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High molecular weight (C_{35}^{+}) *n*-alkanes of high-waxy condensate and its source kitchen orientation in the Qianmiqiao burial-hill zone, Bohai Gulf Basin

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Abstract The high-waxy condensate in the Qianmiqiao Ordovician burial-hill zone, Bohai Gulf Basin, North China has been investigated by way of high temperature gas chromatography. As high-mature oil, its high molecular weight wax fraction is mainly composed of C_{35}—C_{69} *n*-alkanes with CPI_{37-55} values of 0.94—1.10. On conditions that core-drilling of source rocks was limited and the exact location of source kitchen is still uncertain in the region, it is inferred that the orientation of main source kitchen for the condensate should be on the east of the burial-hill zone, i.e. from the direction of Qikou Sag, according to oil-oil correlation between the condensate and surrounding high-waxy oils as well as lateral distribution of the wax content of crude oils. In addition, it is also further confirmed that the oil filling direction for this condensate reservoir is from NE to SW, i.e. from wells BS-4, through BS-7, to BS-8 based on the analyses of 9 maturity and 3 pyrrolic N-compound parameters.

Keywords: Qianmiqiao burial-hill, high temperature gas chromatography (HTGC), high-waxy condensate, high molecular weight (HMW) *n*-alkanes.

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High-waxy condensate is a kind of special hydrocarbon resources, i.e., the high molecular weight (HMW) alkanes, which usually appear in a solid wax fraction under normal temperature and pressure, but are dissolved by hydrocarbon gas as a high-waxy condensate of single gaseous phase under subsurface high temperature and pressure. Nevertheless, once produced in an oil-gas well, the subsurface condensate flows into the well-bottom, and then immediately differentiates into the products of multiple phases due to temperature and pressure decreasing. Hence, gas, liquid high-waxy condensate, and solid waxes or ozocerite could be respectively recovered at the well-head. This kind of special resources is rare in the world, so that it is not specifically reported in geochemical literature. In recent years, however, high-waxy condensate has been found in both the Bohai Gulf Basin, North China and the Tarimu Basin, West China.

The mixture of solid alkanes isolated from crude oil is called paraffin. Paraffin is mainly composed of C_{25}—C_{90} *n*-alkanes, among which, C_{30}^{+} HMW *n*-

alkanes, to some extent, are predominant over iso-alkanes and naphthenes[1,2]. In laboratories, distillation and precipitation tests are commonly used to determine the wax content in crude oils. Usually, the high-waxy oil has a wax content of ≥15% (or ≥ 10%), most of which are rich in C_{35}^{+} HMW wax fraction.

Since the middle of the 1980s, the development of high temperature gas chromatography (HTGC) has extended the detection level of the hydrocarbon compounds, and thus provided a tool for detecting C_{40}—C_{100} HMW alkanes[1−4]. In the present study, GC-MS and HTGC methods were used to investigate the HMW wax fraction of condensate in the Qianmiqiao burial-hill oil-gas field, the Bohai Gulf Basin, North China. On conditions that core-drilling of source rocks was limited and the exact position of source kitchen is still uncertain, the authors try to adopt the conception and techniques of reservoir geochemistry to trace the oil filling pathway and to predict the orientation of source kitchen for the high-waxy condensate.

1 Geological and geochemical backgrounds

The Qianmiqiao burial-hill zone is a large-scale structural zone of horst-style fault-blocks, which is sandwiched by two large-size faults, at the north of the Huanghua Depression, the Bohai Gulf Basin, North China (fig. 1). As one of the major Tertiary hydrocarbon-generating sags, the Banqiao Sag is located on the west of the Qianmiqiao burial-hill zone and the Qikou Sag on its east. The burial-hill is composed of the Middle Ordovician carbonates, which are directly overlaid by the Mesozoic and Tertiary strata for the lack of Permo-Carboniferous sediments. The Ordovician superface is about 4050—4250 m deep and appears as three NE-SW-trending highs within the region studied (fig. 1).

With a high production, high-waxy condensate was first found from the Middle Ordovician carbonate in Well BS-7 at the middle high of the Qianmiqiao burial-hill zone in 1998. By drill stem test (DST), the maximum production can be up to 609.3 m^3/d for oil as well as 454117 m^3/d for gas. Since then, wells BS-8 and BS-4 were disposed respectively at both south and north highs, and high-waxy condensate has also been obtained[5].

Taking twice DSTs as examples, two condensate samples obtained from Well BS-7 are the typical cases for the occurrence of hydrocarbons in the Qianmiqiao burial-hill zone. For the first one at the depth interval of 4627—4281 m, white wax and colorless condensed oil are collected, its wax content is 15.9%; whereas light yellow wax and condensed oil for the second one at the depth interval of 4332—4395.6 m are sampled, the wax content is as high as 34.1%, both of which are followed by a great quantity of hydrocarbon gas. The gas produced from the three wells has different contents of condensed oil, the maximum is up to 314—345.6 g/m^3 in Well BS-7 and the minimum only 42.6 g/m^3 in Well BS-4, in between, 289.3 g/m^3 in Well BS-8.

