00	–34.40	ND	–144	3
Little Washita No. 1	Springer	96.21	1.24	0.10	0.00	0.00	ND	ND	0.00	1.22	1.22	1.37%	–38.90	–34.00	ND	–140	3

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Quanah Parker No. 1	Springer	95.62	1.47	0.16	0.01	0.01	ND	ND	0.00	1.01	1.71	1.70%	−43.00	−36.30	ND	−136	3
Kardokus No. 10-1	Springer	96.02	1.14	0.15	0.02	0.01	ND	ND	0.00	1.80	0.85	1.36%	−38.70	ND	ND	−148	3
APC Long No. A-1	Chester	86.67	2.91	0.97	0.13	0.12	0.00	0.00	0.00	0.19	9.00	4.55%	−40.20	ND	ND	ND	3
McFarland No. 1-32	Chester	87.54	1.99	0.45	0.00	0.00	0.00	0.00	0.00	0.32	9.69	2.71%	−39.20	ND	ND	ND	3
Barby No. 1-10	Chester	86.61	3.04	0.74	0.00	0.09	0.00	0.00	0.00	0.53	8.99	4.28%	−40.20	ND	ND	ND	3
Barby No. 1-25	Morrow	86.46	3.45	0.96	0.08	0.12	0.00	0.00	0.00	0.80	8.75	5.06%	−40.50	ND	ND	ND	3
Barby No. 1-24	Chester	86.14	3.75	1.16	0.13	0.17	0.00	0.00	0.00	0.47	8.19	5.70%	−40.70	−30.70	ND	ND	3
Brown No. 1-H	Red Fork	78.45	3.30	1.00	0.10	0.11	0.00	0.02	0.00	0.35	16.68	5.46%	−40.50	ND	ND	ND	3
Holden No. 1A	Simpson	80.52	9.40	5.90	1.81	1.02	ND	ND	0.00	0.41	0.93	18.38%	−47.00	−34.80	ND	−158	3
Harris No. 2	Bromide 4	85.17	7.97	3.93	0.90	0.58	ND	ND	0.00	0.52	0.93	13.58%	−46.90	−34.70	ND	−161	3
Holden No. 1A	Arbuckle	89.51	5.31	2.41	0.88	0.46	ND	ND	0.00	0.33	1.09	9.19%	−45.40	−34.90	ND	−156	3
Alexander 1-30	Desmoinesian	81.69	9.49	3.91	1.14	0.67	0.36	0.41	0.68	0.54	0.81	16.95%	ND	ND	ND	ND	4
Alice 1-31	Granite Wash	89.74	5.49	2.19	0.56	0.29	0.12	0.14	0.21	0.53	0.61	9.12%	−40.73	−37.12	−32.73	−135	4
Armstrong a 1-30	Desmoinesian	73.69	12.28	6.79	2.09	0.94	0.52	0.48	0.40	0.74	1.27	24.19%	−48.71	−34.49	−29.75	ND	4
Davis 1-20	Desmoinesian	84.31	8.59	3.27	0.89	0.54	0.27	0.31	0.47	0.59	0.58	14.54%	−47.84	−32.26	−28.47	ND	4
Davis 1-29	Desmoinesian	82.88	9.09	3.69	1.00	0.62	0.28	0.34	0.47	0.58	0.83	15.74%	−48.31	−32.51	−28.81	−154	4
Davis 2-30	Desmoinesian	83.02	9.24	3.45	0.85	0.54	0.27	0.26	0.34	0.55	1.20	15.26%	−47.87	−32.47	−28.81	ND	4
Davis 3-20 ST	Desmoinesian	82.19	9.37	3.89	1.07	0.95	0.27	0.33	0.45	0.56	0.71	16.58%	−48.49	−32.73	−28.98	−151	4
Davis 3-30	Desmoinesian	82.11	9.75	3.87	1.05	0.64	0.30	0.35	0.13	0.66	0.77	16.38%	−48.03	−32.72	−29.09	ND	4
Davis 4-30	Desmoinesian	83.31	9.23	3.72	1.02	0.62	0.28	0.34	0.10	0.54	0.67	15.53%	−48.08	−32.44	−28.64	ND	4
Fowler 1-29	Desmoinesian	82.99	9.00	3.49	0.93	0.59	0.26	0.32	0.38	0.58	0.71	15.28%	−48.18	−32.46	−28.84	−150	4
Haley 2-31	Desmoinesian	78.10	10.53	5.51	1.75	0.84	0.43	0.49	0.34	0.77	1.06	20.30%	−48.11	−34.70	−31.83	ND	4
Haley 4-31	Desmoinesian	87.65	6.26	2.23	0.58	0.37	0.15	0.18	0.19	0.51	1.22	10.20%	−45.52	ND	ND	ND	4
Haley 5-31	Desmoinesian	82.65	9.18	3.81	1.07	0.59	0.30	0.34	0.35	0.81	0.73	15.92%	−47.23	−33.67	−30.58	ND	4
Hart 1-31	Desmoinesian	80.95	9.76	4.74	1.31	0.71	0.29	0.34	0.26	0.72	0.82	17.69%	−47.52	−34.40	−31.16	ND	4
Hubert 1-4	Desmoinesian	75.54	9.86	6.09	2.29	1.11	0.67	0.69	0.26	0.98	1.84	21.72%	−48.13	−36.55	−32.41	ND	4
Johnson 1-22	Desmoinesian	76.05	11.13	5.95	2.08	0.99	0.58	0.01	0.49	0.97	1.02	21.82%	−47.48	−32.91	−29.87	−159	4

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Marriot 1-36	Morrow	95.33	0.90	0.16	0.08	0.04	0.01	0.02	0.04	1.15	1.79	1.29%	−38.77	−34.13	−29.93	ND	4
Megan 2-5	Atoka	96.84	1.38	0.24	0.11	0.08	0.02	0.03	0.03	0.93	0.29	1.90%	−39.77	−31.03	−26.24	−130	4
Merit 2-5	Atoka	96.62	1.41	0.27	0.12	0.09	0.03	0.04	0.07	0.96	0.29	2.07%	−39.81	−31.09	−25.96	ND	4
Mulberry 1-20	Desmoinesian	83.46	9.07	3.58	0.99	0.60	0.31	0.35	0.04	0.54	0.78	15.18%	−48.21	−32.31	−28.52	ND	4
Mulberry 2-20	Desmoinesian	84.60	8.59	3.14	0.79	0.50	0.22	0.25	0.47	0.51	0.71	14.17%	−48.03	−32.36	−28.48	ND	4
Seymour 1-12	Cherokee	94.41	3.14	0.60	0.14	0.15	0.02	0.05	0.03	0.69	0.46	4.18%	−43.90	−31.85	−27.89	ND	4
Tipton 1-32	Desmoinesian	80.81	10.14	4.38	1.20	0.76	0.30	0.38	0.41	0.56	0.87	17.87%	−48.48	−32.27	−28.69	ND	4
Tucker 2-17	Desmoinesian	86.24	8.34	2.87	0.65	0.44	0.12	0.17	0.04	0.49	0.59	12.78%	−47.65	−32.06	−28.39	−149	4
Smith 1-11	Cherokee	95.23	2.78	0.52	0.14	0.14	0.02	0.05	0.09	0.66	0.32	3.77%	−42.85	−32.08	−28.07	ND	4
A & C 6	Desmoinesian	86.47	7.75	2.55	0.52	0.43	0.11	0.18	0.30	1.20	0.36	12.05%	−44.88	−33.03	−29.41	ND	4
Apatite Federal 2	Desmoinesian	86.21	7.57	2.48	0.51	0.43	0.11	0.18	0.28	1.14	0.35	11.81%	−44.50	−32.91	−29.20	ND	4
Beals 1	Desmoinesian	79.21	10.83	4.96	1.34	0.72	0.38	0.43	0.33	0.98	0.42	19.33%	−45.83	−34.18	−30.23	ND	4
Beulah 2	U. Desmoinesian	78.23	10.84	5.45	1.41	0.78	0.41	0.48	0.43	1.03	0.44	20.18%	−45.27	−33.68	−30.02	ND	4
Beulah 3	Desmoinesian	81.96	9.58	4.27	1.12	0.67	0.27	0.34	0.25	0.97	0.38	16.76%	−44.92	−33.72	−30.01	−158	4
Beulah 9	Desmoinesian	83.52	8.69	3.63	0.81	0.63	0.20	0.30	0.36	1.16	0.32	14.91%	−43.53	−32.10	−28.20	ND	4
Bottom 3	Desmoinesian	85.91	7.82	2.76	0.55	0.52	0.13	0.22	0.44	1.14	0.34	12.66%	−43.67	−32.35	−28.06	−150	4
Clayton 6	Desmoinesian	81.69	9.89	4.20	0.99	0.63	0.21	0.30	0.47	0.96	0.49	16.97%	−46.08	−32.91	−29.24	ND	4
Earl B-3	Desmoinesian	82.58	8.88	3.79	1.01	0.65	0.31	0.40	0.35	1.15	0.38	15.71%	−44.20	−32.57	−28.76	ND	4
Hohbein 1	Marmaton	82.54	9.54	3.99	0.94	0.69	0.21	0.03	0.47	1.02	0.39	16.14%	−45.45	−32.60	−28.81	−156	4
Hohbein 7	Desmoinesian	84.90	8.03	3.00	0.63	0.61	0.15	0.26	0.34	1.26	0.32	13.31%	−44.01	−32.40	−28.12	ND	4
Kimzey 8-5	Desmoinesian	89.42	6.10	1.60	0.26	0.34	0.07	0.13	0.15	1.33	0.35	8.81%	−42.70	−31.21	−27.21	ND	4
Lamb 2	Red Fork	87.24	6.85	2.28	0.46	0.45	0.10	0.18	0.19	1.33	0.69	10.77%	−43.93	−33.13	−28.91	−142	4
Lovett 3	Desmoinesian	86.02	5.90	2.01	0.39	0.36	0.10	0.16	0.18	0.86	3.23	9.57%	−36.72	−23.97	−21.64	ND	4
Lucas 5	Granite Wash	89.26	5.33	2.31	0.64	0.32	0.18	0.18	0.34	0.43	0.81	9.44%	−41.00	−38.00	−33.69	−134	4
Mooney 2	Desmoinesian	84.82	7.96	2.87	0.59	0.53	0.14	0.23	0.46	1.16	0.31	13.10%	−43.92	−32.45	−28.48	−149	4
Olivia 1	Desmoinesian	82.02	9.53	3.95	0.92	0.69	0.22	0.35	0.55	0.98	0.57	16.49%	−45.37	−32.51	−28.83	ND	4
Patton B-3	Desmoinesian	89.24	5.88	1.98	0.37	0.42	0.07	0.15	0.26	1.26	0.26	9.28%	−42.19	−31.90	−27.60	−140	4

