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Research Advances

The Openness Degree Study of the Jiaoshiba Shale Gas, Sichuan Basin, China–Potential Factor Responsible for Reversed Isotope Series

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Objective

Reversed alkane $\delta^{13}C$ and $\delta^{2}H$ values in many prolific shale plays all over the world have aroused much attention in the study of the formation mechanism of reversed isotope series in alkanes in the past few years(Zou Caineng et al., 2016). Although many researchers have put forward different hypotheses, the mechanism has not been well understood yet. The openness degree of oil and gas system has been neglected in previous studies which may be an important factor responsible for the isotope reversal. Since there is no isotope reversal in closed-system hydrocarbon generation simulation or open system hydrocarbon generation simulation, a relative open oil and gas system is necessary for isotope reversal. It is increasingly accepted that the mixing of natural gas from different maturity or source rock is a very important factor for reversed alkane isotope. However, the mixing effect of natural gas on isotope reversal is only effective on the premise that differential diffusion happens to different endmember in a relative open oil and gas system. Shale gas play is traditionally recognized as a closed self-sourced reservoir, however, more and more researches indicate that Jiaoshiba shale gas experienced multistage gas generation, migration and accumulation, similar with conventional natural gas reservoir. The objective of this study is to discuss the potential relationship between the openness degree of Jiaoshiba mudrock systems and the carbon isotopic reversal.

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Methods

A total of 29 wellhead shale gas samples were collected from the Jiaoshiba shale play. The alkane compositions of shale gas samples were analyzed using Agilent 6890N Gas chromatography. The carbon isotope of alkane in shale gas was measured using DELTA Plus XP mass spectrometer. The isotope analyses of He and Ar were carried out using quadrupole mass spectrometry (QMS). Since the concentration of He and Ar is very low in shale gas, the He and Ar elements were purified from shale gas in a noble gas purification system before isotope analysis. The shale gas was introduced into a Zr-Al purifying furnace (held at 350°C for 20 min) to remove CO_2, hydrocarbons and other active gases. An aliquot of purified noble gases was then introduced to the gas getters for a second round purification, and then the noble gas was introduced into QMS for isotope analyses of He and Ar.

Results

The Jiaoshiba shale gas in this study is dominated by methane, with an average concentration of 99.12%. The carbon isotope of C_{1-3} in the Jiaoshiba shale gas are all in reversed isotope series ($\delta^{13}C_1$> $\delta^{13}C_2$>$\delta^{13}C_3$). The $\delta^{13}C_1$ values vary from −32.7‰ to −29.3‰ with an average value of −30.7‰; the $\delta^{13}C_2$ values vary from −35.6‰ to 33.2‰ with an average value of −34.8‰, and the $\delta^{13}C_3$ values vary from −37.7‰ to −34.1‰ with an average value of −36.2‰. The Jiaoshiba shale gas has $^3He/^4He$ values of 1.41 ppb to 1.69 ppb with an average value of 1.51 ppb, and R/Ra ratios vary from 0.010 to 0.012 with

