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An Isotopic Geochemistry Approach on the Identification of Gas Sources of Two Wells in Tarim Basin

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Abstract Plenty of geochemical analyses were carried out on natural gas, oil and condensate samples collected from two wells in Tarim Basin and results were employed in interpreting their sources and distinguishing one from the other. The chemical compositions of gases from the both wells showed that they are of oilfied associated gas with a low dry coeffieient. Their carbon isotopic compositions might indicate a mixture of gas sources, and the input of the mantle-derived materials was denied by the isotopic parameters of noble gases, such as $^3He/^4He$ and $^4He/^{20}Ne$ ratios. The age of gases from these two wells was identified to be the Palaeozoic by the $^{40}Ar/^{36}Ar$ ratio.

Key words oil and natural gas genesis isotopic composition noble gas chemical composition of gases Tarim Basin

Introduction

Tarim Basin, located in the south of Xingjiang, is the largest hydrocarbon-bearing basin in China. Tectonically, the basin, taking shape of rhomb and covering an area of 560,000 km^2, is surrounded by the Tianshan, Kunlunshan and Arjin megafratures. Within the basin there are three uplifts and four segs, in which Cenozoic-Mesozoic oils and natural gases have been discovered (Fig. 1). Generally speaking, it is ascertained that major hydrocarbon-generating strata in this basin are the Cambrian-Ordovician, Carboniferous-Pemian and Triassic-Jurassic. In addition, the Sinian carbonate and sandy shale, the Silurian black shale and the Upper Cretaceous-Lower Tertiary marine deposit are also possible source rocks. However, the hydrocarbon source in Tarim Basin remains the most complicated among various petroleum-bearing basins in China.

This is not only because that the basin is vast in territory and almost covered by a desert but also because that it has a very complex history in tectonics, namely from the Sinian to Quaternary, almost every period of structural movements has been accomplished by volcanism. Over 600 million years various oil or gas source rocks of the basin have experienced plenty of the depositional formation-rework-reformation cycles, simultaneously petroleum pools have also undergone a complex process such as the accumulation, rework and reaccumulation, especially for the natural gas, which migrates more easily and is genetically characterized by multi-

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ple stages and multiple sources in the gaspool formation. In order to get a better understanding on the sources of natural gases in Tarim Basin, the present paper discusses the gas source of the two production wells in this basin by investigating some geochemical characteristics, such as chemical compositions, hydrocarbon components, carbon isotopic compositions of gaseous hydrocarbons and normal alkanes, and isotopic ratios of some noble gases.

