Geochemical characterization of aromatic hydrocarbons in light crude oil from Tazhong Uplift deep reservoirs, Tarim Basin, NW China

ZW Wei\(^a\,b\), YG Liang\(^a\,b\), B Cheng\(^\ast\), JB Xu\(^a\,b\), Q Deng\(^a\,b\), HZ Zhang\(^c\), O L Faboya\(^d\), ZW Liao\(^a\)

\(^a\) State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, 510640 China
\(^b\) University of Chinese Academy of Sciences, Beijing, 100049 China
\(^c\) Research Institute of Petroleum Exploration & Development, PetroChina Tarim Oilfield Company, Korla 841000, China
\(^d\) Department of Chemical Sciences, Afe Babalola University, Ado-Ekiti, Ekiti-State, Nigeria

Email: chengbin@gig.ac.cn

Abstract. The aromatic compounds in the light crude oil samples from the deep Tazhong structural and the Central Uplift zones in the Tarim Basin, NW China, were investigated by gas chromatography-mass spectrometry (GC-MS). The results from the study showed the distribution of the aromatic hydrocarbon compounds in the order of monocyclic > bicyclic > tricyclic with Tazhong structural zone No. 1 showing relatively higher abundance of mono- and bicyclic aromatic compound when compared with the other structural zones. Based on the distribution of the isomers of naphthalenes in the oils and the equivalent reflectance calculated from them, the oils in the Tazhong structural zone No. 1 indicated wider range of maturity levels and are generally more mature than the other zones. The implication of this is that, the oils in the structural zone No. 1 reservoirs might have been filled with lately generated oils from older source rock.

1. Introduction

Tarim Basin is located in the north-west China, sandwiched between the northern Tianshan and the southern Kunlun Mountains (Fig. 1). After decades of geological exploration, a large number of oils and gas reservoirs have been found in the Basin. In recent years, many light oils have been found in the deep reservoirs of Tazhong area in the Tarim Basin. Due to the multiple tectonic activities, the pattern of the oil and gas accumulation is complex in the Tazhong area. This has resulted in the failure of many conventionally used geochemical parameters for oil and gas geochemical studies [1].

The application of many aromatic hydrocarbons compounds have been found useful in describing oil accumulation in the high thermal evolutionary stages [2-3]. Previous studies have reported that 2-alkyl naphthalene is more thermal stable than 1-alkyl naphthalene. It is believed that hydrocarbons aromatization at a low temperature is mainly controlled by the kinetic mechanism, which would produce more of 1-alkynaphthalene relative to 2-alkyl naphthalene. But at high temperature hydrocarbons aromatization is controlled by the thermodynamic mechanism which would generate
mainly 2-alkyl naphthalene but not the 1-alkynaphthalene isomer \[^4,5,7\]. Therefore, the ratio of 2-methylnaphthalene/1-methylnaphthalene is often used to indicate the degree of thermal evolution of organic matter. The maturity parameters such as the dimethylnaphthalene-index (DNR-1) and the methyl-phenanthrene index (MPI) have been widely used\[^3,6,8\].

Therefore, the present work is aimed at investigating the occurrence and distribution of the aromatic hydrocarbons in oils from deep Ordovician reservoirs in the Zones No.1 and 10 of the Tazhong area and also from the Central Uplift zone. This is expected to provide insight into the thermal evolutionary process of light oils in the deep stratum, which could be helpful in oil and gas exploration and production of the area.

Figure 1. profile of Tazhong structure and the oil wells in the location under study in the Tarim Basin (bottom map reference Liang et al.,\[^2\])

2. Materials and methods
Thirty six light oil samples were collected from Tazhong structural zone No. 1 and 10 including one (1) oil sample from the Central Uplift zone well-heads and were analyzed using gas chromatography-mass spectrometry (GC-MS). The saturated and aromatic fractions of the oils were eluted using n-hexane and mixture of dichloromethane and n-hexane (3: 1), respectively. Thermo TRACE GC Ultra-DSQ II gas chromatography-mass spectrometry was used for the analysis. The GC capillary column used was HP-5MS (30 m × 0.32 mm i.d × 0.25 μm film thickness). The carrier gas used was helium with a velocity flow rate of 1.2 mL / min. The GC conditions for the analysis of the aromatic fractions were as follows: the oven programme initial temperature of 80 °C (held for 4 min) to final temperature of 295 °C (held for 20 min) at 3 °C/min. A subsection Some text.

