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Geochemical characteristics of crude oils from Well Zheng-1 in the Junggar Basin, Xinjiang, China

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Abstract Well Zheng-1 is located in the combined area of the central uplift and the north Tianshan piedmont depression in the Junggar Basin. Two oil-bearing beds are recognized at 4788–4797 m of the Lower Cretaceous Tugulu Formation (K_1tg) and 4808.5–4812.5 m of the Lower Jurassic Sangonghe Formation (J_1s). The geochemical characteristics of family composition, carbon isotopic composition, saturated hydrocarbons, sterane and terpane biomarkers and carotane of two crude oils are described in this paper. The results show that the geochemical characteristics of the two crude oils are basically similar to each other, indicating they were all derived mainly from the high mature, brine, algae-rich lake facies sediments. Oil-source correlation revealed that crude oils of the two beds were derived mainly from the source rocks of Permian and mixed by the oil derived from the source rocks of Jurassic and Triassic. This is consistent with the geological background with several sets of source rocks in the area studied.

Key words crude oil; geochemical characteristics; oil-source correlation; Well Zheng-1; Junggar Basin, Xinjiang

1 Introduction

Well Zheng-1 is located in the combined area of the central uplift and the north Tianshan piedmont depression in the Junggar Basin (Fig. 1). Two oil-bearing beds are recognized at 4788–4797 m of the Lower Cretaceous Tugulu Formation (K_1tg) and 4808.5–4812.5 m of the Lower Jurassic Sangonghe Formation (J_1s) (Table 1). There are several sets of source rocks including the Permian, Triassic and Lower Jurassic Badaowan Formation in the area studied (Cai Xiyuan and Liu Chuanhu, 2005). The fundamental characteristics of the major source rocks have been described (Liu Lufu et al., 2005), and only Permian source rocks are at the high maturity phase in the area studied. Analysis of the family composition, carbon isotopic composition, saturated hydrocarbons GC and GC/MS of two crude oils was carried out at the Analysis Center of Wuxi Research Institute of Petroleum Geology.

2 Geochemical characteristics of crude oils

2.1 Family composition

The family composition of crude oils not only can indicate the maturity of organic matter and the

Table 1. Stratigraphic subdivision of Well Zheng-1

Erathem	System	Series	Formation	Depth of bottom boundary (m)	Thickness (m)
Cenozoic	Quaternary			90	90
	Neogene	Miocene	Shawan (N_1s)	1137.5	1047.5
	Eogene	Eocene-Paleocene	Ziniquanzi ($E_{1\text{-}2}z$)	2342	1204.5
Mesozoic	Cretaceous	Upper Cretaceous	Donggou (K_2d)	2982.5	640.5
		Lower Cretaceous	Tugulu (K_1tg)	4801	1818.5
	Jurassic	Lower Jurassic	Sangonghe (J_1s)	5067	266
			Badaowan (J_1b)	5150 (undrilled through)	>83

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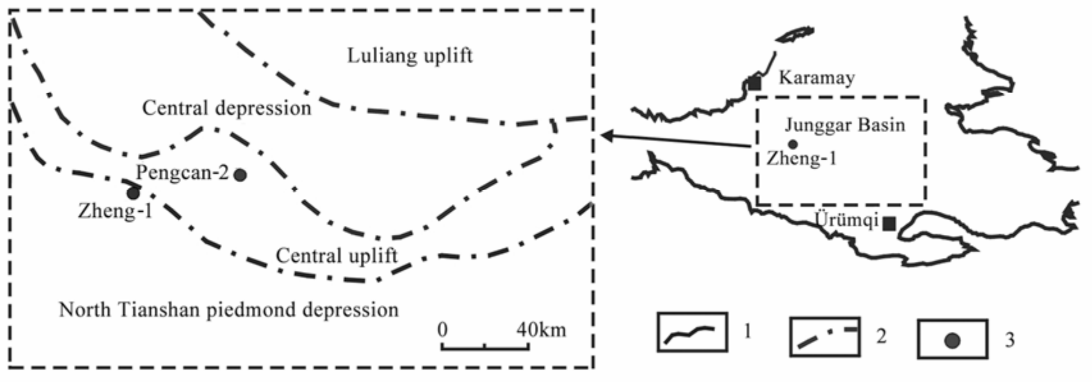

Fig. 1. Structural setting of Well Zheng-1. 1. Boundary of the Junggar Basin; 2. boundary of structural units; 3. well.