The physical properties of the 5 condensed oil samples from wells BS-4, -7 and -8 are characterized by low density (0.78—0.8034 g/cm^3), low viscosity (1.24—2.2 mPa・s), moderate solidifying point (21—27℃), high wax content (15.9%—34.1%) and low resin plus asphaltene contents (3.12%—3.16%), which appear as the features of high-waxy condensate.

According to the previous studies, the Mems. 1 and 3 of the Eogene Shahejie Formation were regarded as the major source beds for crude oils, their dark-colored mudstones are evaluated to be "ordinary" and "good" source rocks in both Banqiao and Qikou sags[6,7]. As far as the Shahejie Formation is concerned, the middle section (Es_1^{md} in the Banqiao Sag) and middle-to-upper sections ($Es_1^{md\text{-}up}$ in the Qikou Sag) were attributed to the immature-marginal mature source beds, whereas the lower section (Es_1^{lw}) was attributed to non-source bed[1)]. Moreover, Es_3 dark-colored mudstone is the mature source bed for the Ordovician carbonate and the Es_3 sandstone reservoirs. In the Huanghua Depression, there is no more Tertiary

1) Lu Hong, The hydrocarbon sources of oil pool in the Qianmiqiao Burial Hill region, Huanghua Depression, Ph. D. Thesis (in Chinese), University of Petroleum (Beijing).

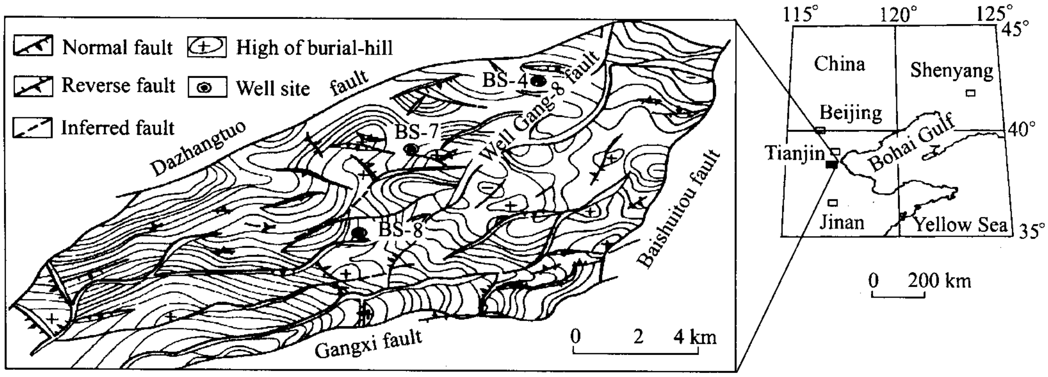

Fig. 1. The tectonic framework of the Qianmiqiao burial-hill zone and well sites of BS-4, -7 and -8.

source bed available below Es_3, only Carboniferous and Ordovician could serve as both potential source beds, but the above-mentioned three source beds have different geochemical characteristics[8−10], crude oils originating from which should be referred to as different oil populations, so far, no mixed oil was found.

In the surrounding region, there is only a deep well, Well BS-35, within the south of the Banqiao Sag on the west of the Qianmiqiao burial-hill zone, which almost penetrated through the whole Es_3 stratum. Not only Es_3 dark-colored mudstone cores, but also light oil were obtained from the depth interval of 4719—4743 m in this well. By way of the correlation between the condensate in wells BS-4, -7, -8 and the light oil or source rocks in Well BS-35, it is verified that the condensate should originate from the Es_3 lacustrine mudstone based on isotopic d^{13}C fingerprints, light hydrocarbon composition and molecular markers[8]1). However, so far there is not any corresponding source rock sample available yet within the limits of Qikou Sag on the east of the Qianmiqiao burial-hill zone, it is still difficult to determine the orientation of source kitchen for the high-waxy condensate.

2 Experimental

Two portions of each high-waxy condensate sample were taken respectively from wells BS-4, -7 and -8. By means of column chromatography, the first portion of each condensate sample was separated into aliphatic and aromatic fractions for the further GC and GC/MS analyses. Based on the practical wax content, the second portion was dissolved into a right amount of tetrahydrofuran solvent, the solution was saved overnight for concentration and precipitation of the HMW wax fraction and then the precipitate was filtered and collected as the HMW wax fraction.

The aliphatic and HMW wax fractions were analysed on a Shimadzu Model GC-17A gas chromatograph respectively with different GC analytical conditions for the detection of *n*-alkane composition, and a Modal CLASSGC-10 working station was used for the data processing. The GC-MS analyses of the aliphatic and aromatic fractions were performed on a Finnigan Model SSQ-710 quadrupole instrument and various maturity parameters were provided. All the details of analytical conditions are reported in a paper by Wang Tieguan et al. (2001)[5].

For the analytical procedure of pyrrolic nitrogen compounds, cf. Wang et al. (2000)[11], from which, carbazole parameters were provided to show the migration and filling pathways of the high-waxy condensate.

3 Results and discussion

3.1 Distribution of wax content in crude oil

(i) Overall distribution. There are numerous physical property data for more than 3300 Tertiary

1) See the footnote on page 256.

crude oil samples around the Qianmiqiao burial-hill zone. All the data, acquired from DST or initial producing test in each oil well, are selected for statistical study, which is expected to reveal the physical properties of crude oils under the original reservoir conditions.