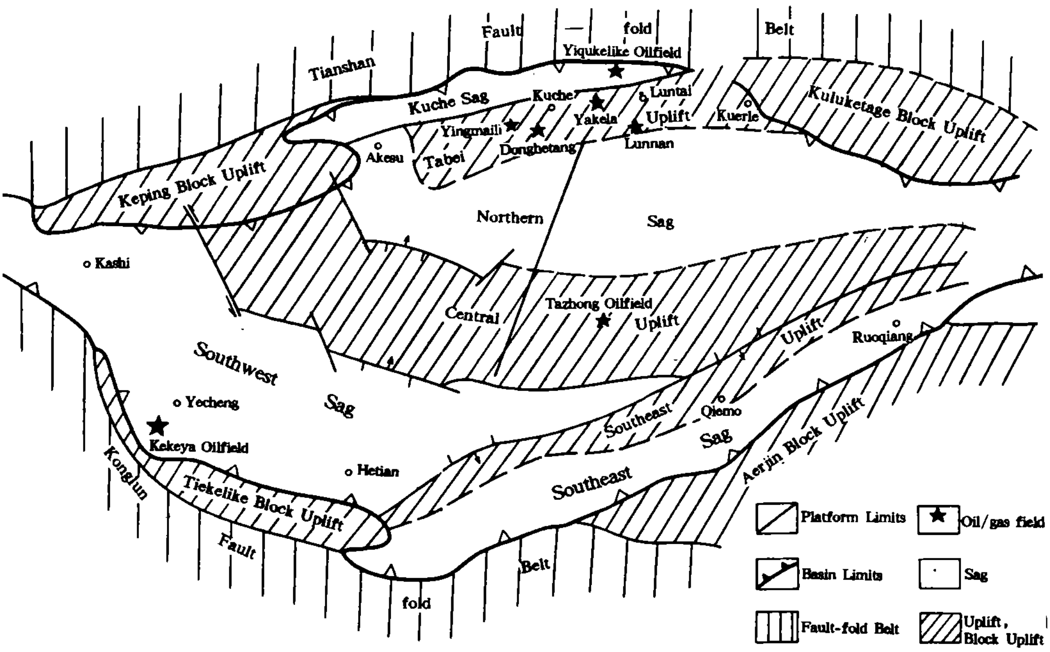

Fig. 1 Structural sketch of Tarim Basin and petroleum fields

Experiments

Samples including gas, oil and condensate were collected from the Sha-3 well and the Shacan-2 well, which lie tectonically within a slope structural zone east to the centre of the Tabei Uplift. Both of these wells are comparatively rich in natural gas and their oil belongs to the light one or condensate. The chemical compositions and the noble gas isotopes such as the $^4He/^{20}Ne$, $^3He/^4He$ and $^{40}Ar/^{36}Ar$ ratios of the gas samples were analysed by MAT-271 Trace Gas Mass Spectrometer and MM 5400 KX Noble Gas Isotope Mass spectrometer, the hydrocarbon components by HP-5890 Gas Chromatograph while MAT-252 Stable Isotope Mass Spectrometer was employed in measuring the carbon isotopes of the gas samples and of the normal alkanes in the light oil or condensate samples. All of these analytical data were applied to the investigation on the source of the natural gases from these two wells and their geochemical significance was discussed as well.

Results and Discussion

1) Table 1 gives chemical compositions of the natural gases from the Sha-3 well and the

Shacan-2 well, from which it can be seen that both the wells have a methane concentration to be around 80%, suggesting a relatively high content of heavy hydrocarbons, thus they are an oilfield associated condensate gaspool. In addition, the Sha-3 well also contains little CO_2, Hg and He and its N_2 and Ar, being very small amounts, are even undetected. On the contrary, the contents of N_2 and CO_2 in the Shacan-2 well are relatively high and their concentrations range around 6.93% and 5.53%, respectively. Generally, according to the nitrogen concentration within the natural gas composition, gaspools can be classified into a nitrogen-poor gaspool with the N_2 concentration less than 5%; a nitrogen-moderate gaspool with that varing from 6% to 15%; and a nitrogen-rich gaspool with that over 15%. Thus, the natural gas of the Shacan-2 well could be considered to come from a nitrogen-moderate gaspool. The abundance of argon in the Sha-2 well is 1.12%, relatively higher even compared with other gaswells in this area.

Table 1 Chemical compositions of natural gases from the Sha-3 well and Shacan-2 well

Well No.	Producing Bed Age	Depth	Composition(%)						Hg(ng/m³)
			CH_4	N_2	CO_2	H_2	He	Ar	
Sha-3	E	5049—5051	80.06	—	0.58	0.119	0.031	—	3.15×10^2
Shacan-2	O	5363—5391	79.25	6.93	5.53	0.050	0.060	1.12	4.2×10^3

Table 2 Hydrocarbon compositions of natural gases from the Sha-3 well and Shacan-2 well

Well No.	Producing Bed Age	Hydrocarbon Composition (%)							Compositional Featares			
		C_1	C_2	C_3	iC_4	nC_4	iC_5	nC_5	C_2^+(%)	C_2/C_1	$\frac{C_1}{C_2+C_3}$	$\frac{iC_4}{nC_4}$
Sha-3	E	66.74	19.43	8.26	1.87	2.09	0.88	0.73	33.26	0.29	2.41	0.89
Shacan-2	O	74.83	10.18	6.83	1.70	3.48	1.38	1.62	25.17	0.14	4.40	0.49

2) Methane concentration of the tolal hydrocarbon components of the natural gas from these two wells is 66.74% and 74.83%, respectively (Table 2), and among C_2^+ hydrocarbons ethane is predominant over the other components in the both wells, indicating a relatively low dry coefficient. Moreover, the natural gas from the Sha-3 well is wetter than that from the Shacan-2 well for the former contains about 33.26% of C_2^+ hydrocarbons while the latter has only 25.17% of C_2^+ hydrocarbons. To sum up, the data of hydrocarbon compositions of the natural gases from the Sha-3 and Shacan-2 wells have shown that both of them belong to an oilfield associated gas.

