

# Distribution and geochemical significance of phenylphenanthrenes and their isomers in selected oils and rock extracts from the Tarim Basin, NW China

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**Abstract** Twenty-two oil samples and eight source rock samples collected from the Tarim Basin, NW China were geochemically analyzed to investigate the occurrence and distribution of phenylphenanthrene (PhP), phenylanthracene (PhA), and binaphthyl (BiN) isomers and methylphenanthrene (MP) isomers in oils and rock extracts with different depositional environments. Phenylphenanthrenes are present in significant abundance in Mesozoic lacustrine mudstones and related oils. The relative concentrations of PhPs are quite low or below detection limit by routine gas chromatography–mass spectrometry (GC–MS) in Ordovician oils derived from marine carbonates. The ratio of 3-PhP/3-MP was used in this study to describe the relative abundance of phenylphenanthrenes to their alkylated counterparts—methylphenanthrenes. The Ordovician oils in the Tabei Uplift have quite low 3-PhP/3-MP ratios ( $<0.10$ ), indicating their marine carbonate origin, associating with low Pr/Ph ratios (pristane/phytane), high ADBT/ADBF values (relative abundance of alkylated dibenzothiophenes to alkylated dibenzofurans), low  $C_{30}$  diahopane/ $C_{30}$  hopane ratios, and low Ts/(Ts + Tm) ( $18\alpha$ -22, 29, 30-trisnorneohopane/( $18\alpha$ -22, 29, 30-trisnorneohopane +  $17\alpha$ -22, 29, 30-trisnorhopane)) values. In contrast, the oils from Mesozoic and Paleogene sandstone reservoirs and related Mesozoic lacustrine mudstones have relatively higher 3-PhP/

3-MP ratios ( $>0.10$ ), associating with high Pr/Ph, low ADBT/ADBF, high Ts/(Ts + Tm), and  $C_{30}$  diahopane/ $C_{30}$  hopane ratios. Therefore, the occurrence of significant amounts of phenylphenanthrenes in oils typically indicates that the organic matter of the source rocks was deposited in a suboxic environment with mudstone deposition. The phenylphenanthrenes may be effective molecular markers, indicating depositional environment and lithology of source rocks.

**Keywords** Phenylphenanthrene · Methylphenanthrene · Depositional environment · Source rock

## 1 Introduction

Phenyl-substituted polycyclic aromatic hydrocarbons (PAHs) and their heterocyclic counterparts are important components in aromatic fractions of some crude oils and sedimentary rock extracts (Marynowski et al. 2001, 2002, 2004; Rospondek et al. 2007, 2009; Li et al. 2012a; Grafka et al. 2015). A series of phenylphenanthrene (PhP), phenylanthracene (PhA), and binaphthyl (BiN) isomers have been firmly identified by using authentic standards (Rospondek et al. 2009).

The 9-phenylphenanthrene and other isomers were detected in volatiles formed during pyrolytic carbonization of coal tar pitches (zu Reckendorf 1997, 2000). All PhP, PhA, and BiN isomers have been discovered in marine sedimentary rocks (Rospondek et al. 2009; Grafka et al. 2015), Tertiary and Jurassic lacustrine shales (Li et al. 2012a) and tire fire products (Wang et al. 2007).

The phenyl-substituted PAHs in combustion products may be generated by consecutive reactions of phenyl free radicals with unsubstituted PAHs in the gaseous phase during combustion (zu Reckendorf 2000). Less work has

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been done on the origin and formation of phenylphenanthrene in crude oils and sedimentary rocks. According to Marynowski et al. (2001), Rospondek et al. (2009), and Grafka et al. (2015), diagenetic/catagenetic oxidation of sedimentary organic matter at the redox interface in buried sedimentary rocks is likely to be the main source of arylated polycyclic aromatic compounds in the geosphere. Laboratory experiments indicate that the reaction of free radical phenylation with phenanthrene or anthracene moieties can account for the distribution of phenylphenanthrenes and phenylanthracenes in oxidized rock samples with Type II and III kerogen (Marynowski et al. 2001; Rospondek et al. 2009; Grafka et al. 2015). Therefore, a significant amount of PhPs and other phenyl-substituted PAHs in ancient sedimentary rocks are commonly associated with oxic to suboxic depositional environments.