It is shown by the statistics that the initial wax content of all Tertiary crude oils ranges from 0.31% to 43.7%, but most of which are concentrated within a range of 5%—15% (fig. 2). Based on the wax content data, the authors try to classify these crude oils and define the crude oil with wax content more than 15% as the high-waxy oil, that between 5% and 15% as the moderate-waxy oil and that less than 5% as the low-waxy oil. Consequently, most of the crude oil samples are attributed to the moderate-waxy content, but a considerable amount of crude oil samples, with a wax content in the range of 15%—45%, are still referred to the high-waxy oil surrounding the Qianmiqiao region.

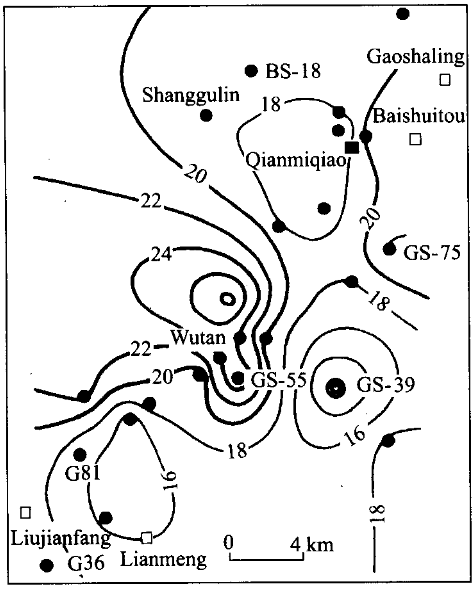

Fig. 2. The lateral variation of wax content in crude oils from oil-producing horizon of the Mem. 3 of the Shahejie Formation, in the Qianmiqiao surrounding region. • indicates the oil well site with oil wax content ≥20%.

(ii) Vertical distribution. The distribution of oil-producing horizons is from the Mem. 3 of the Eogene Shahejie Formation (Es_3) to the Neogene Minghuazhen Formation (Nm) around the Qianmiqiao burial-hill zone. For the sake of statistics, the authors define the rate of the high-waxy oil samples in the total oil samples as the high-waxy oil rate (R_w) for each oil-producing horizon. The statistics show that R_w value vertically appears as a bimodal distributional pattern, i.e. there are two crest values of R_w respectively at the $Es_1^{Up\text{-}Md}$ (85.2%—84.6% in R_w) as well as at the Es_3 (72.7%), i.e. the high-waxy oil is relatively enriched in both the horizons (table 1).

Hsieh et al. (2001) proposed that, as the oil moves from the source moterial, most of the microcrystalline waxes precipitate along the migration pathway and the residual oil will become depleted in HMW hydrocarbons. Thus the horizons, in which high-waxy oil is relatively enriched, are most probably the source beds for the oil. Therefore, based on the vertical distribution of the R_w values (table 1) it is determined that both $Es_1^{Up\text{-}Md}$ and Es_3 should be the potential Eogene source beds around the Qianmiqiao burial-hill zone. As a matter of fact, both the horizons have been verified as the main source beds according to the source rock investigation in the Banqiao and Qikou sags[6—8]1).

(iii) Lateral distribution. As the oil migrates towards lower temperature direction, the long-chain *n*-alkanes with higher melting point are the first compounds to precipitate from the oil[2]. Within the same oil-producing horizon, therefore, the highest wax content zone of crude oil should be laterally at the position near the source kitchen. In view of the fact that the Es_3 lacustrine mudstone is the source bed for the high-waxy condensate reservoir in the Qianmiqiao burial-hill zone[5], the lateral distribution of oil wax content in the Es_3 sandstone reservoirs can serve as the geochemical basis of a fair inference for the orientation of high-waxy condensate in the region.

Fig. 2 shows the lateral distribution of wax content of the Es_3 crude oils around the Qianmiqiao burial-hill zone. Two high-value zones of wax content are

1) See the footnote on page 256.

Table 1 Statistics on the vertical distribution of wax content in crude oils in the Qianmiqiao surrounding region

Stratum			Sample number	Wax content (%)			High-waxy oil rate (R_w)(%)
Series	Mem. & Fm.	Symbol		Max.	Av.	Min.	
Neogene	Minghuazhen Fm.	Nm	32	5.3	14.4	23.7	50
	Guantao Fm.	Ng	17	4.4	15.9	24.6	64.7
Eogene	Up. of Mem. 1 Shahejie Fm.	$Es1^{up}$	13	9.8	20.31	25.8	84.6
	Md.of Mem. 2 Shahejie Fm.	$Es1^{md}$	27	1.8	17.3	25.5	85.2
	Lw. of Mem. 1 Shahejie Fm.	$Es1^{lw}$	80	1.1	17.6	32.8	73.8
	Mem. 2 Shahejie Fm.	Es2	53	1.2	15.5	29.9	52.8
	Mem. 3 Shahejie Fm.	Es3	33	8.4	17.2	28.8	72.7

distributed respectively on the east and west sides in the region, while a low-value zone is just in between. That is, the former is higher than 20% in wax content respectively at Baishuitou——Well GS-75 and Wutan, the latter is lower than 18% from Well BS-18, through Well GS-39, to Lianmeng; whereas the Qianmiqiao burial-hill zone is just located in the north part of the low wax content zone adjacent to Baishuitou. Obviously both the high value zones should indicate two source kitchen orientations for the Es_3 high-waxy oil. It can also be seen that the source kitchen, indicated by the high wax content zone at Baishuitou-Well GS-75, is also a shortcut orientation for the Qianmiqiao oil-gas field to be directly sourced (fig. 2)