Table 2. Family composition and carbon isotopic composition of crude oils from Well Zheng-1

Sampling location		Family composition of oils				Carbon isotope of crude oil
Formation	Depth (m)	St. (%)	Ar. (%)	Resin (%)	Asphalt (%)	$\delta^{13}C_{PDB}$ (‰)
K_1tg	4788–4797	75.51	14.3	9.68	0.51	-29.94
J_1s	4808.5–4812.5	80.99	9.04	9.32	0.68	-29.57

type of oil generating precursor, but also can indicate the subsequent preserved conditions of crude oils and changes after reservoired (Ding Yong et al., 2000). The analysis results of family composition for two crude oils from Well Zheng-1 are listed in Table 2. The family compositions of the two crude oils are basically similar and the contents of polar components for both crude oils are lower, which may suggest the two crude oils have relatively high thermal maturity and further migration effects, and it also indicates the preserved conditions of the two crude oils are better and they have not undergone subsequent changes such as water washing.

2.2 Carbon isotopic composition

Study of the carbon isotopic composition of crude oils in the Junggar Basin shows that the values of $\delta^{13}C_{PDB}$ (‰) for saturated hydrocarbons of oils derived from lake facies sapropelic-type precursors are generally within the range of -30– -32 (Yang Bin, 1985), but the values of $\delta^{13}C_{PDB}$ (‰) for saturated hydrocarbons of oils derived from limnetic facies humic-type precursors are generally within the range of -27– -29 (Fan Guanghua, 1985). It can be seen from Table 2 that the values of $\delta^{13}C_{PDB}$ (‰) of the two oils from Well Zheng-1 are -29.94 and -29.57, respectively. This suggests the type of source rocks for the two oils is basically similar and the two oils were derived mainly from lake facies sapropelic-type precursors.

2.3 Gas chromatographic characteristics of saturated hydrocarbon fraction

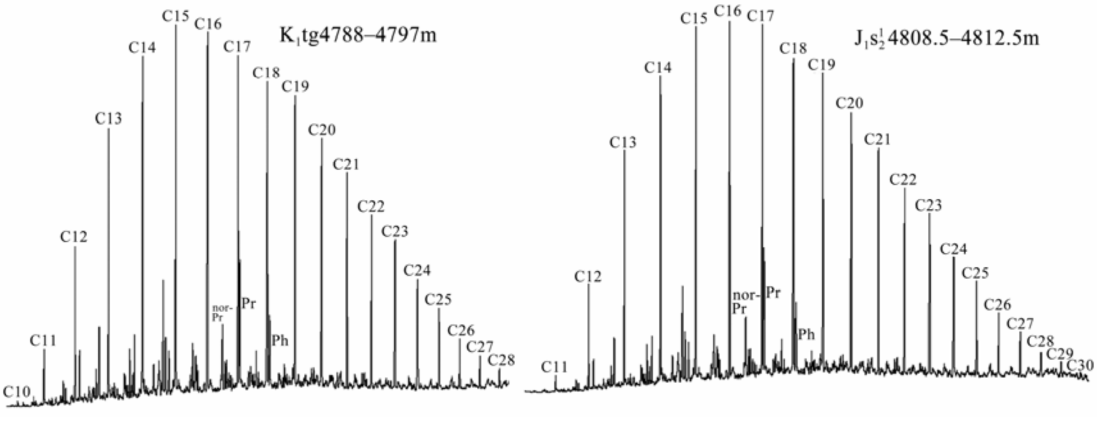

Fig. 2. Gas chromatograms of the saturated hydrocarbon fraction of crude oils from Well Zheng-1.