Table 2.   Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Phillips 3	Desmoinesian	86.45	7.48	2.55	0.50	0.48	0.11	0.20	0.34	1.32	0.40	11.89%	−43.35	−32.20	−28.08	−146	4
Rounds 6-3	Desmoinesian	85.34	8.25	3.00	0.52	0.38	0.13	0.17	0.29	1.19	0.38	12.99%	−43.87	−32.32	−28.30	ND	4
Sam 1	Desmoinesian	86.32	8.08	2.93	0.61	0.58	0.16	0.26	0.56	0.02	0.29	13.25%	−43.90	−32.23	−27.91	−151	4
Welty 3	Desmoinesian	87.52	7.34	2.28	0.42	0.11	0.10	0.17	0.27	1.24	0.32	10.89%	−43.76	−32.79	−28.96	ND	4
Banks 3-20	Cleveland	81.08	7.80	3.50	0.83	0.61	0.19	0.28	0.37	1.04	3.47	14.35%	−45.12	−34.14	−30.01	−154	4
Bloch 3-34	Morrow	85.41	6.95	3.65	1.16	0.47	0.38	0.32	0.47	0.38	0.57	13.56%	−45.83	−37.36	−34.58	−151	4
Bloch 6-34	Morrow	88.51	6.15	2.64	0.75	0.32	0.24	0.21	0.19	0.20	0.47	10.59%	−45.44	−38.29	−35.29	ND	4
Bobbie 1-21	Morrow	85.94	5.99	3.29	1.13	0.46	0.42	0.35	0.68	0.35	0.84	12.53%	−47.01	−38.04	−35.38	−148	4
Flick Trust 1-3	Cherokee	83.26	7.45	2.95	0.63	0.50	0.11	0.20	0.12	1.00	3.10	12.56%	−44.88	−34.42	−30.48	−150	4
Hamby 2-4	Morrow	93.52	1.40	0.17	0.01	0.01	ND	0.01	ND	1.06	3.03	1.69%	ND	ND	ND	−146	4
Hershy 1-4	Granite Wash	84.50	4.79	3.15	1.09	0.53	0.27	0.28	0.38	0.27	4.56	11.05%	−39.44	−41.80	−37.86	−143	4
Indian School 2-32	Cherokee	86.43	7.33	2.58	0.50	0.44	0.11	0.19	0.16	1.14	0.76	11.58%	−44.63	−34.59	−30.46	ND	4
Mackey 1-3	L. Cherokee	95.93	2.43	0.44	0.09	0.10	0.02	0.03	0.06	0.60	0.27	3.20%	−42.75	−33.06	−29.40	−139	4
Mosley 1-29	Cherokee	82.40	7.41	3.07	0.69	0.58	0.18	0.26	0.43	1.12	3.07	13.28%	−44.00	−32.99	−29.02	ND	4
Puckett 1-16	Desmoinesian	84.52	7.30	3.74	1.39	0.50	0.45	0.36	0.28	0.51	0.78	14.23%	−44.10	−38.93	−33.76	ND	4
Red Moon 7-29	Cherokee	82.04	7.69	3.13	0.67	0.56	0.17	0.26	0.44	1.26	2.90	13.61%	ND	ND	ND	ND	4
Slusher 1-28	Morrow	85.64	6.34	3.48	1.22	0.48	0.48	0.40	0.68	0.36	0.65	13.23%	−46.29	−37.98	−35.14	ND	4
Strack Trust 1-1	Morrow	85.31	5.08	3.13	0.88	0.53	0.16	0.27	0.35	0.53	3.03	10.87%	−42.15	−36.07	−32.09	−154	4
Thunder 1-13	Morrow	83.79	5.89	3.17	0.80	0.61	0.21	0.30	0.46	0.80	3.17	12.01%	ND	ND	ND	ND	4
Viersen 2-20	Morrow	90.62	3.41	1.04	0.23	0.13	0.04	0.06	0.11	0.49	3.17	5.25%	ND	ND	ND	ND	4
Viersen 4-20	Morrow	89.07	3.76	1.08	0.19	0.12	0.04	0.06	0.10	0.57	4.02	5.68%	ND	ND	ND	ND	4
Whitledge 1-2	L. Cherokee	95.21	2.64	0.50	0.14	0.13	0.03	0.05	0.07	0.70	0.28	3.61%	−42.84	−32.99	−29.27	ND	4
Wigington 1-31	Morrow	88.99	2.65	0.66	0.11	0.08	0.03	0.03	0.06	0.62	5.73	3.91%	ND	ND	ND	ND	4
Boeckman D-1-20	Morrow	90.50	4.96	2.04	0.50	0.23	0.13	0.13	0.40	0.42	0.39	8.50%	−42.04	−35.64	−32.73	ND	4
Carl 1-2	Morrow	83.49	6.62	3.32	1.12	0.44	0.40	0.32	0.58	0.37	2.55	13.29%	−45.62	−36.97	−34.15	ND	4
Chiles C-2-20	Morrow	93.04	3.09	1.15	0.26	0.14	0.06	0.08	0.33	1.47	0.28	5.20%	−40.31	−36.22	−33.13	ND	4
Ford 1-7	Deese 1	82.47	9.80	4.25	1.12	0.32	0.27	0.17	0.18	0.30	0.96	16.35%	−46.75	−39.84	−36.61	−164	4

Table 2. Molecular and stable isotopic composition of gases from the central Anadarko Basin.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; C_{6+}, six carbon hydrocarbons and higher; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Jenden and Kaplan (1989a), (2) Jenden and others (1988), (3) Rice and others (1988a), and (4) this study]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	C_{6+}	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	S
Ford 4-7	Woodford, Sycamore	81.50	10.28	4.39	1.23	0.34	0.35	0.20	0.28	0.23	0.99	17.32%	−46.29	−39.38	−36.01	−162	4
Haigler Gas Unit 2-28	Morrow	83.81	6.86	4.21	1.35	0.55	0.35	0.36	0.57	0.33	1.21	14.53%	−44.49	−36.13	−33.35	ND	4
Harmon Heirs 4-8	Woodford	83.13	9.53	3.94	1.03	0.30	0.26	0.16	0.18	0.30	1.01	15.63%	−47.12	−39.54	−36.38	−164	4
Harrell 2-7	Bromide	80.32	10.87	4.79	1.32	0.36	0.34	0.20	0.27	0.23	0.85	18.43%	−46.39	−40.37	−36.93	−163	4
Harris 2-8	Woodford, Sycamore	84.04	8.82	3.75	1.05	0.30	0.24	0.14	0.13	0.19	1.20	14.66%	−46.39	−39.18	−35.84	ND	4
Heath Cattle 1-31	Morrow	83.60	6.72	4.01	1.22	0.50	0.28	0.31	0.51	0.40	1.92	13.94%	−44.69	−36.50	−33.72	−148	4
Lyda May 1-2	Morrow	84.07	7.56	3.87	1.30	0.51	0.46	0.36	0.31	0.41	0.67	14.60%	ND	ND	ND	ND	4
Mays 1-8	Hunton, Viola & Sycamore	75.77	12.15	6.19	1.73	0.50	0.48	0.30	0.35	0.27	1.76	22.27%	−46.88	−39.57	−36.11	ND	4
Myia 1-11	Morrow	84.74	6.58	3.38	1.15	0.46	0.41	0.33	0.53	0.24	0.92	13.15%	−45.10	−35.76	−33.09	−146	4
Myia 2-11	Morrow	86.79	6.30	3.12	0.96	0.40	0.31	0.25	0.42	0.17	1.04	11.93%	ND	ND	ND	ND	4
Royle 1-11	Morrow	92.52	4.13	1.36	0.27	0.15	0.06	0.08	0.12	0.69	0.37	6.25%	−45.20	−36.56	−33.91	ND	4
Stewart Blackburn 1-30	Morrow	92.52	4.13	1.36	0.27	0.15	0.06	0.08	0.12	0.69	0.37	6.25%	−41.50	−36.08	−33.32	ND	4
Vera 1-11	Morrow	83.76	6.30	3.16	1.07	0.42	0.39	0.31	0.59	0.18	2.28	12.75%	−45.70	−36.70	−34.02	ND	4
Cassell C-3-7H	Bromide	80.57	9.87	5.26	1.78	0.71	0.50	0.38	0.26	0.33	0.20	18.89%	−48.16	−33.98	−32.58	−162	4