3.2 *n*-alkane distribution in the condensate

In routine gas chromatograms of the aliphaltic fraction of high-waxy condensate from wells BS-4, -7 and -8, the *n*-alkane series ranges from nC_{10} to nC_{38} with the major peak at nC_{14} or nC_{16} as well as a trace of nC_{35}^{+} alkanes, showing a unimodally distributional pattern. Its lower-carbon-number homologues obviously predominate over whole the *n*-alkane series, with the $(nC_{21}+nC_{22})/(nC_{28}+nC_{29})$ ratio up to 2.0—2.5, and there is no odd-carbon-number predominance observed, with CPI_{25-33} and OEP_{15-19} values of 1.05—1.08 and 1.04—1.10, respectively, indicating a higher maturity (fig. 3).

However, HTGC analysis of the aliphaltic fraction of condensate samples shows that the *n*-alkane series has a bimodal pattern and there is a minimum abundance around nC_{35} (fig. 4). The front peaks correspond to the *n*-alkane range in the above routine gas chromatograms of the aliphaltic fractions (fig. 3). Regarded as the HMW fraction, the back peaks are mainly composed of nC_{35}—nC_{69} alkanes with the major peak mostly at nC_{47}, but at nC_{44} only for that of Well BS-8 (fig. 4). Based on both absolute and relative quantitations, CPI_{37-55} and OEP_{45-49} values are respectively 0.94 — 1.10 and 1.10 without any odd-carbon-number predominance (fig. 4 and table 2). Therefore, the high-waxy condensate should be attributed to the category of mature-high mature oil.

3.3 Oil-oil correlation of the HMW wax fraction

In order to remedy the defect of oil-source rock correlation, 8 oil wells surrounding the Qianmiqiao burial-hill zone were selected to sample the high-waxy oil in reservoirs from the Mem. 3 of Shahejie Formation to the Guantao Formation, their HMW wax fractions have been analyzed and correlated with the high-waxy condensate of Well BS-4. By way of the correlation on HMW *n*-alkanes, useful information on oil population and source kitchen has been obtained.

Well B-14-1 is located just on the southwest side of wells BS-4 and -7 (fig. 5), in which heavy oil was produced from the shallow reservoir of Neogene Guantao Formation. The HMW *n*-alkanes in the heavy

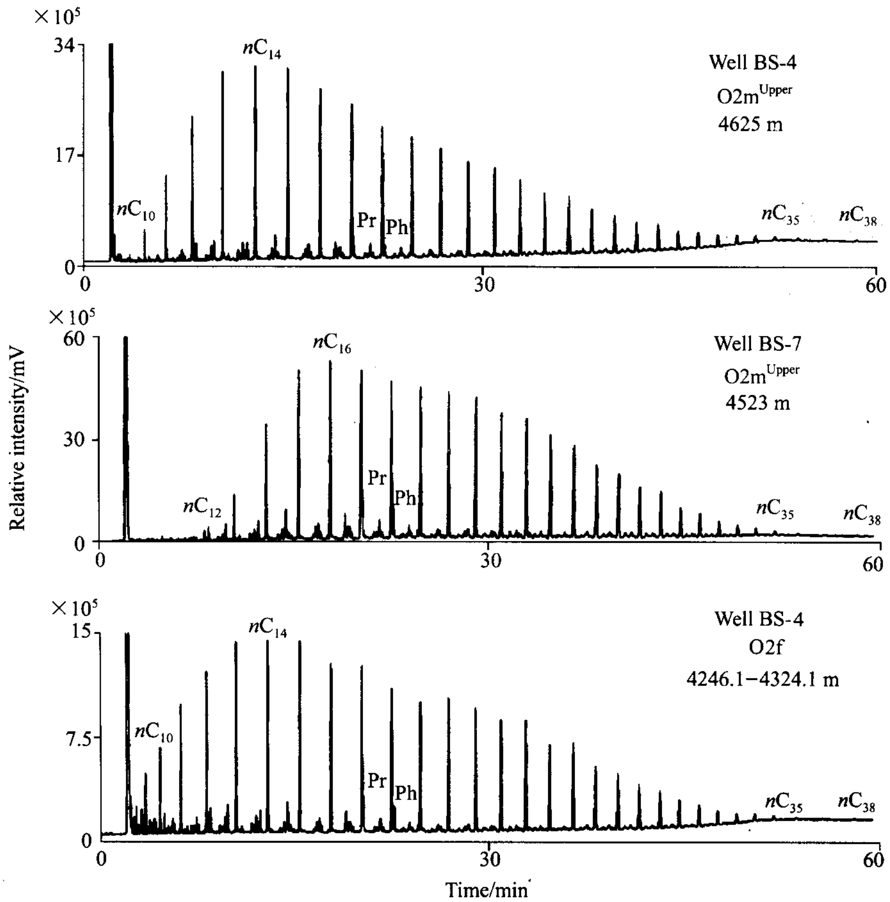

Fig. 3. Gas chromatograms of the aliphaltic fractions of high-waxy condensate. Pr, Pristane; Ph, phytane.