Table 3 Carbon Isotopic compositions of natural gases from the Sha-3 well and Shacan-2 well

Well No.	Producing Bed Age	$\delta^{13}C$ ‰(PDB)				
		C_1	C_2	C_3	C_4	C_5
Sha-3	E	−37.5	−26.1	−23.1	−25.3	—
Shacan-2	O	−47.7	−31.3	−29.5	−30.1	−29.9

3) Carbon isotopic compositions of methane and its homologues are widely used in the genetic study of natural gases[2,7]. When methane and its homologues have a normal order of δ^{13}

C, i. e. $\delta^{13}C_1 < \delta^{13}C_2 < \delta^{13}C_3 < \delta^{13}C_4$, the gas can be regarded to be biogenic and have a single source, however, if the order of $\delta^{13}C$ values is reversed, namely $\delta^{13}C_1 < \delta^{13}C_2 > \delta^{13}C_3 < \delta^{13}C_4$ or $\delta^{13}C_1 < \delta^{13}C_2 > \delta^{13}C_3 > \delta^{13}C_4$, etc. , it might indicate either the mixture of gas sources or the occurrence of the secondary gas. The analytical data of the carbon isotopic compositions of methane and its homologues from the Sha-3 and Shacan-2 wells are shown in Table 3, from which it can be seen that both of them have a normal order of $\delta^{13}C$ values in methane, ethane and propane but a slightly reversed order in butane and pentane, this may suggest a contamination of gases from these two wells. Table 3 also shows that the $\delta^{13}C$ values of the natural gas from the Sha-3 well are relatively heavier than those from the Shacan-2 well, the difference between them is about 10‰ for methane and 5‰ for ethane, propane and butane. One of the explanation for this phenomenon might be that some gases of the Sha-3 well were derived from terrestrial source rocks, which usually have a relatively heavier carbon isotopic ratio.

Studies on carbon isotopic ratios of normal alkanes in the sedimentary organic matter have been reported in recent literatures[1,3,4,5,8]. It can be preliminarily held by some previous investigations [11,12] that the distribution of carbon isotopic ratios of normal alkanes from the crude oils and condensates in Tarim Basin is characterized by ① the older the age of the source rock is, the lighter carbon isotopic ratio of individual normal alkanes of the crude oil or condensate possesses; and ② the carbon isotopic ratio of individual normal alkanes from terrestrial crude oils and condensates becomes lighter with the increase of their carbon numbers while that from marine ones shows a tendency towards the heavier or just keeps unaltered with the increase of their carbon numbers. On the basis of this understanding it can be seen from Fig. 2 that the source material of the condensate in the Sha-3 well is quite different from that in the Shacan-2 well.

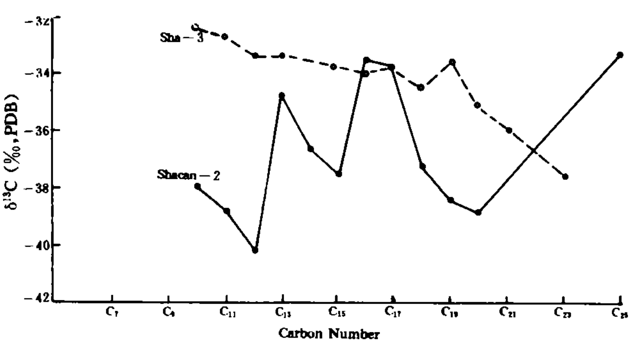

Fig. 2 Distribution of carbon isotopic compositions of normal alkanes from the condensate of the Sha-3 well and Shacan-2 well

The distributive curve of carbon isotopes of individual normal alkanes in the condensate from the Sha-3 well is characteristic of the terrestrial input, the $\delta^{13}C$ values in the lower carbon-numbered fraction (C_{10}—C_{19}) vary from −32. 5‰ to −34. 7‰ while those in the higher one (C_{19+}) apparently become lighter (−35. 2‰——37. 6‰). The curve looks basically smooth, indicating a relatively simple source input and Type Ⅲ kerogen as the major source material. However, the curve of the Shacan-2 well looks a little bit complicated, its lower carbon-numbered fraction has fluctuating $\delta^{13}C$ values, possibly due to the multiple input of source materials, but the tendency of the whole curve still indicates an increasing of $\delta^{13}C$ values with the increase of carbon numbers, suggesting a marine condensate. Compared with the $\delta^{13}C_{10}$ratio of the condensate from the Sha-3 well (−32.50‰), the $\delta^{13}C_{10}$ ratio of that from the Shacan-2 well is only −38.0‰ and the difference between them is 5.5‰. This is probably because that the condensate of the Shacan-2 well is derived from Palaeozoic marine source materials. The difference exists not only in the individual normal alkanes of these two wells but also in their gases as mentioned above.