Table 3.   Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Ratzlaff D "A" #1	Herington	66.20	6.00	4.80	ND	ND	ND	ND	ND	0.19	14.03%	−43.5	−35.6	ND	ND	1
Hefner Gas Unit #1	Fort Riley	68.00	6.20	4.90	ND	ND	ND	ND	ND	0.18	14.03%	−43.4	−35.2	ND	ND	1
Guldner Unit #1	Chase	66.10	5.80	4.40	ND	ND	ND	ND	ND	0.21	13.37%	−43.5	−35.7	ND	ND	1
Guldner Unit #2	Council Grove	65.90	5.80	4.40	ND	ND	ND	ND	ND	0.20	13.40%	−43.6	−35.7	ND	ND	1
Campbell, R.W. #2	Council Grove	69.80	6.50	5.30	ND	ND	ND	ND	ND	0.15	14.46%	−43.6	−35.9	ND	ND	1
Keller, Ernest #2	Council Grove	69.50	6.10	4.60	ND	ND	ND	ND	ND	0.15	13.34%	−43.0	−34.9	ND	ND	1
Jarvis Unit #2	Council Grove	69.50	6.20	4.70	ND	ND	ND	ND	ND	0.15	13.56%	−43.3	−35.1	ND	ND	1
Ball, Clyde H. #2	Council Grove	70.00	6.30	5.10	ND	ND	ND	ND	ND	0.15	14.00%	−43.5	−36.1	ND	ND	1
Wright "C" Unit #1	Chase	66.90	6.20	4.90	ND	ND	ND	ND	ND	0.16	14.23%	−43.9	−35.7	ND	ND	1
Baughman H-2	Chase	70.20	4.00	2.40	ND	ND	ND	ND	ND	0.18	8.36%	−45.1	−35.3	ND	ND	1
Crayton A-1	Chase	68.20	6.40	5.20	ND	ND	ND	ND	ND	0.17	14.54%	−43.5	−36.0	ND	ND	1
Mills C-1	Herington	71.50	5.70	4.20	ND	ND	ND	ND	ND	0.13	12.16%	−43.4	−36.0	ND	ND	1
Parsely A-1	Herington	71.30	4.30	3.00	ND	ND	ND	ND	ND	0.15	9.29%	−44.9	−35.5	ND	ND	1
Oberly A-1	Topeka	64.60	6.30	5.80	ND	ND	ND	ND	ND	0.21	15.78%	−44.5	−36.4	ND	ND	1
Tucker B-1	Chase	68.40	5.80	4.80	ND	ND	ND	ND	ND	0.15	13.42%	−43.3	−35.2	ND	ND	1
Barnes A-1	Topeka	59.20	8.20	10.30	ND	ND	ND	ND	ND	0.20	23.81%	−44.9	−37.0	ND	ND	1
Hill A-1	Chase	68.40	6.00	4.60	ND	ND	ND	ND	ND	0.15	13.42%	−43.1	−35.1	ND	ND	1
Buzzard D-1	Permian Lm.	65.20	5.60	4.70	ND	ND	ND	ND	ND	0.18	13.64%	−43.2	−34.9	ND	ND	1
Stonebraker A-69	Permian Lm.	62.60	5.30	4.90	ND	ND	ND	ND	ND	0.21	14.01%	−43.0	−34.9	ND	ND	1
Coffee Estate #1	Brown Dolomite	69.10	6.60	4.90	ND	ND	ND	ND	ND	0.14	14.27%	−43.5	−35.5	ND	ND	1
Blake Trust Estate #2	Brown Dolomite	65.10	6.00	3.60	ND	ND	ND	ND	ND	0.21	12.85%	−43.3	−35.8	ND	ND	1
Mary A Long #1	Brown Dolomite	68.50	6.10	5.20	ND	ND	ND	ND	ND	0.17	14.16%	−44.0	−35.7	ND	ND	1
Donelson et al #1	Brown Dolomite	56.10	5.00	4.80	ND	ND	ND	ND	ND	0.26	14.87%	−43.2	−35.0	ND	ND	1
Sarah Claybaugh #1	Brown Dolomite	60.30	5.40	5.30	ND	ND	ND	ND	ND	0.25	15.07%	−42.4	−35.1	ND	ND	1
Cameron Walls #1	Brown Dolomite	62.80	5.70	5.60	ND	ND	ND	ND	ND	0.18	15.25%	−43.1	−36.4	ND	ND	1
Hormer #1	Brown Dolomite	64.90	6.20	5.30	ND	ND	ND	ND	ND	0.22	15.05%	−42.1	−35.0	ND	ND	1
Whitherbee #2	Brown Dolomite	61.70	9.30	11.50	ND	ND	ND	ND	ND	0.08	25.21%	−44.1	−36.2	ND	ND	1

Table 3. Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Flores 23	Brown Dolomite	69.20	6.50	5.60	ND	ND	ND	ND	ND	0.14	14.88%	−42.6	−35.2	ND	ND	1
Nisbett #1	Brown Dolomite	68.80	7.20	7.30	ND	ND	ND	ND	ND	0.14	17.41%	−42.7	−35.1	ND	ND	1
McDade #2+#5	Brown Dolomite	59.40	10.50	17.20	ND	ND	ND	ND	ND	0.07	31.80%	−42.4	−35.0	ND	ND	1
Brumley A#1	Brown Dolomite	60.00	7.30	12.30	ND	ND	ND	ND	ND	0.09	24.62%	−42.6	−35.2	ND	ND	1
Helm #1	Glorieta	0.01		0.00	0.00	0.00	0.01	0.00	0.06	93.50	55.17%	ND	ND	ND	ND	2
Arnold #1-1	Chase	49.60	3.18	2.19	0.72	0.29	0.18	0.15	0.00	43.50	11.92%	−42.1	−34.8	−30.2	−145	2
Atkins B#5	Chase	70.00	5.36	2.90	0.70	0.36	0.13	0.14	0.02	17.00	12.04%	−43.9	−35.0	ND	−163	2
Beaver #1	Brown Dolomite	74.60	6.13	3.27	0.73	0.36	0.13	0.13	0.03	13.20	12.60%	−43.3	−34.5	ND	−162	2
Benedict A#1	Brown Dolomite	75.40	7.68	5.60	2.35	1.09	0.64	0.61	0.02	4.49	19.25%	−41.9	−36.6	−31.4	−149	2
Bivins A-111	Brown Dolomite	67.10	4.63	2.82	0.96	0.42	0.25	0.25	0.98	18.80	12.21%	−42.3	−34.2	ND	−165	2
Bivins A#21	Red Cave	67.00	8.04	7.18	2.63	1.13	0.59	0.59	0.20	10.90	23.13%	−42.6	−34.0	−30.1	−166	2
Bivins A#64	Dolomite	71.90	5.82	3.69	1.09	0.51	0.25	0.27	1.13	13.70	13.93%	−42.6	−34.3	−30.3	−161	2
Bivins A#9	Dolomite	65.90	4.02	1.88	0.44	0.22	0.08	0.09	0.94	24.10	9.27%	−43.0	−35.1	ND	−167	2
Burton No. 1	Herington	70.90	6.45	3.67	0.98	0.43	0.20	0.19	0.03	16.50	14.39%	−43.7	−34.5	ND	−163	2
Cherokee No. 1B	Morrow	84.10	4.36	2.53	0.75	0.40	0.25	0.23	0.36	6.79	9.20%	−43.0	−33.5	ND	−161	2
Crawford No. 1R	Red Cave	75.10	9.13	4.78	1.23	0.58	0.24	0.25	0.02	5.94	17.75%	−44.7	−32.8	−28.8	−173	2
Cubine #1	Brown Dolomite	66.60	11.30	11.20	3.87	1.95	0.78	0.86	0.06	3.46	31.02%	−41.6	−36.5	−31.4	−150	2
Dear #1	Brown Dolomite	68.70	6.58	4.52	1.47	0.63	0.34	0.31	0.34	14.80	16.77%	−42.8	−34.4	ND	−157	2
Dunaway #1R	Red Cave	80.00	6.08	2.57	0.60	0.27	0.12	0.12	0.03	8.55	10.88%	−43.9	−32.1	−27.4	−165	2
Eagley A#1	Wabaunsee	66.40	4.80	2.02	0.36	0.18	0.33	0.15	0.05	25.20	10.56%	−43.5	−35.1	−30.3	−160	2
Esta #1	L. Krider	48.40	4.42	4.13	1.48	0.70	0.32	0.31	0.05	36.60	19.01%	−42.6	−33.8	ND	−155	2
Evers A#1	Chase	60.90	4.84	2.83	0.81	0.31	0.18	0.17	0.02	29.30	13.05%	−44.0	−35.0	ND	−166	2
Fecht #7	Chase	52.30	4.39	2.89	0.89	0.36	0.24	0.21	0.00	37.70	14.65%	−43.2	−34.9	−30.4	−188	2
Fee A#3	Dolomite	71.50	8.05	6.71	2.33	1.00	0.53	0.50	0.61	7.85	21.10%	−42.3	−34.8	−30.3	−157	2
Fee #3R	Red Cave	81.50	6.52	2.82	0.60	0.32	0.10	0.11	0.00	7.23	11.38%	−44.1	−31.7	−27.0	−163	2
Finley Dolomite #11	Brown Dolomite	16.10	6.08	11.70	5.48	2.29	1.12	1.14	0.33	50.50	63.33%	−41.1	−34.5	−30.2	−152	2
First National Bank B#1	Chase	66.30	5.20	2.94	0.80	0.31	0.17	0.16	0.06	23.80	12.63%	−44.3	−35.2	ND	−168	2

Table 3. Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Fox #8 Composite)	Granite Wash	30.60	16.70	23.60	6.11	2.96	0.79	0.87	1.07	17.60	62.51%	−42.1	−34.6	−30.3	−152	2
Gracey #1	Chase	71.20	6.21	3.51	0.84	0.41	0.13	0.15	0.02	12.40	13.64%	−43.1	−34.3	ND	−162	2
Hobson #1A	Brown Dolomite	67.30	6.00	3.90	1.10	0.51	0.21	0.21	0.10	18.50	15.05%	−42.3	−34.3	−30.1	−156	2
Hyer A#3	Chase	51.50	4.05	2.38	0.71	0.28	0.15	0.14	0.02	39.10	13.03%	−43.6	−34.8	−30.4	−165	2
Kaser No. 1	Permian Lm.	73.60	6.44	3.95	0.12	0.53	0.31	0.28	0.05	11.40	13.65%	−43.2	−34.4	ND	−161	2
Kaser No. 2	U. Morrow	84.30	5.86	2.60	0.79	0.25	0.21	0.15	0.27	1.86	10.47%	−43.6	−36.1	ND	−158	2
Kaser No. 2	Oswego	77.30	7.38	5.25	1.79	0.71	0.55	0.43	0.30	4.73	17.25%	−45.3	−34.3	ND	−164	2
Lela (Composite)	Granite Wash	27.60	19.50	22.30	6.49	3.34	1.10	1.23	1.21	19.60	66.16%	−42.3	−36.1	−31.0	−147	2
Lemon C#1	Chase	72.00	4.39	2.21	0.53	0.26	0.11	0.11	0.02	20.80	9.57%	−44.4	−35.4	ND	−167	2
Long A#1	Chase	71.00	6.42	3.81	1.08	0.42	0.26	0.22	0.03	16.30	14.68%	−43.8	−35.1	−30.4	−164	2
Masterson A#35R	Red Cave	76.40	6.66	3.19	0.71	0.35	0.12	0.13	0.02	11.50	12.74%	−44.1	−32.6	−28.8	−166	2
Masterson B#14	Brown Dolomite	67.40	6.86	6.21	2.92	1.13	0.88	0.80	0.29	10.80	21.81%	−42.4	−34.3	−30.1	−156	2
Masterson B#37	Dolomite	75.10	6.03	3.11	0.84	0.38	0.16	0.17	0.15	12.60	12.46%	−43.3	−33.5	−29.2	−166	2
Masterson G#3	Dolomite	68.40	7.87	7.38	3.21	1.27	0.88	0.82	0.28	8.16	23.85%	−42.4	−34.3	−30.2	−157	2
Masterson #16R	Red Cave	69.30	8.75	6.76	2.15	0.93	0.40	0.44	0.06	9.11	21.89%	−43.3	−33.1	−28.9	−165	2
Masterson #31R	Red Cave	74.70	8.75	5.02	1.30	0.62	0.23	0.25	0.04	8.12	17.79%	−44.1	−32.7	−28.5	−166	2
Masterson #97R	Red Cave	17.00	2.71	2.28	0.83	0.28	0.18	0.18	0.01	73.00	27.52%	−42.7	−30.5	−27.3	−159	2
McCall #18	Permian Lm.	55.60	5.02	3.95	1.24	0.57	0.26	0.25	0.06	31.00	16.88%	−42.5	−34.1	ND	−158	2
Morris B#1	Chase	55.70	3.13	1.64	0.44	0.20	0.01	0.10	0.02	37.10	9.01%	−44.8	−35.1	ND	−168	2
Morris #1-33	Chase	74.00	6.44	3.77	1.08	0.47	0.23	0.21	0.03	12.50	14.15%	−43.4	−34.4	−30.2	−162	2
Osborne #10	Brown Dolomite	76.80	7.42	5.77	2.34	1.08	0.64	0.62	0.02	4.73	18.88%	−41.8	−36.3	−31.2	−150	2
Osborne #4 (Composite)	Brown Dolomite	60.00	16.40	11.30	2.64	1.34	0.55	0.53	0.02	6.90	35.31%	−41.9	−33.4	−29.6	−162	2
Parmele #1	Dolomite	70.90	6.00	3.68	1.05	0.46	0.24	0.22	0.00	15.70	14.11%	−44.5	−35.3	−30.9	−165	2
Porter A#1	Chase	73.10	6.58	3.80	1.06	0.42	0.24	0.21	0.02	14.00	14.41%	−43.6	−34.9	ND	−166	2
Posey A#1	Topeka	68.00	6.67	4.23	1.33	0.47	0.38	0.30	0.09	18.20	16.44%	−45.1	−35.9	−30.9	−173	2
Posey A#2A	Morrow, Upper	70.40	6.42	5.22	1.08	0.61	0.23	0.21	0.14	14.70	16.37%	−46.1	−34.0	−27.8	−187	2
Posey A#2B	Marmaton	64.40	5.77	3.18	0.96	0.39	0.25	0.24	0.05	25.00	14.36%	−44.3	−34.7	−30.1	−172	2