Table 2 Composition of HMW (C_{35}^{+}) wax fraction in the high-waxy condensate

Well No.	Depth/m	Stratum	Wax content (%)	Distribution of HMW (C_{35}^{+}) *n*-alkanes					
				carbon number	major peak	abs. quant.[a)]		rel. quant.[b)]	
						CPI_{37-55}	OEP_{45-49}	CPI_{37-55}	OEP_{45-49}
BS-4	4625	O_2m^{up}	–	nC_{35}—nC_{66}	nC_{47}	1.09	1.09	1.09	1.11
BS-7	4523	O_2m^{up}	15.9	nC_{35}—nC_{66}	nC_{47}	1.10	1.10	1.10	1.11
BS-8	4246—4324	O_2m^{up}	33.3	nC_{35}—nC_{69}	nC_{47}	0.94	1.04	0.94	1.05
BG-5	3229—3234	Es_2	24.6	nC_{35}—nC_{72}	nC_{47}	1.17	1.18	1.18	1.18
BS-78-1	2208—2210	Ed_2	–	nC_{35}—nC_{75}	nC_{47}	1.20	1.17	1.20	1.18
Bai-21-4	3133—3151	Es_2	23.2	nC_{35}—nC_{72}	nC_{45}	1.18	1.22	1.18	1.18
B-14-1	1801—1806	Ng_1^{III}	1.62	nC_{35}—nC_{73}	nC_{43}	1.17	1.16[c)]	1.17	1.20[c)]

a) Absolute quantitation based on internal standard squalane coinjection. b) Relative quantitation calculated based on HTGC peak areas. c) OEP_{41-45} values.

oil show a distribution fingerprint completely different from the high-waxy condensate, i.e. a broadened and gentle peak shape for the overall fingerprint, a major peak moving to nC_{43}, an obvious odd-carbon-number predominance with CPI_{37-55} and OEP_{41-45} values of 1.17 and 1.16—1.20, respectively[5], a very low correlation coefficient of 0.48 with the condensate (figs. 5, 6 and table 2), indicating remarkable difference not only in oil sources, but also in oil maturity. Moreover, based on the molecular markers of terpanes and polycyclic aromatic hydrocarbons (PAHs), the oil-source rock correlation has also confirmed the difference in

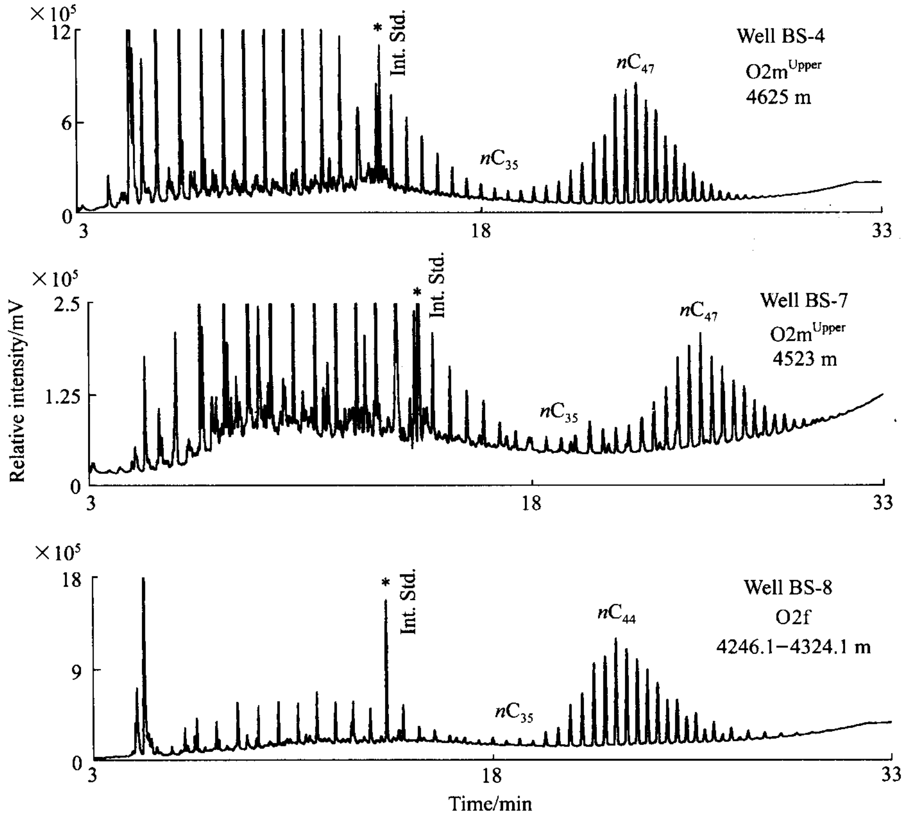

Fig. 4. High temperature gas chromatograms of the HMW C_{35}^{+} *n*-alkanes in the high-waxy condensate. ∗, Co-injected internal standard squalene peak.