The gas chromatograms (GC) of saturated hydrocarbon fraction of the two oils from Well Zheng-1 are shown in Fig. 2. It is obviously that the GC characteristics of saturated hydrocarbon fraction of oil from 4788 to 4797 m of the Lower Cretaceous Tugulu Formation (K_1tg) is very similar to the result of oil from 4808.5 to 4812.5 m of the Lower Jurassic Sangonghe Formation (J_1s). The carbon numbers of peak are low and both are C_{16}, and the contents of low carbon number n-alkane are higher. The ratios of C_{21}^{-}/C_{22}^{+} are 5.75 and 4.57 for the two oils, respectively and the $(C_{21}+C_{22})/(C_{28}+C_{29})$ ratios are 11.92 and 9.63 for the two oils, respectively. There is no predominance in odd-carbon number or even-carbon number for the two oils, the values of OEP for the two oils are 1.002 and 0.999, respectively, which shows the characteristics of mature oil. The contents of isoprenoid alkanes such as pristine (Pr) and phytane (Ph) are relatively low and pristine has weak predominance as compared with phytane. The ratios of Pr/nC_{17} for the two oils are both 0.37, and the ratios of Ph/nC_{18} for the two oils are 0.25 and 0.24, respectively, and the ratios of Pr/Ph for the two oils are 1.62 and 1.61, respectively. The values of $Ph/nC_{18}-Pr/nC_{17}$ for the two oils are -0.123 and -0.127, respectively, both being less than -0.025. Meanwhile, the values of nC_{18}/Ph for the two oils are 4.1 and 4.2, respectively, and the values of nC_{17}/Pr are both 2.8. Obviously, all the above gas chromatographic characteristics of the saturated hydrocarbon fraction show that crude oils from Well Zheng-1 were derived from lake facies mature source rocks (Wang Peirong et al., 1998).

2.4 Characteristics of sterane and terpane biomarkers

Sterane series are the most important biomarkers of crude oils, which represent mainly the contribution of algal organic matter, and meanwhile they offer valuable information about crude oil maturity (Yin Wei et al., 2003). The characteristics of sterane biomarker of the two crude oils from Well Zheng-1 are very similar (Fig. 3). The regular steranes of the two crude oils are both dominated by C_{29} sterane, secondarily by C_{28} sterane, and C_{27} sterane content is lowest. Steranes of the $\alpha\alpha\alpha$-20R type show a distribution of "/". The rearranged steranes have the same characteristics as regular steranes, dominated by C_{29} sterane, secondarily by C_{28} sterane, and C_{27} sterane is lowest, but the relative contents of rearranged steranes are lower than those of regular steranes. The ratios of rearranged steranes/regular steranes in the two oils are 0.27 and 0.23, respectively. The ratios of $C_{29}\alpha\alpha\alpha$ sterane $20S/C_{29}\alpha\alpha\alpha$ sterane (20S+20R) are higher, they are 0.56 and 0.55 for the two oils, respectively, which indicates the oils have higher maturity.