Table 3. Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1+C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Ree #1	Chase	73.00	6.25	3.67	1.02	0.47	0.23	0.22	0.04	11.90	13.97%	−43.1	−34.4	ND	−161	2
Rees A#1	Chase	79.70	5.88	3.77	1.40	0.52	0.52	0.40	0.00	5.44	13.56%	−44.8	−34.8	ND	−163	2
Ross #1	Chase	61.80	5.24	3.28	1.04	0.37	0.28	0.22	0.02	27.20	14.44%	−43.9	−35.1	−30.6	−169	2
Schaaf #1	Chase	66.60	5.89	3.45	1.00	0.37	0.23	0.20	0.01	23.00	14.32%	−44.0	−35.0	ND	−166	2
Shores A#1	Chase	58.00	5.30	4.00	1.20	0.55	0.25	0.25	0.09	28.20	16.61%	−42.7	−34.2	ND	−158	2
Stonebraker #1AA	Permian Lm.	65.00	5.61	3.87	1.18	0.51	0.27	0.25	0.06	22.00	15.24%	−42.2	−33.7	ND	−159	2
Stonebraker A#12	Permian Lm.	60.20	5.40	3.29	0.84	0.37	0.14	0.15	0.02	23.00	14.48%	−41.9	−34.0	ND	−162	2
Stonebraker A#50	Herington	72.20	6.11	3.71	1.04	0.45	0.21	0.20	0.06	14.90	13.97%	−43.0	−34.3	ND	−160	2
Stonebraker A#62	Permian Lm.	64.20	5.48	3.61	1.01	0.47	0.20	0.20	0.06	20.00	14.60%	−43.1	−34.2	ND	−158	2
Stoops A#1	Chase	70.50	2.50	0.99	0.25	0.14	0.06	0.07	0.02	24.50	5.38%	−45.4	−35.8	−30.3	−167	2
Stubbs A#1	Chase	73.50	6.59	3.76	1.01	0.43	0.22	0.19	0.02	14.40	14.24%	−43.5	−34.6	−30.3	−162	2
Tate B#1	Chase	72.40	6.14	3.44	0.87	0.38	0.18	0.16	0.02	14.30	13.36%	−43.5	−34.6	−30.3	−164	2
Thompson B#4	Dolomite	69.90	6.86	5.37	2.25	0.88	0.65	0.59	0.56	10.90	19.19%	−42.6	−34.3	ND	−161	2
Towler #1-21	Chase	70.50	6.31	3.59	0.95	0.42	0.19	0.19	0.02	14.50	14.17%	−43.6	−34.7	ND	−163	2
Tucker #1-12	Chase	68.80	5.70	3.46	1.01	0.37	0.25	0.21	0.03	19.20	13.78%	−43.6	−35.1	−30.7	−160	2
United #1	Dolomite	69.90	6.97	5.28	1.84	0.74	0.45	0.40	0.41	11.20	18.33%	−42.1	−34.4	−30.5	−158	2
Vent A#1	Dolomite	72.20	6.74	5.19	2.15	0.84	0.64	0.55	0.23	8.31	18.25%	−42.5	−34.6	−30.3	−157	2
Wheat (Composite)	Brown Dolomite	44.40	10.50	16.80	4.02	2.25	0.68	0.76	0.07	20.30	44.09%	−42.4	−33.8	−29.5	−169	2
Whitman #1	Chase	70.70	6.28	3.63	1.01	0.39	0.21	0.20	0.02	17.10	14.22%	−43.8	−35.0	−30.5	−164	2
Wilson #1-4	Chase	74.30	6.45	3.71	0.97	0.43	0.20	0.19	0.03	11.80	13.86%	−43.2	−34.4	ND	−161	2
Wolff C#1	Chase	70.70	6.33	3.60	0.95	0.43	0.18	0.18	0.06	14.90	14.17%	−43.6	−34.6	ND	−161	2
Zimmerman No. 1-35	Chase	73.20	6.65	3.81	0.99	0.44	0.20	0.19	0.02	14.20	14.35%	−43.7	−34.6	−30.2	−161	2
Fecht No. 7	Chase	52.4	4.39	2.89	0.888	0.356	0.239	0.214	0.001	37.70	14.63%	−43.2	−34.9	−30.4	−188	3
Eagley A 1	Wabaunsee	65.6	4.80	2.02	0.364	0.182	0.325	0.150	0.046	25.20	10.68%	−43.5	−35.1	−30.3	−160	3
Posey A 1	Topeka	67.4	6.67	4.23	1.330	0.468	0.382	0.300	0.089	18.20	16.56%	−45.1	−35.9	−30.9	−173	3
Arnold 1-1	Chase	49.6	3.18	2.19	0.719	0.291	0.180	0.151	0.001	43.50	11.92%	−42.1	−34.8	−30.2	−145	3
Burton 1	Chase	70.9	6.45	3.67	0.980	0.429	0.199	0.189	0.030	16.50	14.39%	−43.7	−34.5	−30.2	−163	3

Table 3. Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1+C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Evers A 1	Chase	61.0	4.84	2.83	0.805	0.313	0.183	0.169	0.015	29.30	13.03%	−44.0	−35.0	ND	−166	3
First National Bank B 1	Chase	66.1	5.20	2.94	0.801	0.314	0.168	0.158	0.058	23.80	12.66%	−44.3	−35.2	ND	−168	3
Gracey 1	Chase	72.6	6.21	3.51	0.842	0.408	0.129	0.147	0.020	12.40	13.41%	−43.1	−34.3	ND	−162	3
Hyer A 3	Chase	51.5	4.05	2.38	0.709	0.282	0.153	0.140	0.021	39.10	13.03%	−43.6	−34.8	−30.4	−165	3
Lemon C 1	Chase	71.1	4.39	2.21	0.532	0.261	0.110	0.114	0.023	20.80	9.68%	−44.4	−35.4	ND	−167	3
Long A 1	Chase	70.7	6.42	3.81	1.080	0.422	0.259	0.221	0.025	16.30	14.73%	−43.8	−35.2	−30.5	−166	3
Morris B 1	Chase	55.8	3.13	1.64	0.435	0.200	0.010	0.099	0.016	37.10	8.99%	−44.8	−35.1	ND	−168	3
Morris 1-33	Chase	74.1	6.44	3.77	1.080	0.469	0.228	0.211	0.031	12.50	14.13%	−43.4	−34.4	−30.2	−162	3
Porter A 1	Chase	72.8	6.58	3.80	1.060	0.420	0.241	0.209	0.019	14.00	14.46%	−43.6	−34.9	ND	−166	3
Ross 1	Chase	61.6	5.24	3.28	1.040	0.372	0.275	0.222	0.024	27.20	14.48%	−43.9	−35.1	−30.6	−169	3
Schaaf 1	Chase	65.4	5.89	3.45	0.998	0.365	0.233	0.199	0.011	23.00	14.55%	−44.0	−35.0	ND	−166	3
Stoops A 1	Chase	70.4	2.50	0.99	0.246	0.138	0.064	0.066	0.017	24.50	5.39%	−45.4	−35.8	−30.3	−167	3
Stubbs A 1	Chase	73.0	6.59	3.76	1.010	0.426	0.224	0.194	0.021	14.40	14.32%	−43.5	−34.6	−30.3	−162	3
Tate B 1	Chase	72.6	6.14	3.44	0.874	0.375	0.176	0.158	0.017	14.30	13.33%	−43.5	−34.6	−30.3	−164	3
Towler 1-21	Chase	70.8	6.31	3.59	0.949	0.416	0.185	0.185	0.018	14.50	14.11%	−43.6	−34.7	ND	−163	3
Tucker 1-12	Chase	68.7	5.70	3.46	1.010	0.366	0.248	0.211	0.033	19.20	13.80%	−43.6	−35.1	−30.7	−160	3
Whitman 1	Chase	70.3	6.28	3.63	1.010	0.394	0.213	0.196	0.018	17.10	14.29%	−43.8	−35.0	−30.5	−164	3
Wolff C 1	Chase	70.8	6.33	3.60	0.952	0.425	0.180	0.184	0.061	14.90	14.15%	−43.6	−34.6	ND	−161	3
Zimmerman 1-35	Chase	73.8	6.65	3.81	0.987	0.438	0.196	0.187	0.020	14.20	14.25%	−43.4	−34.6	−30.2	−161	3
Cherokee 1B	Morrow	84.1	4.36	2.53	0.752	0.402	0.251	0.230	0.361	6.79	9.20%	−43.0	−33.5	−28.1	−161	3
Posey A-2A	U. Morrow	70.0	6.42	5.22	1.080	0.611	0.233	0.212	0.140	14.70	16.44%	−46.1	−34.2	−27.8	−189	3
Posey A-2B	Marmaton	64.1	5.77	3.18	0.963	0.392	0.254	0.236	0.047	25.00	14.41%	−44.3	−34.7	−30.1	−172	3
G.W. Deahl No. 2R	Red Cave	75.78	7.15	4.12	1.17	0.48	0.30	0.30	0.32	10.38	15.14%	−44.0	−32.2	ND	−164	4
Burnett No. 3R	Leonardlan	74.17	6.97	3.88	1.14	0.45	0.28	0.28	0.09	12.72	14.91%	−43.9	ND	ND	ND	4
Interstate No. C-6	Red Cave	50.46	1.61	0.91	0.30	0.19	0.00	0.10	0.00	46.43	5.81%	−46.4	ND	ND	ND	4
G.W. Deahl No. 2	Red Cave	63.00	10.63	10.12	3.69	1.69	0.92	0.88	0.60	8.44	30.72%	−42.0	ND	ND	ND	4
Burnett No. 5G	Chase	72.72	6.48	5.20	2.19	0.92	0.77	0.67	0.69	10.32	18.25%	−42.4	ND	ND	ND	4