3. Results and Discussion
3.1 Occurrence and distribution of aromatic compounds in the light oil
The total ion chromatogram (TIC) of the light oils from the Tazhong area and the Central Uplift zone is shown in Figure 2. The light oils are generally dominated by n-alkanes in the range of n-C\(_7\) to n-C\(_{17}\) showing unimodal distributions. There are abundances of aromatic compounds in the crude oils including, benzene, naphthalene, phenanthrene and their homologues, which were identified from
mass spectrometry. Based on the analysis of the aromatic hydrocarbons, the relationship between monocyclic, bicyclic – and tricyclic aromatic hydrocarbons is discussed in the present work.

The numeric codes represent the carbon number of \( n \)-alkanes, Tol- toluene, C2B- disubstituted benzene, C3B- trisubstituted benzene, C4B- tetrasubstituted benzene, N-naphthalene.

The toluene + benzene, naphthalene + methyl naphthalene and phenanthrene + methyl phenanthrene are the representatives of the monocyclic, bicyclic and tricyclic aromatic hydrocarbons, respectively. The ternary plot of the relative concentrations of these compounds is shown in Figure 3. It shows the distribution in the order of monocyclic > bicyclic > tricyclic aromatic hydrocarbons. Generally, structural zone No.1 oils show a relatively higher abundance of both monocyclic and bicyclic aromatic when compared with structural zone No. 10 oils.
3.2 Maturity parameters from aromatic hydrocarbons

The values derived for the DNR-1 based on the distribution of 2,6-, 2,7- and 1,5-dimethylnaphthalene for the Tazhong structural zone No. 1 and No. 2 ranged from 3.79 to 20.69 (mean value of 8.29%) and 3.16 to 10.74 (mean value of 6.15%), respectively. The calculated vitrinite reflectance values based on the DNR-1 values are in the range of 0.85 to 2.35% (mean value of 1.25%) and 0.82 to 1.42% (mean value of 1.06%) for Tazhong structural zone No. 1 and No. 2, respectively. The DNR-1 value and the derived vitrinite reflectance calculated for the only oil collected from the Central Uplift zone are 6.64 and 1.09%, respectively. These values indicate that the oils in the Tazhong structural zone No. 1 have received more impute of more mature oils when compare with other zones.

Again, the abundance of 2,3,6-, 1,4,6- and 1,3,5-trimethylnaphthalene could be used to assess thermal maturity of oils due to their different responses to thermal stress. The TNR-1 values derived from these isomers for oils from Tazhong structural zone No. 1 and 10 ranges from 0 to 2.79 with a mean value of 0.98 and 0 to 2.04 with a mean value of 0.83, respectively. The TNR-1 obtained for the Central Uplift zone is 1.21. The distributions further confirm the relatively higher thermal maturity status of the Tazhong structural zone No. 1 oils. It showed that the equivalent Ro values calculated by the two indexes are closed in most of the light crude oils (Table 1). Figure 4 shows a general increase in the relative contents of (M+MN) with increasing thermal maturity of the oils. This indicates an increase in the degree of aromatization with increasing thermal stress.