The mass chromatograms of terpanes of the two oils from Well Zheng-1 are showed in Fig. 4. The characteristics of terpane biomarkers of the two oils are also very similar. Triacyclic terpanes are mainly related to lake facies algae and the precursor of lower hydrobios, meanwhile they can be enriched by secondary enrichment, migration and thermal effects (Wang Yutao, 1994), and the organic matter deposited in salt water environment can produce triacyclic terpanes more easily than the organic matter deposited in fresh water environment (Zhang Zhihuan and Guan Qiang, 1998). The contents of triacyclic terpanes in the two oils from Well Zheng-1 are both relatively higher, they are 13.25% and 12.43% respectively, which may indicates the oil-generating precursor rich in salt-water lake facies primary organic matter and/or oils have undergone further migration and have higher maturity. As for the triacyclic terpanes, the contents of C_{21}, C_{20} and C_{23} are relatively high, coming next are those of C_{24}, C_{19} and C_{22}, and others are lower. The ratios of C_{19}/C_{21} in the two oils are 0.22 and 0.23, respectively and the ratios of C_{19}/C_{23} in the two oils are 0.28 and 0.30, respectively. The contents of C_{24} tetracyclic terpane are variable between the contents of C_{24} triacyclic terpane and those of C_{19} triacyclic terpane and are close to those of C_{19} triacyclic terpane.

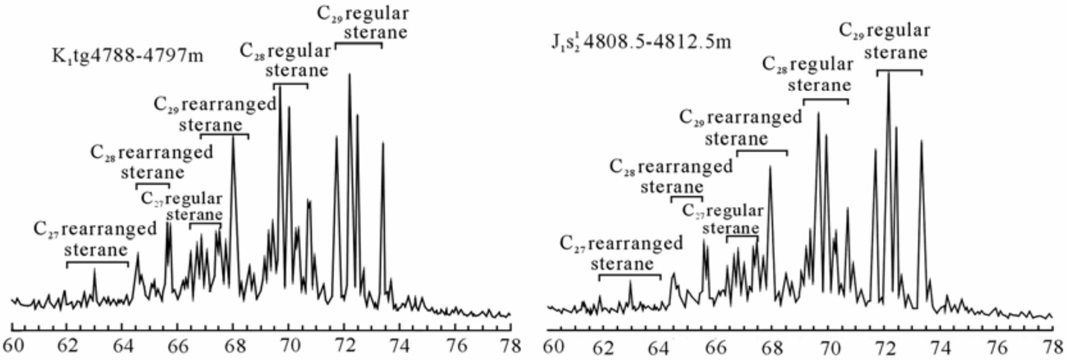

Fig. 3. Mass chromatograms (m/z=217) of crude oils from Well Zheng-1.