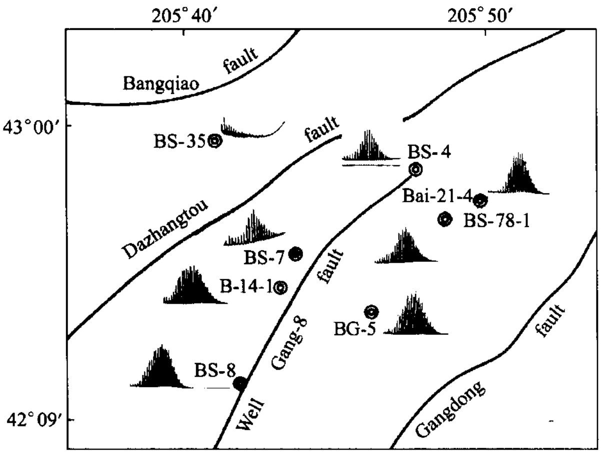

Fig. 5. Oil-oil correlation of HMW C_{35}^{+} *n*-alkane fingerprints between the high-waxy condensate and crude oils.

their oil sources. The heavy oil in Well B-14-1 is the representative of an oil population derived from the immature-marginal mature mudstones of the middle-to-upper sections of Mem. 1 of Shahejie Formation[5]1), while the high-waxy condensate in wells BS-4, -7 and -8 is sourced by the Es_3 mature-high mature source rocks[8].

Even though the aliphatic fractions of the light oil and source rocks in Well BS-35 are well correlated with the high-waxy condensate in wells BS-4, -7 and –8[8]1), the C_{35}—C_{47} HMW *n*-alkanes of the light oil are only in trace and the fingerprints of C_{35}^{+} HMW *n*-alkanes between the light oil and the condensate are completely different and incomparable (figs. 5, 6). Therefore, the light oil in the Banqiao Sag and the high-waxy condensate in the Qianmiqiao region should be referred to different oil populations. The source kitchen in the Banqiao Sag cannot supply the C_{35}^{+} *n*-alkanes for the high-waxy condensate.

1) See the footnote on page 256.

However, the fingerprints of nC_{35}^{+} HMW *n*-alkanes are well correlated between the high-waxy condensate in wells BS-4, -7, -8 and the high-waxy oils in wells BS-78-1 (the Mem. 2 of the Dongying Formation, Ed_2), BG-5 (the Mem. 2 of the Shahejie Formation, Es_2) and Bai-21-4 (Es_2), most of which show a major peak at *n*-C_{47}; in particular, the correlation coefficient between wells BS-4 and BS-78-1 is as high as 0.99 (figs. 5, 6 and table 2). Therefore, all these oils/condensate should be referred to as an identical source bed or the same oil population. By comparison with the condensate, just duo to the shallower depth, newer stratigraphic horizon and lower maturity, these high-waxy oils have a certain odd-even preference of *n*-alkanes, CPI_{37-55} and OEP_{45-49} values are 1.17—1.20 and 1.17—1.22, respectively (fig. 6 and table 2). Particularly, wells BG-5, BS-78-1 and Bai-21-4 are all located on the east side of the Qianmiqiao burial-hill zone and belong to the range of the Qikou Sag (fig. 5). Taking well BS-4 as an example, therefore, the oil-oil correlation reveals that the high-waxy condensate should mainly originate from the orientation of the Qikou Sag on the east side of the Qianmiqiao burial-hill zone in stead of the direction of the Banqiao Sag on the northwest side of Qianmiqiao.

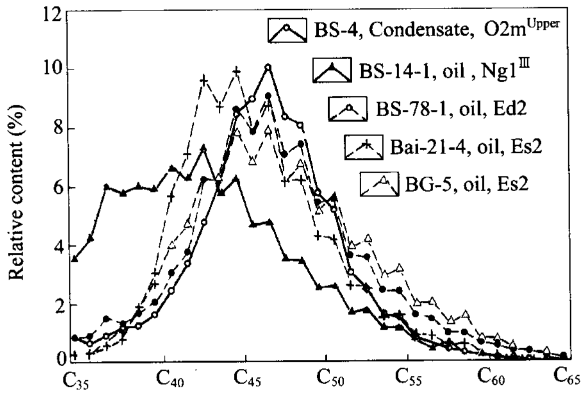

Fig. 6. The HMW C_{35}^{+} *n*-alkane GC correlation between the high-waxy condensate and crude oil in the Qianmiqiao surrounding region.

3.4 Tracing oil migration

The oil filling mode established by England et al. (1987) suggests that during oil migration and reservoir filling, the source bed will continue to subside, an increasingly mature oil will enter the reservoir and the flowing oil will fill the reservoir in a set of advancing oil fronts, thus the relatively low mature oil is in the front of the oil flow, while the back oil has the higher maturity[12]. As for a single reservoir or a tectonic zone, therefore, the direction of oil variation from higher maturity to lower maturity can trace the pathway of petroleum migration; in other words, the laterally highest mature oil should be at the place most close to its source kitchen.