| Well      | DNR-1 | TNR-1 | \( R_{\text{eq}}(\text{DNR-1}) \) | \( R_{\text{eq}}(\text{MDR})^* \) |
|-----------|-------|-------|-------------------------------|-------------------------------|
| **Tazhong zone. No. 1** |       |       |                               |                               |
| ZG6-2     | 8.61  | 0.84  | 1.26                          | 1.29                          |
| ZG10      | 11.67 | 1.05  | 1.54                          | 1.31                          |
| ZG12      | 13.12 | 0.84  | 1.67                          | 0                             |
| Location | Value 1 | Value 2 | Value 3 | Value 4 |
|----------|---------|---------|---------|---------|
| ZG19     | 7.91    | 0.86    | 1.2     | 0       |
| ZG22     | 9.67    | 0.93    | 1.36    | 1.41    |
| ZG151    | 9.49    | 0.7     | 1.34    | 1.33    |
| ZG162    | 10.19   | 1.14    | 1.41    | 1.25    |
| ZG503    | 12.33   | 0.9     | 1.6     | 1.31    |
| ZG2      | 6.13    | 0       | 1.04    | 0       |
| ZG5      | 10.2    | 1.67    | 1.41    | 0       |
| ZG13-1H  | 20.69   | 0       | 2.35    | 1.38    |
| ZG14-1   | 7.15    | 0       | 1.13    | 1.34    |
| ZG15-1H  | 4.74    | 1.73    | 0.99    | 0       |
| ZG15     | 11.69   | 1.34    | 1.54    | 0       |
| ZG17     | 5.31    | 2.79    | 1.04    | 1.25    |
| ZG17-H1  | 3.79    | 0       | 0.86    | 1.31    |
| ZG70     | 5.64    | 0       | 1       | 1.18    |
| ZG101    | 4.93    | 2.3     | 0.93    | 1.1     |
| ZG103    | 8.48    | 1.36    | 1.42    | 1.39    |
| ZG105    | 7.25    | 1.03    | 1.16    | 1.18    |
| ZG106    | 5.76    | 1.25    | 1.01    | 1.41    |
| ZG111    | 3.96    | 1.24    | 0.85    | 0       |
| ZG501    | 4.95    | 0       | 0.94    | 1.5     |
| ZG702    | 5.3     | 1.64    | 0.97    | 1.36    |
| Mean     | 8.29    | 0.98    | 1.25    | 0.93    |

**Tazhong Zone, No. 10**

| Location  | Value 1 | Value 2 | Value 3 | Value 4 |
|-----------|---------|---------|---------|---------|
| ZG432     | 4.34    | 1.08    | 0.88    | 0       |
| ZG462     | 4.15    | 0.83    | 0.86    | 1.18    |
| ZG45      | 3.16    | 1.57    | 0.77    | 1.29    |
| ZG42      | 7.78    | 1.78    | 1.19    | 0       |
| ZG43-1    | 10.74   | 0       | 1.46    | 1.51    |
| ZG44C     | 6.08    | 0       | 1.04    | 1.33    |
| ZG46      | 8.36    | 2.04    | 1.24    | 1.3     |
| ZG47      | 10.38   | 1.79    | 1.42    | 1.39    |
| ZG48      | 3.72    | 0       | 0.82    | 1.25    |
| ZG441     | 4.09    | 0       | 1.1     | 1.34    |
| ZG461     | 4.83    | 0       | 0.9     | 1.37    |
| Mean      | 6.15    | 0.83    | 1.06    | 1.09    |

**Cental Uplift Zone**

| Location | Value 1 | Value 2 | Value 3 | Value 4 |
|----------|---------|---------|---------|---------|
| ZS1      | 6.64    | 1.21    | 1.09    | 1.37    |

DNR-1=(2,6-dimethylnaphthalene + 2,7-dimethylnaphthalene)/1,5-dimethylnaphthalene; TNR-1=2,3,6-trimethylnaphthalene/(1,4,6-trimethylnaphthalene +1,3,5-trimethylnaphthalene); eq Ro(DNR-1)= 0.49+0.09*(DNR-1)^[5]; “* ” represents the data are from the reference [2].

*DNR-1=(2,6-dimethylnaphthalene + 2,7-dimethylnaphthalene)/1,5-dimethylnaphthalene; TNR-1=2,3,6-trimethylnaphthalene/(1,4,6-trimethylnaphthalene +1,3,5-trimethylnaphthalene); eq Ro(DNR-1)= 0.49+0.09*(DNR-1)^[5]; “* ” represents the data are from the reference [2].
4. Conclusion

The occurrence and thermal maturity assessment based on the aromatic compounds in the light crude oils from the deep stratum of the Ordovician reservoirs in the Tazhong and Central Uplift zones were analyzed using gas chromatography – mass spectrometry (GC-MS). The results showed the distribution of the aromatic hydrocarbon compounds in the order of monocyclic > bicyclic > tricyclic in the studied oils with the Tazhong structural zone No. 1 indicating more abundant of the mono- and bicyclic aromatic compounds than the other zones. Again, based on the distribution of the isomers of naphthalenes in the oils and the equivalent reflectance calculated from the isomers, the oils in the Tazhong structural zone No. 1 indicated wider range of maturity levels and are generally more mature than the other zones.

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