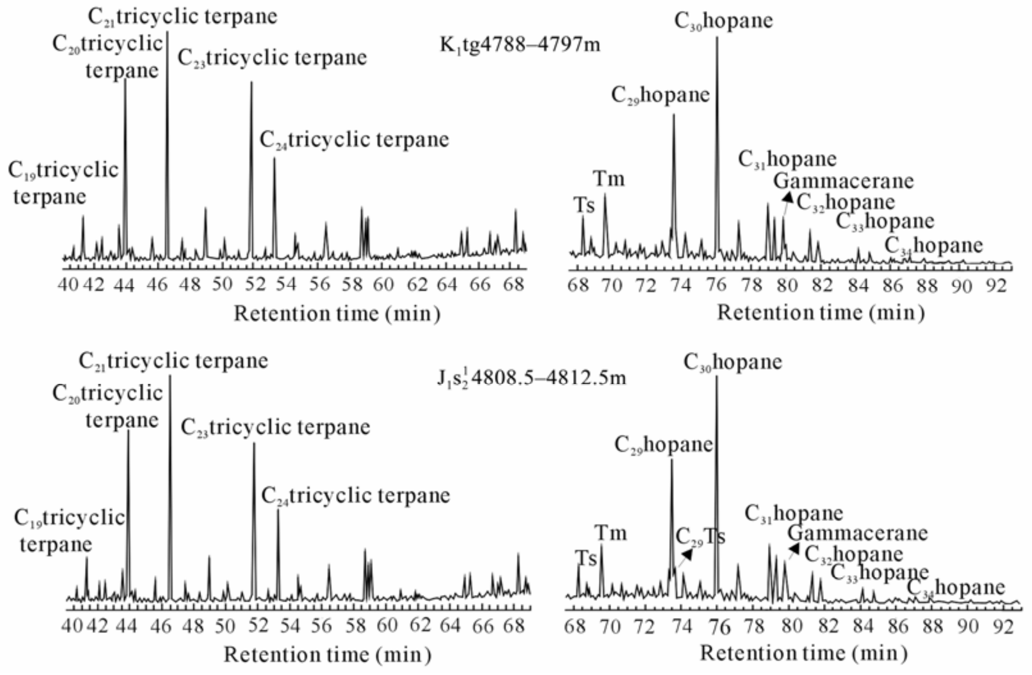

Fig. 4. Mass chromatograms (m/z=191) of crude oils from Well Zheng-1.

The ratios of C_{24} tetracyclic terpane/C_{19} triacyclic terpane for the two oils are 1.01 and 1.04, respectively.

The characteristics of pentacyclic terpane biomarkers for the two oils are basically identical with little difference (Fig. 4). The same aspects are: the high carbon number (>C_{31}) pentacyclic terpane biomarkers are lower, but the contents of gammacerane are relatively high, close to the contents of C_{31} hopane (22R), but lower than the contents of C_{30} hopane. The ratios of gammacerane/C_{31} hopane (22R) in the two oils are 1.04 and 0.98, respectively, and the ratios of gammacerane/C_{30} hopane in the two oils are relatively high, 0.21 and 0.17, respectively. Gammacerane was derived largely from lower hydrobios and C_{30} hopane mainly from higher plants (Zhang Zhihuan and Guan Qiang, 1998). This indicates that the precursor type of source rocks of the two oils is better. Meanwhile, gammacerane is the characteristic biomarker for salt lake or highly saline depositing environment with the water body stratification (Moldowan et al., 1985), and it is usually in concert with the high abundance of β-carotane. Gammacerane and the high abundance of β-carotane jointly suggest the organic matter was deposited in the salt water environment. The contents of Ts and Tm in the two oils are relatively high, and the contents of Ts are lower than those of Tm. The ratios of Ts/Tm in the two oils are larger, both being 0.64. Meanwhile, the ratios of C_{31} hopane (22S)/C_{31} hopane (22R+22S) in the two oils are also larger, being 0.53 and 0.54, respectively. This indicates the thermal maturity of the two crude oils is higher. In addition, the contents of pentacyclic triterpanes in the two oils are lower, both less than 0.13%, which also indicates a higher thermal maturity of the two crude oils. The different aspect is that the oil at 4808.5–4812.5 m of the Lower Jurassic Sangonghe Formation (J_1s) contains some C_{29}Ts and minor C_{35} hopane, but C_{29}Ts and C_{35} hopanes have not been detected in the oil at 4788–4797 m of the Lower Cretaceous Tugulu Formation (K_1tg). This may indicate that the source rocks of the two oils have a little difference.

2.5 Characteristics of carotene

The precursor of carotane is carotene which is easily oxidated and destroyed. Therefore, in the sedimentation process, only these rapid subsidence basins with a reducing depositional environment have the advantages to preserve and enrich carotane (Jiang Zhusheng, 1983). β-carotane is a fully-saturated C_{40} dicyclic alkyl compound which is attributed to algal organic matter deposited under less oxic, salt lake facies conditions (Hall and Douglas, 1983; Jiang Zhusheng and Flower, 1986). Meanwhile, γ-carotane and β-carotane are affected by thermal maturity, the contents of γ-carotane in mature oil are higher than those of its precursor in nature. So γ-carotane may be the product of pyrolysis of β-carotane (Wang Yutao, 1994). The mass chromatograms (m/z=125) show that γ-carotane and β-carotane are present in the two oils and their contents are relatively high, and the relative contents of γ-carotane in the two oils are 1.17% and

1.75%, respectively, and the relative contents of β-carotane in the two oils are 5.21% and 7.27%, respectively. The characteristics of carotane for the two oils from Well Zheng-1 indicate the oils were derived mainly from highly mature, reducing, salty- and alga-rich lake facies sediments.