The distribution patterns of PhPs and BiNs in mass chromatograms ( $m/z$  254) of aromatic fractions in sedimentary organic matters are relative to the maturation levels. For example, the most stable isomers 2-PhP and 3-PhP predominate, whereas the thermally unstable 9-PhP, 1-PhP, and 4-PhP disappear in highly mature sedimentary organic matter (Rospondek et al. 2009; Li et al. 2012a; Grafka et al. 2015). Among all binaphthyl isomers, 1,1-BiN is the most thermally unstable one and was found only in less mature samples; while 2,2-BiN is more stable and also present above the oil window range (Rospondek et al. 2009; Li et al. 2012a). Therefore, some indices, such as phenylphenanthrene ratio [defined as  $(2- + 3-PhP)/(2- + 3- + 4- + 1- + 9-PhP)$ ] (Rospondek et al. 2009) and  $2,2'-BiN/1,2'-BiN$  (defined as  $2,2'$ -binaphthyl/ $1,2'$ -binaphthyl) (Li et al. 2012a) have been proposed as maturity indicators. In addition, some maturity indicators associated with aromatic compounds including phenylphenanthrene ratios have also been used as frictional stress indicators (Polissar et al. 2011).

Previous studies mainly focused on the formation and application of PhPs in maturation assessment. This paper reported the occurrence of PhPs in Ordovician oils, Mesozoic lacustrine sedimentary rocks, and related oils from the Tarim Basin, NW China. Their potential significance to the depositional environment and lithology of source rocks and application in oil-to-source correlation in oil petroleum system are discussed. The result can further broaden the geochemical significance and application of phenylphenanthrenes in sedimentary rocks and related oils.

## 2 Samples and geological settings

A total of eight cores and outcrop samples were collected from the Tarim Basin, NW China. Two cores were sampled from Well S5, which is located in the Yakela Faulted Uplift

(Fig. 1). One outcrop was sampled in the Kuchehe profile in the Kuqa Depression, which is the prolific hydrocarbon-bearing foreland basin in the Tarim Basin (Zhao et al. 2005). These three rock samples are Upper Triassic mudstones.

Four Jurassic sandy mudstones were collected from the Kuzigongsu profile in the southwest of the Tarim Basin (Fig. 1). The Middle Jurassic in the Tarim Basin is represented by deep lacustrine deposits (Zhang et al. 2000; Liu et al. 2006; Cheng et al. 2008; Wang et al. 2009; Song et al. 2013). In addition, one Jurassic coal sample from the Well YL1 in the eastern Tarim Basin is also investigated. All these samples are good source rocks with total organic carbon (TOC) content of 0.71 %–1.12 % (Table 1), and they underwent moderate to relatively higher thermal maturation with vitrinite reflectance ( $R_o$  %) of 0.51 %–1.10 % (Table 1).

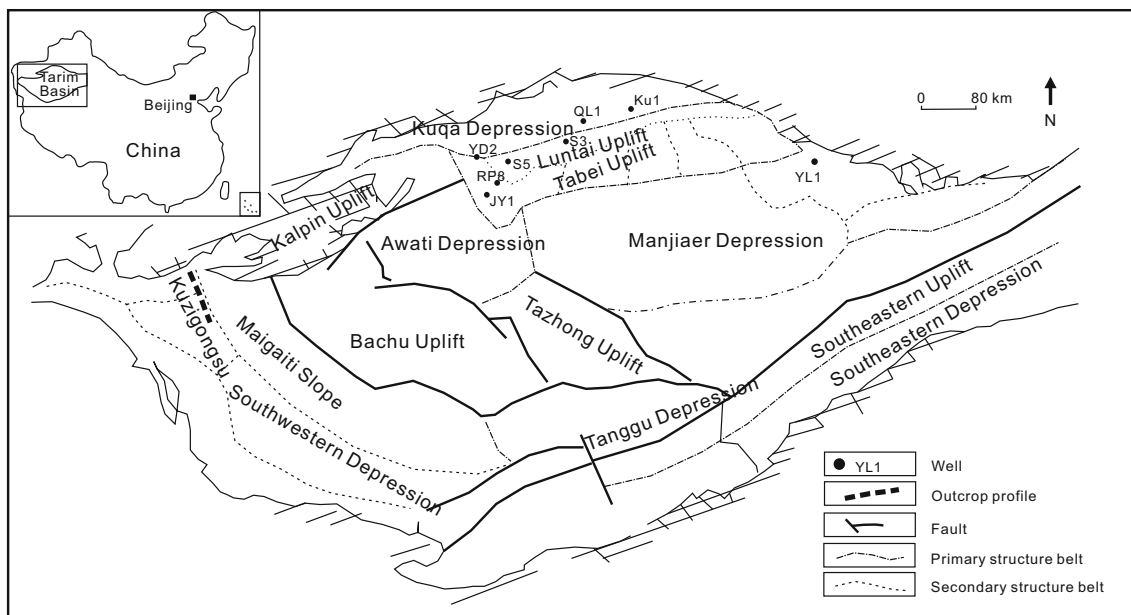
A total of 22 oil samples were collected from the Ordovician carbonate reservoirs in the Halahatang Sag, Yakela Faulted Uplift and Akekule Uplift, and the Mesozoic and Paleogene sandstone reservoirs in the Kuqa Depression and Yakela Uplift of the Tarim Basin (Table 1). The Ordovician carbonate oils from the Tabei Uplift were sourced from Paleozoic carbonate source rocks (Zhang and Huang 2005; Wang et al. 2008; Pang et al. 2010; Li et al. 2012b). Oils in wells QL1, Ku1, and S3 were derived from Mesozoic lacustrine mudstones (Xiao et al. 2004; Song et al. 2015).