Table 3. Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Burnett No. 1-12	Chase	75.62	6.25	4.88	1.93	0.87	0.70	0.61	0.37	8.73	16.77%	−41.8	−34.3	ND	−154	4
Burnett No. 7	Chase	73.52	6.36	4.77	1.85	0.86	0.64	0.55	0.31	11.10	16.97%	−42.0	ND	ND	ND	4
Burnett No. 24	Chase	76.99	6.30	4.33	1.71	0.73	0.01	0.02	0.14	9.75	14.54%	−42.1	−34.0	ND	−157	4
State No. 1	Herington	54.97	4.90	4.00	1.23	0.58	0.28	0.28	0.18	33.57	17.01%	−42.8	ND	ND	ND	4
L.C. Christian No. 1	Chase	76.76	7.80	4.77	1.36	0.44	0.37	0.24	0.30	7.96	16.33%	−46.1	ND	ND	ND	4
Sharpe No. 1	Krider	59.20	5.38	3.90	1.19	0.53	0.30	0.98	0.15	29.07	17.18%	−42.5	ND	ND	ND	4
Myers No.1	Permian Lm.	69.85	6.07	3.66	0.97	0.43	0.21	0.19	0.13	18.49	14.17%	−42.8	ND	ND	ND	4
Mackay No. 2	Council Grove	72.39	6.08	3.51	0.84	0.42	0.15	0.16	0.16	16.27	13.36%	−42.5	−33.4	ND	−163	4
Mackay No. 1	Permian Lm.	72.76	6.25	3.64	0.83	0.40	0.17	0.17	0.12	15.66	13.61%	−42.8	ND	ND	ND	4
Cargill No. 11	Chase	67.97	5.88	3.66	1.02	0.39	0.27	0.26	0.15	20.41	14.45%	−43.5	ND	ND	ND	4
Cargill No. 2	Council Grove	67.42	5.88	3.57	0.98	0.38	0.24	0.21	0.22	21.10	14.31%	−43.3	−32.2	ND	−164	4
Kinsler No. 1	Krider	68.53	5.91	3.70	0.98	0.43	0.24	0.21	0.14	19.85	14.34%	−43.2	ND	ND	ND	4
Conan No. A-1	Morrow	70.24	6.43	3.95	1.11	0.41	0.28	0.24	0.15	17.18	15.03%	−43.5	ND	ND	ND	4
Conan No. A-2	Council Grove	68.93	6.33	3.78	1.06	0.41	0.26	0.22	0.20	18.88	14.89%	−43.5	ND	ND	ND	4
Bond No. 1	Chase	67.67	6.31	4.05	1.12	0.45	0.30	0.25	0.16	19.70	15.57%	−43.8	ND	ND	ND	4
Bond No. 2	Council Grove	68.26	6.44	4.07	1.10	0.45	0.29	0.24	0.15	18.94	15.57%	−43.8	ND	ND	ND	4
Collingwood No. 1	Herington	67.45	6.30	3.79	1.09	0.42	0.27	0.23	0.12	20.50	15.21%	−44.0	ND	ND	ND	4
Julian No. 3	Chase	69.80	6.44	3.81	1.02	0.41	0.25	0.21	0.11	17.95	14.82%	−43.7	−33.7	ND	−165	4
Claypool	Chase	62.28	5.46	3.54	1.04	0.39	0.28	0.22	0.11	26.69	14.93%	−43.1	−33.7	ND	−169	4
Bentley	Chase	68.19	6.27	3.83	1.06	0.41	0.28	0.22	0.13	19.62	15.04%	−43.4	ND	ND	ND	4
Kenny	Hollenberg	65.65	5.60	3.40	0.90	0.36	0.21	0.19	0.15	23.52	13.97%	−43.3	ND	ND	ND	4
Rohlman No. A-1	Chase	64.64	5.79	3.60	0.37	0.29	0.25	0.21	0.11	24.75	13.99%	−43.3	−33.6	ND	−161	4
Rohlman No. A-2	Council Grove	65.19	5.80	3.57	0.91	0.39	0.20	0.18	0.10	23.65	14.49%	−43.3	ND	ND	ND	4
Berryman No. B-1	Winfield	64.38	4.79	2.37	0.44	0.25	0.06	0.08	0.00	27.65	11.04%	−42.8	−33.6	ND	ND	4
Webster No. C-4	Wabaunsee	61.11	5.28	3.10	0.49	0.33	0.00	0.10	0.11	29.48	13.21%	−42.6	−34.9	ND	ND	4
Roseberry No. 2	Cherokee	74.89	5.03	3.35	1.05	0.57	0.08	0.22	0.32	14.48	12.09%	−45.2	ND	ND	ND	4
L.C. Christian No. 2	U. Morrow	65.45	5.85	3.76	1.03	0.47	0.24	0.22	0.21	22.76	15.02%	−42.7	−35.9	ND	−172	4

Table 3. Molecular and stable isotopic composition of gases from the Panhandle Hugoton region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. S indicates the source of the data and the numbers refer to the following publications: (1) Ballentine and Sherwood Lollar (2002), (2) Jenden and Kaplan (1989), (3) Jenden and others (1988), and (4) Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_{13}$	δ^2HC_1	S
Gardner No.1	Chase	71.79	5.22	3.11	0.87	0.39	0.22	0.20	0.43	17.75	12.24%	−43.1	ND	ND	ND	4
Wiggins No. 1	Morrow	75.83	6.00	3.75	1.19	0.47	0.38	0.30	0.25	11.82	13.75%	−43.8	ND	ND	ND	4
Wiggins No. 1	Morrow	77.33	5.99	3.67	1.18	0.46	0.40	0.30	0.41	10.27	13.43%	−43.7	ND	ND	ND	4
Carpenter No. 6-8	L. Morrow	90.36	2.48	1.06	0.28	0.14	0.10	0.09	0.40	5.08	4.39%	−39.9	ND	ND	ND	4

Table 4. Molecular and stable isotopic composition of gases from the Sooner trend region of the Anadarko Basin Province.

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. Data are from Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	Source
Little Charlie No. 1	Desmoinesian	64.75	9.22	3.69	0.60	0.30	0.04	0.09	0.21	21.11	17.72%	−46.10	−35.60	ND	ND	Rice and others, 1988
Jarvis No. 1	Bartlesville	51.00	13.09	9.42	1.51	1.26	0.04	0.21	0.26	23.22	33.36%	−47.30	ND	ND	−149	Rice and others, 1988
Walker No. 1-35U	Manning	82.84	4.27	1.72	0.28	0.26	0.02	0.07	0.12	10.42	7.40%	−42.30	−31.20	ND	ND	Rice and others, 1988
Dietz No. 1	Manning	74.39	5.48	2.52	0.51	0.31	0.06	0.11	0.07	16.54	10.78%	−42.10	ND	ND	−146	Rice and others, 1988
Gilger No.1	Mississippian	64.88	4.43	1.45	0.32	0.20	0.03	0.07	0.32	28.31	9.11%	−43.10	ND	ND	ND	Rice and others, 1988
Schneider No. 1	Middle Mississippian	66.40	5.26	1.84	0.30	0.20	0.02	0.05	0.27	25.67	10.36%	−41.80	ND	ND	ND	Rice and others, 1988
Meadowlake No. 1	Middle Mississippian	70.81	5.63	1.92	0.21	0.24	0.00	0.02	0.21	20.95	10.17%	−43.80	−31.70	ND	ND	Rice and others, 1988
Quintle No. 1	Chester	85.86	0.57	0.23	0.12	0.12	0.01	0.04	0.02	13.03	1.25%	−42.80	ND	ND	−142	Rice and others, 1988
Hill No. 1	Mississippian	67.93	10.69	4.64	0.70	0.35	0.02	0.07	0.41	15.19	19.51%	−46.00	−38.10	ND	ND	Rice and others, 1988
Simmons No. 1	Hunton	66.08	8.92	3.71	0.49	0.42	0.01	0.07	0.21	20.09	17.09%	−46.70	−31.00	ND	−157	Rice and others, 1988
Killough No. 1-21	Hunton	67.61	5.80	2.46	0.32	0.16	0.02	0.04	0.08	23.51	11.52%	−45.30	ND	ND	−150	Rice and others, 1988
Rigdon Unit No. 2	Cleveland	67.43	8.70	3.45	0.60	0.45	0.02	0.08	0.19	19.08	16.47%	−42.90	ND	ND	ND	Rice and others, 1988
Blaney Nos. 2,3,5	Cleveland	66.91	7.90	3.74	0.57	0.46	0.02	0.08	0.20	20.12	16.03%	−43.20	ND	ND	ND	Rice and others, 1988
Waswo No. 1	Desmoinesian, Mississippian, and Hunton Group	71.16	7.46	2.30	0.27	0.25	0.02	0.02	0.19	18.33	12.67%	−43.50	ND	ND	ND	Rice and others, 1988

Table 4. Molecular and stable isotopic composition of gases from the Sooner trend region of the Anadarko Basin Province.—Continued

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and δ^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. Data are from Rice and others (1988a)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	Source
Mach No. 1	Skinner	72.41	8.81	3.36	0.48	0.27	0.03	0.07	0.45	14.12	15.24%	−44.50	−34.90	ND	ND	Rice and others, 1988
Schein Nos. 1,2,3	Mississippian	71.79	8.75	3.34	0.09	0.56	0.04	0.09	0.41	14.73	15.20%	−45.20	ND	ND	−164	Rice and others, 1988
FIFI No. 1	Hunton	71.50	8.17	2.89	0.47	0.28	0.03	0.07	0.25	16.33	14.28%	−43.60	ND	ND	ND	Rice and others, 1988
Omega No. 19-1	Chester	76.31	6.37	2.07	0.38	0.28	0.09	0.08	0.14	14.28	10.83%	−43.10	ND	ND	ND	Rice and others, 1988

Table 5. Molecular and stable isotopic composition of gases from the central Kansas uplift region of the Anadarko Basin Province.