3 Oil-source correlation

Studies on the geochemical characteristics of source rocks in the Junggar Basin (Chen Jianping et al., 2003a; Yang Bin and Li Jianxin, 1992; Wang Xulong and Kang Sufang, 1999) showed that the carbon isotopic values of the extracts from Permian source rocks are lower, less than -30.0‰ in general; the steranes are dominated by C_{29} sterane and C_{28} sterane, and the rearranged steranes are almost not present or their contents are very low and the contents of C_{27} sterane are very low as well; the distinctive characteristics of terpane distribution are that the contents of gammacerane are usually relatively high, and tricyclic terpane distribution is characterized by the main peak of C_{21} tricyclic terpane, and relatively higher contents of C_{20} tricyclic terpane and C_{23} tricyclic terpane, whereas C_{19} tricyclic terpane is very low; in general, the abundance of tricyclic terpanes is relatively higher than that of the pentacyclic terpanes, and pentacyclic terpanes are dominated by C_{30} hopanes and C_{29} hopanes, the contents of other hopanes are relatively low; meanwhile, Pr/Ph ratios are usually lower than 2.0, and the contents of β-carotane are relatively high, which is an important biomarker characteristic of Permian source rocks. The carbon isotopic value of crude oils derived from Triassic source rocks is -31‰, and they are rich in rearranged steranes, Ts, C_{29}Ts and rearranged hopanes, whereas the contents of gammacerane and β-carotane are low (Chen Jianping et al., 2003c). The carbon isotopic value of the extracts from Jurassic source rocks is generally larger than -30.0‰, and Pr/Ph ratio is usually larger than 3.0, and the main characteristic feature is the enrichment in pentacyclic terpanes and C_{29} steranes and depletion in tricyclic terpanes, gammacerance, C_{27} and C_{28} steranes; C_{19} tricyclic terpane is the main peak of tricyclic terpanes (Chen Jianping et al., 2003a). The significant characteristics of crude oils derived from Carboniferous source rocks are that carbon isotope is very heavy, with the values varying between -25‰ and -23‰ in general (Chen Jianping et al., 2003b). It is obvious that the geochemical characteristics of the two oils from Well Zheng-1 are basically the same as those of Permian source rocks. But there are some differences in carbon isotopic composition and ratios of C_{19} tricyclic