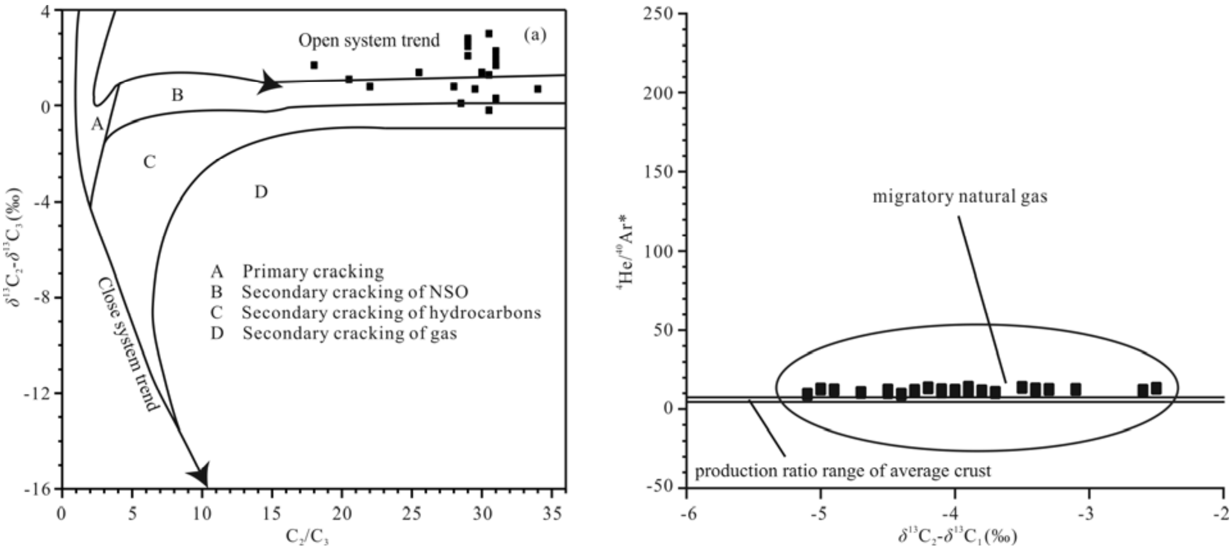

Fig. 1. (a), Plots of C_2/C_3 versus $\delta^{13}C[C_2–C_3]$ indicating that Jiaoshiba shale gases are derived from open system (modified from Xiao, 2011); (b), Plots of $^4He/^{40}Ar^*$ versus $\delta^{13}C[C_2–C_1]$ indicating that Jiaoshiba shale gases are migratory natural gas (modified from Hunt et al., 2012).

an average value of 0.011, indicative of a typical crustal origin. The $^{40}Ar/^{36}Ar$ values vary from 9.96 to 19.8 with an average of 15.4, far greater than the $^{40}Ar/^{36}Ar$ value of air (295.5), indicating an overall stable conservation condition. The Jiaoshiba shale gas samples are distributed along the open system trend in Fig. 1a, suggesting that Jiaoshiba shale gas is derived from an open system. The enrichments of light noble gases (^4He and $^{40}Ar^*$), high production ratio of $^4He/^{40}Ar^*$ close to crustal production levels and reversed carbon isotope values between methane and ethane in Fig.1b indicate that the Jiaoshiba shale gas is a migratory natural gas ($^{40}Ar^*$ represents ^{40}Ar exclusively from radiogenic production).

Conclusion

The openness study suggests that the Jiaoshiba shale gas is a migratory natural gas derived from an open system, which may be related with the multiple hydrocarbon accumulation process. Meanwhile, the far greater $^{40}Ar/^{36}Ar$ values of Jiaoshiba shale gas than that of air indicate an overall good conservation condition. Accordingly, the moderate openness degree of Jiaoshiba shale play is probably an important factor responsible for reversed isotope series. The detailed studies of differential accumulation and loss of hydrocarbons responsible for isotope reversal during the multiple hydrocarbon generation and accumulation processes are in progress.

Acknowledgments

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Appendix 1 Composition and isotopes of alkane and noble gas in the Jiaoshiba shale gas