[Units for the compositional data are in mole percent, and the $\delta^{13}C$ and d^2H values are in per mil relative to the Vienna Pee Dee Belemnite and Vienna Standard Mean Ocean Water scales, respectively. Gas wetness is calculated as $\Sigma C_{2+}/\Sigma C_1 + C_{2+}$. C_1, methane; C_2, ethane; C_3, propane; n-C_4, n-butane; i-C_4, i-butane; n-C_5, n-pentane; i-C_5, = i-pentane; CO_2, carbon dioxide; N_2, nitrogen; Wet, gas wetness in percent and $\delta^{13}C_1$, $\delta^{13}C_2$, and $\delta^{13}C_3$ are the stable carbon isotopic composition of methane, ethane, and propane, respectively. δ^2HC_1 is the stable hydrogen isotopic composition of methane. ND, not determined. Data are from Jenden and others (1988)]

Well name	Formation name	C_1	C_2	C_3	n-C_4	i-C_4	n-C_5	i-C_5	CO_2	N_2	Wet	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	δ^2HC_1	Source
Dutton I-17	Kinderhook	85.8	3.92	1.62	0.56	0.25	0.19	0.16	0.12	3.89	7.24%	−40.0	−34.6	−30.9	−150	Jenden and others, 1988
Embry Lease	Kansas City	63.8	8.64	8.35	3.72	1.56	1.20	0.97	0.20	7.98	27.70%	−41.9	−34.5	−31.2	−164	Jenden and others, 1988
Chalk A 1-18	Cherokee	83.6	4.29	1.77	0.50	0.26	0.16	0.11	0.13	7.88	7.81%	−39.7	−34.4	−30.5	−150	Jenden and others, 1988
Enlow-Miller #1	Limestone	85.5	4.88	2.36	0.93	0.42	0.33	0.26	0.20	4.51	9.70%	−39.6	−35.1	−30.8	−151	Jenden and others, 1988
Thurow #1	Foraker Limestone	84.0	2.36	0.68	0.15	0.08	0.05	0.04	0.02	11.60	3.85%	−40.8	−35.1	−30.5	−154	Jenden and others, 1988
Isern #1	Arbuckle	79.2	3.81	1.22	0.29	0.23	0.05	0.10	0.04	12.70	6.72%	−42.2	−34.2	−30.4	−148	Jenden and others, 1988
Miller #1-34	Indian Cave	87.4	2.30	1.47	0.43	0.22	0.13	0.12	0.11	5.11	5.06%	−41.2	−35.9	−31.4	−152	Jenden and others, 1988
Urban Q3	Lansing-Kansas City	54.0	1.97	1.56	1.12	0.53	0.38	0.31	0.19	36.40	9.81%	−39.2	−35.6	−31.2	−148	Jenden and others, 1988
Doran 2-14	Arbuckle	74.9	6.59	3.49	1.02	0.62	0.24	0.24	0.67	9.69	14.00%	−41.1	−34.3	−30.4	−149	Jenden and others, 1988
Wessler A-1	Fractured Quartzite	43.9	13.00	16.60	8.58	3.51	1.79	2.06	2.18	7.53	50.92%	−40.9	−37.4	−33.3	−162	Jenden and others, 1988
Apple 2	Topeka	65.9	3.07	1.30	0.50	0.35	0.22	0.22	0.12	27.10	7.91%	−41.5	−34.3	−30.2	−148	Jenden and others, 1988
Honderick "D" 1	Granite Wash	77.5	3.75	1.48	0.50	0.32	0.15	0.16	0.04	14.70	7.57%	−41.7	−34.1	−29.9	−147	Jenden and others, 1988
Muth 1	Chase	63.6	2.18	0.92	0.30	0.22	0.11	0.10	0.01	30.50	5.67%	−40.0	−34.5	−30.4	−139	Jenden and others, 1988
Wellman 2	Simpson	77.7	6.29	2.68	1.01	0.38	0.28	0.19	0.14	12.10	12.24%	−44.1	−35.0	−32.2	−174	Jenden and others, 1988
Colglazier 1	Viola	68.1	4.15	1.68	0.45	0.24	0.16	0.11	0.21	22.00	9.06%	−39.6	−34.4	−30.7	−149	Jenden and others, 1988

for stable isotopic analysis; so only the $\delta^{13}C$ of methane was determined. After the stable carbon isotopic analyses were performed, 31 samples contained sufficient amounts of methane for stable hydrogen isotopic analysis. One sample was analyzed for the stable hydrogen isotopic composition of methane prior to stable carbon isotopic analysis, and the residual gas was not sufficient for further isotopic analyses.

The results of the stable isotopic analyses of the 75 gas samples that were analyzed are presented in table 2. For the samples collected for this study, the $\delta^{13}C$ composition of methane ranges from -48.7 ‰ to -36.7 ‰ and averages -44.9 ‰ (1σ = 2.6 ‰); the $\delta^{13}C$ composition of ethane ranges from -41.8 ‰ to -24.0 ‰ and averages -34.4 ‰ (1σ = 2.9 ‰); the $\delta^{13}C$ composition of propane ranges from -37.9 ‰ to -21.6 ‰ and averages -30.8 ‰ (1σ = 3.1 ‰); and the $\delta^{2}H$ composition of methane ranges from -164 ‰ to -130 ‰ and averages -150 ‰ (1σ = 9 ‰). In addition to the data generated from the samples collected for this study, stable isotopic data from producing gas wells in the central Anadarko Basin published by Jenden and others (1988), Rice and others (1988a), and Jenden and Kaplan (1989a) are included in table 2. Additional published stable isotopic data from the Panhandle-Hugoton field, the Sooner trend, and the central Kansas uplift are included in tables 3, 4, and 5, respectively, and these values are taken from the works of Jenden and others (1988), Rice and others (1988a), Jenden and Kaplan (1989a), and Ballentine and Sherwood Lollar (2002).

Discussion

A plot of the stable carbon isotopic composition of methane, ethane, and propane can be used to distinguish among abiogenic, thermogenic, and microbial sources of natural gases (Schoell, 1983a; Chung and others, 1988; Sherwood Lollar and others, 2002). Figure 3 shows the average $\delta^{13}C$ composition of methane, ethane, and propane for the four regions within the study area; these data clearly indicate that the gases of the Anadarko Basin Province are from organic sources (that is, there is no significant contribution of natural gases from abiogenic sources). These data also indicate that the majority of the gases in the province are from thermogenic sources, which is consistent with the findings of previous studies of the gas geochemistry of the province (Jenden and others, 1988; Rice and others, 1988b, 1989). Although the average stable carbon isotopic values for methane, ethane, and propane for the four regions within the Anadarko Basin Province are consistent with a single thermogenic source (fig. 3), individual wells in parts of the study area do contain methane that is isotopically lighter than expected, given the $\delta^{13}C$ composition of the associated ethane and propane. A significant contribution of methane from microbial sources is expected to result in methane depleted in ^{13}C relative to the stable carbon isotopic composition of ethane and propane (Schoell, 1980; Rice and Claypool, 1981; Schoell, 1983a; Whiticar, 1994). Consequently, microbial methane contributions in restricted portions of the province
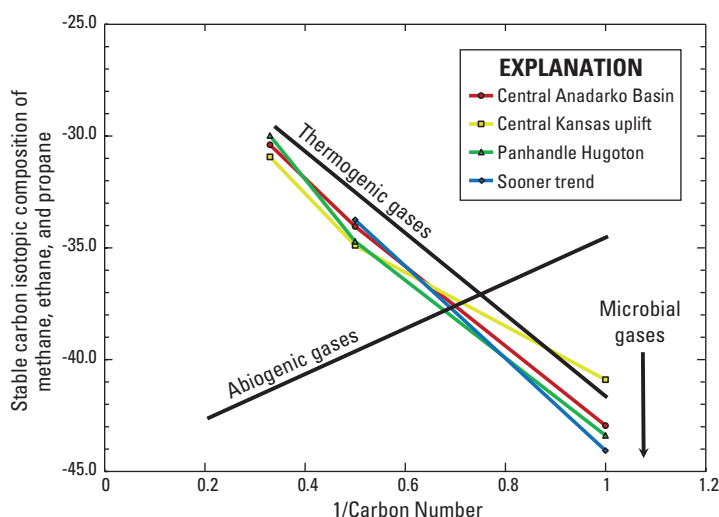
Figure 3.   Plot of the stable carbon isotopic composition of methane, ethane, and propane versus the reciprocal of the carbon number of the hydrocarbon species. Data are average values for each of the interpretive regions of the study area. Heavy black lines indicate the expected trends for thermogenic and abiogenic sources of hydrocarbon gases. Microbial gases have isotopically depleted methane compositions as shown by the arrow.

cannot be completely discounted. An alternative explanation for the occurrence of isotopically light methane is that it is the product of thermal cracking of oil (Tang and Schoell, 2005; Fusetti and others, 2010).

Plots of the $\delta^{13}C$ composition of methane versus the δ^2H of methane and versus the gas wetness (that is, the sum of the C_{2+} hydrocarbon gases) are widely used to identify the thermal regime of natural gas generation (Schoell, 1980; Schoell, 1983a, 1983b; Jenden and others, 1988; Rice and others, 1988b). For the Anadarko Basin Province data, the $\delta^{13}C$ composition of methane plotted against the δ^2H of methane (fig. 4) and against the gas wetness (fig. 5) indicate mature (oil window) to post-mature (dry gas window) sources for gas generation consistent with the findings of previous studies (Jenden and others, 1988; Rice and others, 1988b). The variation in thermal maturity of the generated gases is undoubtedly the result of differential burial of the source rocks in the basin. To address this point, Rice and others (1988b) attempted to correlate the $\delta^{13}C$ of methane with the depth of the reservoir from which it was produced. They observed a wide scatter in the data and concluded that a significant portion of the gases had migrated variable distances from different sources into a single reservoir resulting in a lack of correlation between reservoir depth and gas maturity.