All the 9 conventional parameters of oil maturity, including paraffin index PI_1 and heptane value PI_2 for light hydrocarbons, the light to heavy ratio $(C_{21}+C_{22})/(C_{28}+C_{29})$ for *n*-alkanes, Ts/Tm for triterpanes, methylphenanthrene indices MPI_1, MPI_2, MPI_3 and F_1, F_2 for aromatic hydrocarbons, identically show that the maturity tendency of the high-waxy condensate in the Qianmiqiao burial-hillzone indicates the highest mature condensate at Well BS-4, the moderate one at Well BS-7 and the lowest one at Well BS-8 (table 3, fig. 7). Therefore, the high-waxy condensate should migrate from northeast to southwest, Well BS-4 be just at the place near the filling point and source kitchen. As an auxiliary parameter, moreover, the solidifying point data of condensate in fig. 7 and table 3 reflect the decreasing process of the dissolved wax in condensate, which is also indicative of oil migration (fig. 7).

Due to the geochromatographic fractionation effect during oil migration, the isomer composition of pyrrolic nitrogen compounds can also serve as the tracers for oil migration[13,14]. The isomer abundance ratios of oils, such as "NH-partially exposed isomers/1,8-dimethylcarbazole" (abb. PE/1,8-DMC) and "benzo[a]carbazole/(benzo[a]carbazole + benzo-[c]carbazole)" (abb. [a]/[a] + [c]), are effective parameters for tracing oil migration/filling. As the distance of oil migration increases, the PE/1,8-DMC ratio tends to reducing, but the [a]/[a]+[c] ratio increasing[11,14]. Therefore, from Wells BS-4, through Well BS-7, to Well BS-8, the varying tendency of pyrrolic nitrogen compounds in the high-waxy condensate shows reducing PE/1,8-DMC and increasing [a]/[a]+[c] values, this also confirms the oil migration/filling orientation from northeast to southwest for the high-

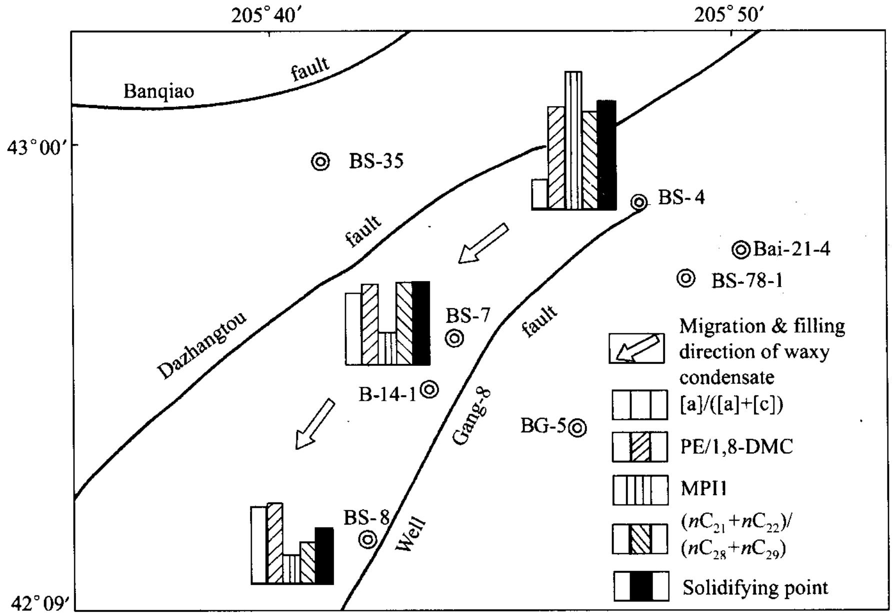

Fig. 7. Tracer oil migration and reservoir filling of the high-waxy condensate in the Qianmiqiao surrounding region. [a]/[a]+[c], Benzo[a]carbazole/(benzo[a]carbazole + benzo[c]carbazole); PE/1,8-DMC, partially exposed dimethylcarbazoles/1,8-dimethylcarbazole; MPI1, methylphenanthrene index 1 =1.5×[(3-MP)+(2-MP)]/[P+(9-MP)+(1-MP)], where M stands for methyl, and P, phenanthrene; numbers indicate the methyl position on the methylphenanthrene molecule; (nC_{21}+ nC_{22})/ (nC_{28}+ nC_{29}), the abundance ratio of *n*-alkane homologues.

Table 3 Tracing parameters for the condensate migration in the Qianmiqiao burial-hill zone

Well No.		BS-4		BS-7			BS-8	
Depth/m		4025	4625	4267—4281	4332—4395.6	4523	4151—4166	4266—4324
Phs. prp.[a)]	*T*sld./℃[b)]	27	–	24	24	–	21	22
Light hydrocarbons	PI_1	3.4	–	3.38	–	2.95	3.05	3.02
	PI_2	15.3	–	9.1	–	5.5	6.6	6.4
Aliphaltics	$(nC_{21}+nC_{22})/(nC_{28}+nC_{29})$	2.58	2.45	–	–	2.42	1.96	–
	T_s/Tm	1.38	1.5	–	1.11	–	–	1.27
Aromatics	MPI_1	2.02	–	1.24	–	1.24	1.21	–
	MPI_2	2.8	–	1.64	–	1.67	1.62	–
	MPI_3	2.54	–	2.13	–	2.05	1.85	–
	F_1	0.72	–	0.68	–	0.67	0.65	–
	F_2	0.43	–	0.39	–	0.38	0.38	–
N-compounds	PE/1,8-DMC	–	5.31	–	4.79	–	–	4.76
	NE/1,8-DMC	–	2.38	–	2.42	–	–	2.75
	[a]/[a]+[c]	–	0.37	–	0.46	–	–	0.47