Well number	Alkane composition			Alkane isotope				Noble gas isotopes								
	CH_4	C_2H_6	C_3H_8	$\delta^{13}C_1$(‰)	$\delta^{13}C_2$(‰)	$\delta^{13}C_3$(‰)	$\delta^{13}C_2-\delta^{13}C_1$	^4He(ppm)	$^3He/^4He$(ppb)	R/Ra	^{36}Ar(ppm)	^{40}Ar(ppm)	$^{40}Ar^*$(ppm)	$^{40}Ar/^{36}Ar$	$^4He/^{40}Ar^*$	$^{38}Ar/^{36}Ar$
JY0001	99.36%	0.62%	0.02%	−29.7	−33.7	−34	−4	311.3	1.43	0.010	0.023	32.63	25.85	1421.7	12.04	0.163
JY0002	99.38%	0.60%	0.02%	−30.5	−35	−36.4	−4.5	315.4	1.41	0.010	0.022	32.63	26.12	1481.4	12.07	0.163
JY0003	99.37%	0.61%	0.02%	−31.2	−34.7	−36	−3.5	338.5	1.53	0.011	0.018	30.06	24.61	1629.2	13.76	0.168
JY0004	99.39%	0.59%	0.02%	−30.6	−35.6	−36.3	−5	335.4	1.55	0.011	0.023	33.18	26.44	1455.0	12.68	0.163
JY0005	99.40%	0.58%	0.02%	−30.8	−34.9	−37.7	−4.1	297.6	1.52	0.011	0.019	29.79	24.16	1562.6	12.32	0.167
JY0006	99.36%	0.62%	0.02%	−30.1	−33.2	−35.2	−3.1	281.9	1.69	0.012	0.032	32.09	22.57	996.1	12.49	0.169
JY0007	99.38%	0.60%	0.02%	−30.4	−34.5	−35.9	−4.1	211.7	1.40	0.010	0.016	24.24	19.54	1525.4	10.83	0.167
JY0008	99.40%	0.58%	0.02%	−30.6	−33.9	−36.6	−3.3	273.5	1.53	0.011	0.019	27.35	21.85	1468.7	12.52	0.172
JY0009	99.40%	0.58%	0.02%	−30.3	−34.2	−36.3	−3.9	238.9	1.47	0.011	0.019	26.27	20.78	1412.9	11.50	0.161
JY0010	99.40%	0.58%	0.02%	−30.7	−34.9	−37.4	−4.2	393.0	1.49	0.011	0.027	37.00	29.02	1369.4	13.54	0.183
JY0011	99.37%	0.61%	0.02%	−29.3	−33.6	−36.6	−4.3	212.7	1.47	0.011	0.016	24.24	19.49	1508.8	10.91	0.167
JY0012	99.37%	0.61%	0.02%	−30.6	−34.3	−34.1	−3.7	264.1	1.57	0.011	0.016	30.06	25.37	1894.3	10.41	0.163
JY0013	99.42%	0.56%	0.02%	−31.5	−36.4	−37.2	−4.9	288.2	1.40	0.010	0.018	28.84	23.58	1620.4	12.22	0.160
JY0014	99.36%	0.62%	0.02%	−30.6	−34.6	−36.3	−4	242.1	1.57	0.011	0.018	26.13	20.74	1430.5	11.67	0.161
JY0015	99.47%	0.51%	0.02%	−32.7	−36.1	−37.5	−3.4	405.6	1.66	0.012	0.027	41.98	33.88	1532.3	11.97	0.161
JY0016	99.36%	0.62%	0.02%	−30.6	−34.6	−36.3	−4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
JY0017	99.41%	0.57%	0.02%	−30.1	−34.8	−34.9	−4.7	257.8	1.58	0.011	0.018	29.79	24.38	1627.2	10.57	0.159
JY0018	99.36%	0.62%	0.02%	−30.7	−35	−37.3	−4.3	250.5	1.56	0.011	0.015	25.46	21.04	1701.6	11.91	0.170
JY0019	99.30%	0.68%	0.02%	−30.9	−34.7	−35.4	−3.8	251.5	1.45	0.010	0.021	27.89	21.60	1309.2	11.65	0.163
JY0020	99.62%	0.36%	0.02%	−31.4	−35.3	−37	−3.9	364.7	1.55	0.011	0.025	39.68	32.21	1571.4	11.32	0.164
JY0021	99.57%	0.41%	0.02%	−30.2	−35.3	−36.4	−5.1	536.6	1.61	0.012	0.032	66.62	57.07	2061.7	9.40	0.169
JY0022	99.54%	0.44%	0.02%	−31.3	−35.2	−36	−3.9	440.2	1.41	0.010	0.022	38.19	31.61	1716.2	13.92	0.160
JY0023	99.35%	0.63%	0.02%	−30.8	−33.4	−36.2	−2.6	294.0	1.46	0.011	0.020	30.68	24.62	1496.9	11.94	0.164
JY0024	99.33%	0.67%	n.d.	−29.8	−33.2	n.d.	−3.4	298.0	1.44	0.010	0.023	29.96	23.30	1329.8	12.79	0.167
JY0025	99.33%	0.67%	n.d.	−30.3	−34.3	n.d.	−4	329.0	1.52	0.011	0.023	35.38	28.49	1516.4	11.55	0.165
JY0026	99.34%	0.66%	n.d.	−32.4	−34.9	n.d.	−2.5	329.0	1.55	0.011	0.025	32.25	24.87	1291.8	13.23	0.165
JY0027	99.34%	0.66%	n.d.	−29.8	−33.5	n.d.	−3.7	301.0	1.54	0.011	0.025	35.81	28.44	1434.7	10.59	0.170
JY0028	99.36%	0.64%	n.d.	−30.7	−35.1	n.d.	−4.4	322.0	1.49	0.011	0.020	40.09	34.12	1984.9	9.44	0.163
JY0029	99.45%	0.55%	n.d.	−31.0	−35.5	n.d.	−4.5	326.0	1.43	0.010	0.022	37.81	31.16	1680.7	10.46	0.164