Given the size (approximately 58,000 mi^2) and complexity of the Anadarko Basin Province, the study area has been broken down into four separate regions to facilitate a more detailed discussion of the natural gas geochemistry. Following the approach of Rice and others (1988b) and Jenden and others (1988), these four regions are defined as the central Anadarko Basin, the Panhandle-Hugoton field, the Sooner trend, and the central Kansas uplift (fig. 1). Details of the gas geochemistry of each of these regions are given in the following four sections.
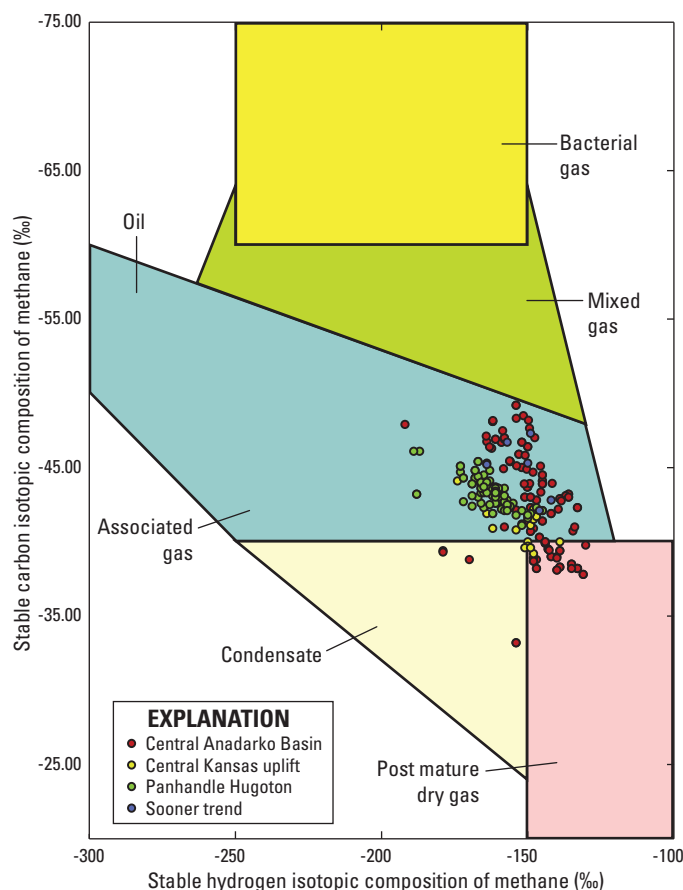
Figure 4. Plot of the stable carbon versus the stable hydrogen isotopic composition of methane. Note that stable hydrogen isotopic data for methane are not available for all of the gases in this study. Assoc. Gas, oil associated natural gas.
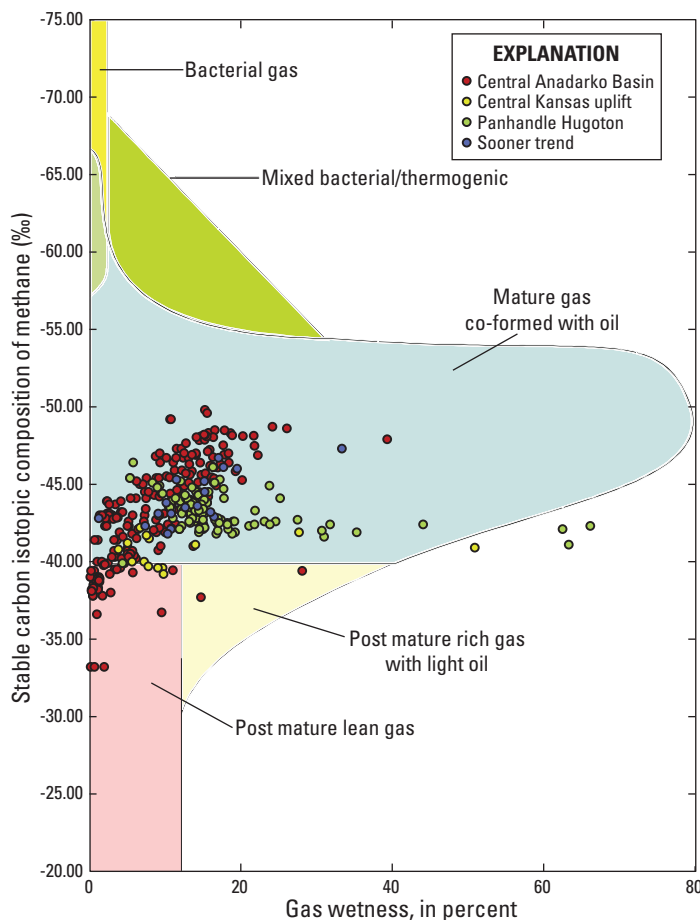
Figure 5. Plot of the gas wetness ($\Sigma C_{2+}/\Sigma C_1 + C_{2+}$) versus the stable carbon isotopic composition of methane.

Central Anadarko Basin

Rice and others (1988b) reported that gases in Upper Mississippian and Pennsylvanian reservoirs in the central Anadarko Basin become chemically drier (that is, lower C_{2+} content) and isotopically heavier (that is, increased ^{13}C content) with increasing age of the producing formation. They noted that (1) for gases derived from the Virgilian, the average $\delta^{13}C$ of methane is -46.6 ‰ and the mean C_{2+} value is 12 percent; and (2) gases produced from the Atokan and Desmoinesian contain methane with a mean $\delta^{13}C$ value of -43.9 ‰ and an average C_{2+} content of 7 percent. The authors concluded that these gases were most likely generated during the mature stage of hydrocarbon generation, which is consistent with the genetic classification scheme proposed by Schoell (1983a). Furthermore, the data presented by Rice and others (1988b) showed that gases produced from Springer Formation and Morrowan reservoirs contain methane with a mean $\delta^{13}C$ value of -39.9 ‰ and an average C_{2+} content of 3 percent, which likely indicates a mature to post-mature source for these gases.

The authors proposed two explanations for these observations. First, the Springer and Morrowan reservoirs are older and more deeply buried than the Virgilian, Atokan, and Desmoinesian reservoirs and are sourced from older, deeper source rocks that have reached a higher level of thermal maturity. Second, potential source rocks in the Springer and Morrowan intervals contain predominately Type III kerogen, whereas the Atokan and Desmoinesian lithologies contain mixed Type II and III and in the Virgilian the kerogen is mainly Type II (Rice and others, 1988b). Numerous field observations from around the world have shown that, in general, Type III kerogens generate gases that are drier and have enriched ^{13}C compositions relative to Type II kerogen-sourced gases of equivalent thermal maturity (Whiticar, 1994).

Rice and others (1988b) further noted that the geochemistry of gases in lower Paleozoic reservoirs in the central Anadarko Basin does not follow the trend observed in the Upper Mississippian and Pennsylvanian reservoirs. Whereas these deeper reservoirs would be expected to contain drier and heavier gases than those encountered in the shallower Springer

and Morrowan lithologies, in fact the lower Paleozoic gases are, on average, the lightest ($\delta^{13}C_1$ = -46.4‰) and wettest (C_{2+} = 14%) gases in the central basin (Rice and others, 1988b). The authors explained this finding as the result of the source of the gases being a Type II kerogen and the fact that the gases are coproduced with oil. Most of the gases from the younger reservoirs examined by Rice and others (1988b), however, were from nonassociated accumulations. They did not consider the possibility that some gas generation resulted from oil cracking, but given that the average depth for the lower Paleozoic reservoirs is greater than 16,000 feet, it is reasonable to expect that some oil cracking has occurred and contributed to the associated gas pool. Gases derived from the thermal cracking of oil are expected to contain isotopically light methane and to have a greater C_{2+} content than primary gases generated at an equivalent thermal maturity (Tang and Schoell, 2005; Fusetti and others, 2010).

Data from other published studies of the geochemistry of gases from the central Anadarko Basin (Jenden and others, 1988; Jenden and Kaplan, 1989a) combined with the results of this study generally support the findings of Rice and others (1988b) that for Upper Mississippian and Pennsylvanian reservoirs, gas composition becomes chemically drier and isotopically heavier with increasing age. This expanded dataset (table 2) shows that gases derived from Virgilian reservoirs have an average $\delta^{13}C$ composition for methane of -45.5‰ and a mean C_{2+} value of 14 percent, and gases produced from Atokan and Desmoinesian units contain methane with a mean $\delta^{13}C$ value of -44.7‰ and an average C_{2+} content of 10 percent. Additionally, gases produced from Springer and Morrowan reservoirs contain methane with a mean $\delta^{13}C$ value of -40.6‰ and an average C_{2+} content of 6 percent. The mean $\delta^{13}C$ composition for methane from lower Paleozoic reservoirs is -46.1‰ and the average wetness is 16 percent. These values are consistent with the numbers reported by Rice and others (1988b) and support their interpretation of the geochemistry of gases from the central Anadarko Basin.

Panhandle Hugoton Field

The molecular and stable isotopic composition of the gases produced from the Panhandle Hugoton field region is remarkably consistent given the size of these giant fields (table 3). Plots of the $\delta^{13}C$ composition of methane versus both the δ^2H of methane (fig. 4) and gas wetness (fig. 5) for this region indicate that the gases are derived from a thermally mature source. Previous studies have noted the general absence of thermally mature source rocks in this region (Cardott and Lambert, 1985), and this has led to the inference that the Panhandle Hugoton gases are not locally sourced (Jenden and others, 1988; Rice and others, 1988b). Based on similarities among the gas wetness and the $\delta^{13}C$ composition of methane of Panhandle Hugoton gases and those from Desmoinesian and Atokan reservoirs in the central Anadarko Basin, Rice and others (1988b) suggested that Pennsylvanian and (or) older source rocks in the central basin are the source of

the gases in the Panhandle and Hugoton fields. Consequently, the gases produced from reservoirs in the Texas and Oklahoma Panhandles and in western Kansas are thought to have migrated several hundred kilometers from source kitchen areas in central Oklahoma. Sorenson (2005) proposed that hydrocarbons from the central Anadarko Basin initially charged structural traps in the pre-Laramide Panhandle field, and that early Tertiary Laramide orogenic events resulted in a remigration of fluids that charged the Hugoton field with gas. However, Jenden and others (1988) pointed out that, for a given level of thermal maturity, gases sourced from Type III (humic) kerogen tend to be enriched in ^{13}C relative to Type II (sapropelic) sourced gases. Consequently, early thermogenic gases derived from humic organic matter may be difficult to distinguish from mature gases generated from sapropelic organic matter, and Jenden and others (1988) proposed that the amount of natural gas derived from local source rocks in the Panhandle Hugoton region may be underestimated.