a) Phs. prp., Physical property of condensate; b) *T*, solidifying point. PI_1, paraffin index; PI_2, heptane value; Ts/Tm, triterpane parameter; MPI_1, MPI_2, MPI_3, F_1 & F_2, methylphenanthrene indices; PE/1,8-DMC, NH · partially exposed isomers/1,8-dimethylcarbazole; [a]/[a]+[e], benzo[a]-carbazole/benzo[a]carbazole+benzo[c]carbazole.

waxy condensate in the Qianmiqiao burial-hill zone (fig. 7).

4 Conclusion

The Ordovician high-waxy condensate in the Qianmiqiao burial-hill zone shows high wax content (15.9%—34.1%) and bimodal *n*-alkane distribution, its HMW wax fraction has a carbon-number range of *n*-alkanes from nC_{35} to nC_{69}, with a major peak mainly at nC_{47} and CPI value ≤ 1.10 and without odd-carbon-number predominance. Due to the lack of source rock core and the uncertain source kitchen, based on the oil-oil correlation of HMW *n*-alkanes, in combination with the lateral distribution of the high-wax condensate, it is confirmed that the Ordovician reservoir of high-waxy condensate in the Qianmiqiao burial-hill zone should originate from the source kitchen around Baishuitou—Well GS-75 in the range of the Qikou Sag, the high-waxy condensate was migrating and the reservoir was filled along with the pathway from Well BS-4, through Well BS-7, to Well BS-8.

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References

1. Philp, R. P., Bishop, A. N., Del Rio, J., Characterization of high molecular weight hydrocarbons (>C_{40}) in the oils and reservoir rocks, in The Geochemistry of Reservoirs (eds. Cubitt, J. M., England, W. A.), London: The Geological Society, 1995, 71—85.
2. Hsieh, M., Philp, R. P., Ubiquitous occurrence of high molecular weight hydrocarbons in crude oils, Organic Geochemistry, 2001, 32: 955—966.
3. Lipsky, S. R., Duffy, M. L., High temperature gas chromatography: The development of new aluminum clad flexible fused silica glass capillary columns coated with thermostable nonpolar phases (Part 1), J. of High Resolution Chromatography, 1986, 9: 376—382.
4. Philp, R. P., High temperature gas chromatography for the analysis of fossil fuels: A review, J. of High Resolution Chromatography, 1994, 17: 398—406.
5. Wang Tieguan, Zhu Dan, Lu Hong et al., High molecular weight (C_{35}+) *n*-alkanes of Neogene heavily biodegraded oil in the Qianmiqiao region, North China, Chinese Science Bulletin, 2002, 47: 1402—1407.
6. The Editorial Board of Petroleam Geology of Dogang Oilfield, Petroleum Geology of China, Vol. 4: Dagang Oilfield, Beijing: Petroleum Industry Press, 1991, 149—153.
7. Yu Zhihai, Yang Chiyin, Liao Qianjun et al., Natural Gas Geology in Huanghua Depression, Beijing: Petroleum Industry Press, 1997, 122—145.
8. Lu Hong, Wang, T. –G., Wang Chunjiang et al., Hydrocarbon sources of high waxy oil and gas pools in Qianmiqiao buried-hill zone, Huanghua depression, Petroleum Exploration and Development (in Chinese), 2001, 28(4): 17—21.
9. Zhang Yousheng, Wang Tieguan, Wang Feiyu, Oil source and entrapment epoch of the Mesozoic oil reservoir in the Kongxi Burial-hill zone, Huanghua Depression, North China, Scientia Geologica Sinica, 1001(4): 257—274.
10. Wang Tieguan, Wang Feiyu, Lu Hong et al., Oil source and entrapment epoch of the Ordovician oil reservoir in the Kongxi Burial-hill zone, Huanghua Depression, North China, Acta Geologica Sinica, 2001, 5(2): 212—219.
11. Wang Tieguan, Li Sumei, Zhang Aiyun et al., A discussion on petroleum migration in the Lunnan oilfield of Xinjiang based on nitrogen compounds, Acta Geologica Sinica (in Chinese), 2000, 74(1): 85—93.
12. England, W. A., Mackenzie, A. S., Mann, D. et al., The movement and entrapment of petroleum fluids in the subsurface, J. of the Geological Society, London, 1987, 144: 327—347.
13. Li, M., Larter, S., Stoddart, D. et al., Fractionation of pyrrolic nitrogen compounds in petroleum during migrations: Derivation of migration-related geochemical parameters, in The Geochemistry of Reservoirs (eds. Cubitt, J. M., England, W. A.), London: The Geological Society, 1995, 103—123.
14. Wang Tieguan, Li Sumei, Zhang Aiyun et al., Oil migration analysis with pyrrolic nitrogen compounds, J. of the University of Petroleum, China (in Chinese), 2000, 24(4): 83—86.