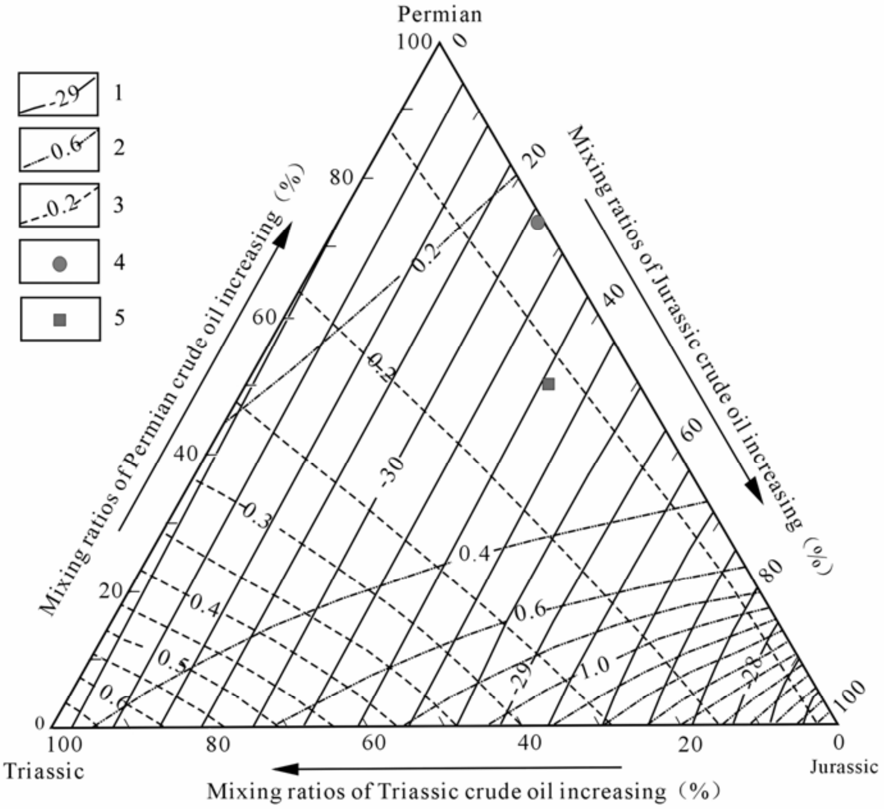

Fig. 5. Diagram of oil-source correlation of crude oils from Well Zheng-1 (Boundary lines from Chen Jianping et al., 2003d). 1. Carbon isotope of crude oil; 2. tricyclic terpane C_{19}/C_{21}; 3. C_{29}Ts/C_{29} hopane; 4. oil of K_1tg 4788–4797 m; 5. oil of $J_1s_2^1$ 4808.5–4812.5 m.

terpane/C_{21} tricyclic terpane and C_{29}Ts/C_{29} hopane from the results for the typical oils derived from Permian source rocks.

Chen Jianping et al. (2003d) established a distinguishing diagram (Fig. 5) used for oil-source correlation of mixed oils derived from multiple source rocks according to analysis results of mixed oils in different proportions of typical oils derived from Permian, Triassic and Jurassic source rocks. Because the contents of Ts and C_{29}Ts in the oils derived from Triassic source rocks are very high, and these biomarkers are lower in the oils derived from Permian and Jurassic source rocks, the ratio of C_{29}Ts/C_{29} hopane will increase gradually to the end-member of oil derived from Triassic source rocks with increasing mixing proportion of oil derived from Triassic source rocks. On the other hand, C_{19} tricyclic sterane is rich and C_{21} tricyclic sterane is relatively low in oils derived from Jurassic source rocks. Therefore, the ratio of C_{19} tricyclic sterane/C_{21} tricyclic sterane will increase gradually to the end-member of oil derived from Jurassic source rock s with the mixing proportion of oils derived from Jurassic source rocks. Similarly, because the carbon isotopic values of oils derived from Jurassic source rocks are obviously higher than those of oils derived from Permian and Triassic source rocks, those will increase gradually to the end-member of oil derived from Jurassic source rocks with the mixing proportion of oils derived from Jurassic source rocks. It can be seen from Fig. 5 that the oil at 4788–4797 m of the Lower Cretaceous Tugulu Formation (K_1tg) was derived mainly from Permian source rocks, which accounts for 75% of the total oil, and it may be mixed by 25% oil derived from Jurassic source rocks; the oil at 4808.5–4812.5 m of the Lower Jurassic Sangonghe Formation (J_1s) was also derived mainly from Permian source rocks, which comes to 50% of the total oil, and it may be mixed by 10% oil derived from Jurassic source rocks and 40% oil derived from Triassic source rocks. This is consistent with the geological background having several sets of source rocks in the area studied.

4 Conclusions

The geochemical characteristics of family composition, carbon isotopic composition, saturated hydrocarbons, sterane and terpane biomarkers and carotane of the two crude oils from Well Zheng-1 in the Junggar Basin are basically similar, indicating they were all derived mainly from the highly mature, brine, alga-rich lake facies sediments. Oil-source correlation revealed that crude oils of the two beds were derived mainly from the source rocks of Permian and mixed by the oils derived from the source rocks of Jurassic and Triassic. This is consistent with the geological background having several sets of source rocks in the area studied.

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