## 3 Methods

All rocks were ground into powder in a crusher to <80 mesh. The TOC content was measured on an LECO CS-230 carbon/sulfur analyzer. The vitrinite reflectance values (%) were measured on polished rock blocks using a Leitz MPV-microscopic photometer.

To extract soluble bitumen, the powder was processed for 24 h in a Soxhlet apparatus using 400 mL of dichloromethane and methanol as the solvent (93:7, v:v). Asphaltenes were removed from approximately 20–50 mg oils and bitumen by precipitation using 50 mL of *n*-hexane and then fractionated by liquid chromatography using alumina/silica gel columns into saturated and aromatic hydrocarbons using 30 mL *n*-hexane and 20 mL dichloromethane: *n*-hexane (2:1, v:v) as respective eluents (Fang et al. 2015).

The GC–MS analyses of the aromatic fractions were performed on an Agilent 5975i GC–MS system equipped with an HP-5MS (5 %-phenylmethylpolysiloxane)-fused silica capillary column (60 m × 0.25 mm i.d., with a 0.25- $\mu$ m film thickness). The GC operating conditions were as follows: the temperature was held initially at 80 °C for



**Fig. 1** Map showing the major tectonic terrains in the Tarim Basin (NW China) and the locations of sampled wells and profiles

1 min, increased to 310 °C at a rate of 3 °C/min, and then kept isothermal for 16 min. Helium was used as the carrier gas. The injector temperature was set to 300 °C. The MS was operated in the electron impact (EI) mode with ionization energy of 70 eV, and a scan range of *m/z* 50–600 Da.

## 4 Results and discussion

### 4.1 Identification of phenylphenanthrenes and methylphenanthrenes

The identification and elution order of all isomers of methylphenanthrenes (MPs), phenylphenanthrenes (including their isomers: phenylanthracene and binaphthyl) were determined by the comparison of their mass spectra and standard retention indices (*I*<sub>HP-5MS</sub>) with those reported in literature (Lee et al. 1979; Rospondek et al. 2009). Figure 2 shows the chemical structures of MPs and PhPs and the mass chromatograms (*m/z* 178, 192, 254) of aromatic fractions of selected sediment extracts in this study. The methyl and phenyl substitution pattern on parent rings is indicated on the corresponding peaks (Fig. 2).

Phenanthrene and its alkylated homologues are important polycyclic aromatic hydrocarbons (PAHs) and present in significant concentrations in crude oils and sedimentary rock extracts. Four methylphenanthrene isomers and one methylanthracene isomer (2-methylanthracene: 2-MA) were identified in all rocks and oils in this study. The elution order of the *m/z* 192 isomers is as follows: 3-MP, 2-MP, 2-MA, 9-MP, and 1-MP. The isomer 2-MA is

present in quite low concentration or below detection limit in oils (Figs. 3, 4). However, it seems abundant in some rocks and coals (Figs. 2c, 4a, b e).

The distribution of arylated homologues of phenanthrenes (phenylphenanthrenes) is shown in Fig. 2. In addition, their binaphthyl (BiN) isomers were also detected in oils and rock extracts. The elution sequence of *m/z* 254 isomers on an HP-5MS capillary column is as follows: 1,1'-BiN, 4-PhP, 9-PhA, 1,2'-BiN, 9-PhP, 1-PhP, 3-PhP, 2,2'-BiN, 2-PhP, and 2-PhA. The 1-PhA isomer may co-elute with 1,2'-BiN on HP-5MS column, but it is typically absent in geochemical samples (Rospondek et al. 2009). The isomers 3-PhP, 2-PhP, and 2,2'-BiN are typically present in higher abundance relative to other PhP and BiN isomers.

### 4.2 Depositional environment and lithologies of crude oils and source rocks

Previous studies suggested that oils in wells Ku1 and QL1 of the Kuqa Depression and wells YD2 and S3 of the Tabei Uplift (Fig. 1) are of typical lacustrine mudstone origin (Li et al. 2004; Xiao et al. 2004; Song et al. 2015). Oils from Ordovician carbonate reservoirs were derived from Paleozoic carbonate source rocks (Zhang and Huang 2005; Wang et al. 2008; Chang et al. 2013).