4) Analyses on some isotopic compositions of noble gases from the natural gases of the Sha-3 and Shacan-2 wells were carried out in this study and the results are listed in Table 4. The $^{3}He/^{4}He$ and $^{4}He/^{20}Ne$ ratios are common geochemical indicators to distinguish mantle-derived materials from the crust-derived ones. Generally speaking, the standard $^{3}He/^{4}He$ ratio is 1×10^{-5} for the mantle, 1.4×10^{-6} for air and 1×10^{-8} for the crust while the standard $^{4}He/^{20}Ne$ ratio is 0.318 for air, 1000 for the mantle-derived gas and in between for the crust-derive one[6-9]. It is shown in Table 4 that the $^{3}He/^{4}He$ ratios of natural gases from these two wells as well as the $^{4}He/^{20}Ne$ ratio from the Shacan-2 well have indicated that they are both crust-derived gases and no mantle-derived helium is found to be present in these gases.

According to the age accumutation effect of the radiogenic argon, the $^{40}Ar/^{36}Ar$ ratio increases with the increase of source rock age [10]. The $^{40}Ar/^{36}Ar$ ratio of the natural gases from the Sha-3 and Shacan-2 wells is remarkably different, one is 1410 and the other is 3231. By the integration of other $^{40}Ar/^{36}Ar$ ratios in Tarim Basin with the specific geological settings, it can be identified that the natural gas from the Sha-3 well is generated in the Upper Palaeozoic strata (Carboniferous or Permian) and reservoired in the Eogene strata by migration, but the natural gas from the Shacan-2 well originates from the Ordovician marine carbonate rock and is reservoired in the same aged gaspool. Moreover, the condensate and gas from the Sha-3 well do not share the same source rock, the condensate like the oil in the well came from the Jurassic-Triassic terrestrial source rock while the possible source rock for the gas is mainly the Carboniferous marine one even though small amount of the gas may be derived from the Jurassic-Triassic strata (Table 5).

Table 4 Isotopic compositions of noble gases in natural gases from the Sha-3 well and Shacan-2 well

Well No.	Producing Bed Age	$^{30}Ar/^{36}Ar$	$^{3}He/^{4}He$ ($\times10^{-6}$)	$^{4}He/^{20}Ne$
Sha-3	E	1410	0.059±0.002	—
Shacan-2	O	3231	0.104±0.002	133

Table 5 Geochemical parameters of the oil and gas from the Sha-3 well

Producing Bed Age	Petroleum			Gas	
	Pr/Ph	Methylbezene/n-Heptane	$\delta^{13}C$ (‰)	$^{40}Ar/^{36}Ar$	Hg(ng/m³)
E	2.16	1.18	−25.57	1410	3.15×10^{2}
Hydrocarbon Source	J—T terrestrial source rocks			Most from Carboniferous marine source rocks and small amount from J—T terrestrial source rocks	

CONCLUSIONS

(1) Chemical compositions of gases from the both wells have shown that the concentration of methane is not high, ranging from 66. 74% to 74. 83% and ethane predominates in quantity over propane, indicating that they are an oilfield associated gas with a low dry coefficient. The Shacan-2 well, containing 6. 39% of nitrogen, is a nitrogen-bearing moderate, and its argon content up to 1. 12% is also relatively high compared with other wells in Tarim Basin.

(2) The carbon isotopic compositions of gases from the both wells are in the normal order from methane to propane, i. e. $\delta^{13}C_1 < \delta^{13}C_2 < \delta^{13}C_3$, but in a reversed order with butane and pentane, this might indicate that they are mixed or secondary gases. The carbon isotopic compositions of n-alkanes in condensates from these two wells suggest that there are some differences in the source material input, the condensate in the Sha-3 well, like its oil, is characterized by a terrestrial origin while that in the Shacan-2 well is mainly derived from Palaeozoic marine source materials.

(3) The isotopic parameters of noble gases, such as the $^{3}He/^{4}He$ and $^{4}He/^{20}Ne$ ratios, have shown that natural gases from these two wells are of the crust-derived gas and no mantle-derived materials are found to be present in these gases. The $^{40}Ar/^{36}Ar$ ratios also indicate that the gas in the Sha-3 well mainly comes from Upper Palaeozoic Carboniferous or even older mixed sources, this is quite different from the origin of the oil in this well, which is derived from Triassic and Jurassic source rocks, moreover, the gas of the Shacan-2 well originates from the Cambrian and Ordovician marine carbonate rocks.

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