Examination of all of the published gas geochemistry data available for the Panhandle Hugoton region (table 3) shows that the average gas wetness is 16.0 percent (1σ = 8.2 percent) and the mean $\delta^{13}C$ composition of methane is -43.4 ‰ (1σ = 1.0 ‰). These values are comparable to the mean values reported for gases produced from Atokan and Desmoinesian reservoirs in the central Anadarko Basin. However, given the significant migration distance (hundreds of miles) required for gases generated in the central Anadarko Basin to charge reservoirs in the Panhandle Hugoton region, it seems likely that the long-distance-migrated gases might represent an earlier stage of gas generation compared to the more locally reservoired gases. This implies that the source of the Panhandle Hugoton gases is pre-Pennsylvanian, with the Woodford Shale being the most likely candidate.

An interesting feature of the geochemistry of the gases of the Panhandle Hugoton region is the elevated concentration of nitrogen. Based on more than 12,000 gas samples collected and analyzed by the U.S. Bureau of Mines, the median nitrogen concentration in produced natural gases throughout the United States is 3 percent (Jenden and Kaplan, 1989b). By contrast, for the gases examined in this study the average concentration of nitrogen from the Panhandle Hugoton region is 15.3 percent (1σ = 12.0 percent) (table 3), which is in agreement with the approximate 15 percent value reported by Ballentine and Sherwood Lollar (2002). Nitrogen in natural gas reservoirs is generally thought to be derived from one or more of the following sources: (1) atmospheric nitrogen dissolved in groundwater, (2) thermogenic degradation of nitrogen containing sedimentary organic matter, (3) release of mineral bound nitrogen during metamorphism, and (4) igneous or deep mantle sources (Ballentine and Sherwood Lollar, 2002, and references therein). On the basis of the consistent association of helium with nitrogen throughout the Panhandle and Hugoton fields, Gold and Held (1987) suggested that all of the nitrogen must be derived from a source deeper than the total sedimentary accumulation of the Anadarko Basin (that is, a crustal and (or) mantle source). Jenden and others (1988)

noted that in the Hugoton field higher concentrations of N_2 are associated with enriched ^{13}C compositions in methane and that the N_2/Ar ratio is nearly five times that of the atmospheric ratio indicating that an immature sedimentary origin for the N_2 is unlikely. Citing the work of Oxburgh and others (1986), Jenden and others (1988) reported that more than 98 percent of the helium in the Panhandle and Hugoton fields is derived, at least in part, from crustal sources and that the nitrogen can be inferred to have a similar source. A more recent study of the noble gases ($^3He/^4He$, $^{21}Ne/^{22}Ne$, and $^{40}Ar/^{36}Ar$) and the stable isotopic composition of the hydrocarbon and nonhydrocarbon gases ($\delta^{13}C$ of methane, ethane and propane; and $\delta^{15}N$ of N_2) excludes the possibility of significant atmospheric and magmatic sources, and concludes that the nitrogen in the Panhandle Hugoton region is derived from a mixture of crustal rocks and thermally mature sedimentary organic matter (Ballentine and Sherwood Lollar, 2002).

Sooner Trend

All of the data for gases from the Sooner trend presented in this study are taken from Rice and others (1988a) (table 4). Gas production in this region is generally associated with oil, and the oils have been geochemically correlated with a Woodford Shale source (Rice and others, 1989). Hydrocarbon production in the Sooner trend is from relatively shallow (less than 3,000 meters) Silurian, Devonian, and Mississippian carbonate reservoirs (Rice and others, 1988b). Plots of the $\delta^{13}C$ of methane versus both the δ^2H of methane (fig. 4) and gas wetness (fig. 5) for this region indicate that the gases are derived from a thermally mature source rock containing Type II kerogen. The Woodford Shale is the most likely source for these gases given that the associated oils are derived from this formation. Within the Sooner trend region the Woodford Shale is only marginally mature; therefore, it is most likely that the gases have migrated from deeper portions of the central Anadarko Basin (Rice and others, 1988b).

Central Kansas Uplift

The central Kansas uplift gas geochemistry data presented in table 5 are from Jenden and others (1988). The gases appear to be derived primarily from a thermally mature Type II kerogen source, as shown in the plots of the $\delta^{13}C$ of methane versus both the δ^2H of methane (fig. 4) and gas wetness (fig. 5). The limited data available for thermal maturity in the central Kansas uplift region indicate that the local source rocks are marginally mature; consequently the shallow reservoirs were most likely charged by gases that had migrated hundreds of miles from the deeper central Anadarko Basin (Jenden and others, 1988). The average wetness for produced gases from the central Kansas uplift is 12.4 percent (1σ = 12.0 percent) and the mean $\delta^{13}C$ composition of the methane is -40.9 ‰ (1σ = 1.3 ‰), which are comparable to the mean values reported for gases produced from Springer and Morrowan reservoirs in the central Anadarko Basin (6.0 percent and -40.6 ‰). However, as noted for the

gases of the Panhandle Hugoton region, the long-distance migrated gases likely represent an earlier stage of gas generation compared to the more locally reservoired gases in the central Anadarko Basin. Consequently, the deep source of the central Kansas uplift gases is probably Early Mississippian or older, and may be the Woodford Shale.

Importantly, there is some evidence to suggest that gases in the central Kansas uplift region may contain a contribution of locally sourced early thermogenic gas. Figure 3 shows that the average $\delta^{13}C$ composition of methane is slightly heavier than the expected value if the methane, ethane, and propane were derived from a single source of similar thermal maturity. The best explanation for this observation is that a dry mature gas mixed with a wetter lower maturity gas. Moreover, as discussed for the Panhandle Hugoton gases, gases sourced from Type III kerogen tend to be enriched in ^{13}C relative to Type II-sourced gases at an equivalent level of thermal maturity. Therefore, early Type II thermogenic gases may be difficult to distinguish from mature Type III gases, and Jenden and others (1988) suggested that the amount of natural gas derived from local source rocks in the central Kansas uplift region may be underestimated.

Conclusions

Approximately 100 produced gases were collected from the Anadarko Basin Province and analyzed for their molecular and stable isotopic composition. The study of these gases is intended to provide an interpretation of the significance of these new geochemical data in the context of the previous studies that have been conducted in the province. Given the extensive area encompassed by the province, natural gas production was considered in four separate regions within the province: the central Anadarko Basin, the Panhandle-Hugoton field, the Sooner trend, and the central Kansas uplift. These regions were largely defined on the basis of the age of the reservoir rocks, type of trap, and the composition and origin of the gases following the distinctions made in previous studies (Jenden and others, 1988; Rice and others, 1988b).

As noted in previous studies of the geochemistry of gases from the Anadarko Basin Province (Jenden and others, 1988; Rice and others, 1988b, 1989; Ballentine and Sherwood Lollar, 2002), the average $\delta^{13}C$ composition of methane, ethane, and propane for the four regions within the study area indicate that (1) the majority of the natural gases are from organic sources with no significant contribution of gas from abiogenic sources (fig. 3), and that (2) most of the gases in the province were generated by thermogenic processes; although, limited contributions from microbial sources may be possible in localized areas. The molecular and stable carbon and hydrogen isotopic compositions of the hydrocarbon gases indicate mature (oil window) to post-mature (dry gas window) sources for gas generation (figs. 4 and 5), consistent with the findings of previous studies (Jenden and others, 1988; Rice and others, 1988b).

In the central Anadarko Basin region, gas composition becomes chemically drier (lower C_{2+} content) and isotopically heavier (increased ^{13}C content) with increasing age of the producing formation within the Upper Mississippian and Pennsylvanian reservoirs. This is apparently the result of two factors. First, the older and more deeply buried reservoirs (Springer and Morrowan) are sourced from older, deeper, and more thermally mature source rocks (compared to the younger Virgilian, Atokan, and Desmoinesian reservoirs). Second, potential source rocks in the older intervals (Springer and Morrowan) contain predominately Type III kerogen, whereas the intermediate age lithologies (Atokan and Desmoinesian) contain mixed Type II and III, and in the youngest rocks (Virgilian) the kerogen is mainly Type II (Rice and others, 1988b). The geochemistry of gases in lower Paleozoic reservoirs in the central Anadarko Basin does not follow the trend observed in the Upper Mississippian and Pennsylvanian reservoirs; in fact, the gases in these deeper reservoirs are, on average, the wettest and isotopically lightest gases in the central basin (table 2). This is most likely the result of some contribution of gas from oil cracking because of the significant burial depth of these reservoirs (averaging more than 16,000 feet).

The geochemical composition of the gases produced from the giant Panhandle Hugoton field region is notably homogeneous and indicative of a thermally mature source. However, the general lack of thermally mature source rocks in this region (Cardott and Lambert, 1985) has led to the interpretation that these gases are not locally sourced (Jenden and others, 1988; Rice and others, 1988b). Based on similarities in the geochemistry of Panhandle Hugoton gases and those from Desmoinesian and Atokan reservoirs in the central Anadarko Basin, Rice and others (1988b) suggested that Pennsylvanian and (or) older source rocks in the central basin are the source of the gases in the Panhandle and Hugoton fields. However, long-distance-migrated gases likely represent an earlier stage of gas generation compared to the more locally reservoired gases in the central Anadarko Basin. This indicates a probable Early Mississippian or older source (possibly Woodford Shale) for the Panhandle Hugoton field gases.

The Panhandle Hugoton gases are also remarkable for their elevated nitrogen content (greater than five times the median concentration for United States gases) (Jenden and Kaplan, 1989b). Studies of the molecular and stable isotopic composition of the hydrocarbon and nonhydrocarbon gases (including noble gases) of the Panhandle Hugoton fields have shown that the nitrogen is derived from a mixture of crustal sources and thermally mature sedimentary organic matter (Oxburgh and others, 1986; Jenden and others, 1988; Rice and others, 1988b; Ballentine and Sherwood Lollar, 2002).

Gas production in the Sooner trend is associated with Woodford Shale-sourced oil, and the geochemistry of the gases indicates that they are derived from a thermally mature Type II kerogen source (most likely the Woodford Shale). Locally the Woodford Shale is only marginally mature; therefore, the gases must have migrated from deeper portions of the central basin (Rice and others, 1988b).

The central Kansas uplift gases appear to be primarily derived from a thermally mature Type II kerogen source. Local source rocks in the region are thought to be marginally mature, and consequently the source of the gas is most likely hundreds of miles away in the deeper central Anadarko Basin (Jenden and others, 1988). Comparison of the molecular and stable isotopic composition of the central Kansas uplift gases with those of the central Anadarko Basin gases indicates that the source may be Early Mississippian or older (possibly the Woodford Shale). However, it should be noted that there is some evidence to suggest that gases in the region may contain a contribution of locally sourced early thermogenic gas.

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