Dibenzothiophene, dibenzofuran, and their alkylated homologues are effective molecular markers in inferring depositional environment, maturation assessment and in tracing oil charging pathways (Bao et al. 1996; Wang et al. 2014; Li et al. 2008; Zhang and Philp. 2010; Li et al. 2011, 2014). A cross-plot of alkyldibenzothiophene/alkyldibenzofuran ratio

**Table 1** Bulk properties and selected geochemical parameters for oils and rocks in this study

Sample no.	Fm.	Description	TOC, %	$R_o$ , %	Methylphenanthrene index (MPI1)	3-PhP/3-MP	Pr/Ph	ADBT/ADBF	$C_{30}DiaH/C_{30}H$	Ts/(Ts + Tm)
YD2	Cretaceous	Oil, Tabei Uplift	–	–	0.51	0.12	2.17	0.54	0.48	0.67
S3	Cretaceous	Oil, Yakela Faulted Uplift	–	–	1.11	0.09	1.63	0.33	0.92	0.66
Ku1	Jurassic	Oil, Kuqa Depression	–	–	0.13	0.17	1.84	0.26	0.50	0.55
QL1	Paleogene	Oil, Kuqa Depression	–	–	0.66	0.60	1.79	0.48	0.64	0.63
RP10	Ordovician	Oil, Halahatang Sag	–	–	0.78	0.03	0.81	7.52	0.09	0.37
RP4	Ordovician	Oil, Halahatang Sag	–	–	0.38	0.01	0.76	8.06	0.08	0.42
RP3013	Ordovician	Oil, Halahatang Sag	–	–	0.96	0.03	0.92	9.06	0.12	0.53
RP11	Ordovician	Oil, Halahatang Sag	–	–	0.78	0.02	0.97	6.71	0.12	0.45
RP8	Ordovician	Oil, Halahatang Sag	–	–	0.87	0.03	0.75	10.5	0.12	0.45
JY1	Ordovician	Oil, Halahatang Sag	–	–	0.96	0.02	0.83	7.16	0.12	0.58
JY7	Ordovician	Oil, Halahatang Sag	–	–	0.92	0.02	1.04	9.06	0.09	0.49
JY3	Ordovician	Oil, Halahatang Sag	–	–	0.70	0.02	1.03	8.61	0.09	0.45
XK5	Ordovician	Oil, Halahatang Sag	–	–	0.85	0.02	0.82	6.81	0.10	0.42
XK4	Ordovician	Oil, Halahatang Sag	–	–	0.71	0.01	0.97	5.39	0.08	0.40
XK7	Ordovician	Oil, Halahatang Sag	–	–	0.79	0.03	0.81	7.69	0.09	0.29
XK9005	Ordovician	Oil, Halahatang Sag	–	–	0.94	0.01	1.05	9.83	0.08	0.46
Ha601	Ordovician	Oil, Halahatang Sag	–	–	0.72	0.02	0.88	5.63	0.17	0.44
Ha7-1	Ordovician	Oil, Halahatang Sag	–	–	0.80	0.01	1.00	9.08	0.17	0.43
Ha8	Ordovician	Oil, Halahatang Sag	–	–	0.70	0.02	0.98	6.52	0.12	0.37
Ha13-6	Ordovician	Oil, Halahatang Sag	–	–	0.74	0.01	1.01	6.84	0.11	0.46
TP12-8	Ordovician	Oil, Akekule	–	–	0.89	0.03	0.91	2.72	0.08	0.49
TP14	Ordovician	Oil, Akekule	–	–	0.65	0.02	0.87	10.10	0.06	0.45
S5	Triassic	Mudstone, core, 5400.8 m	0.71	0.74	0.48	0.11	1.26	0.17	0.65	0.85
S5	Triassic	Mudstone, core, 5405.4 m	0.73	0.75	0.42	0.10	1.21	0.75	n.d.	0.87
Ku-13	Jurassic	Sandy mudstone, outcrop, Kuzigongsu	1.64	1.10	0.72	0.17	1.56	0.47	1.55	0.76
Ku-18	Jurassic	Sandy mudstone, outcrop, Kuzigongsu	2.02	0.99	0.64	0.16	2.10	0.22	2.97	0.86
Ku-26	Jurassic	Sandy mudstone, outcrop, Kuzigongsu	3.53	0.94	0.19	0.98	1.59	0.12	6.71	0.96
Ku-30	Jurassic	Sandy mudstone, outcrop, Kuzigongsu	3.27	0.93	0.22	0.90	2.00	0.10	4.48	0.92
YL1	Jurassic	Coal, core, 2878.0 m	38.4	0.51	0.35	0.33	3.77	0.50	n.d.	n.d.
KCH-01	Triassic	Mudstone, outcrop, Kuchehe	1.12	–	0.26	1.44	2.08	0.31	n.d.	0.88

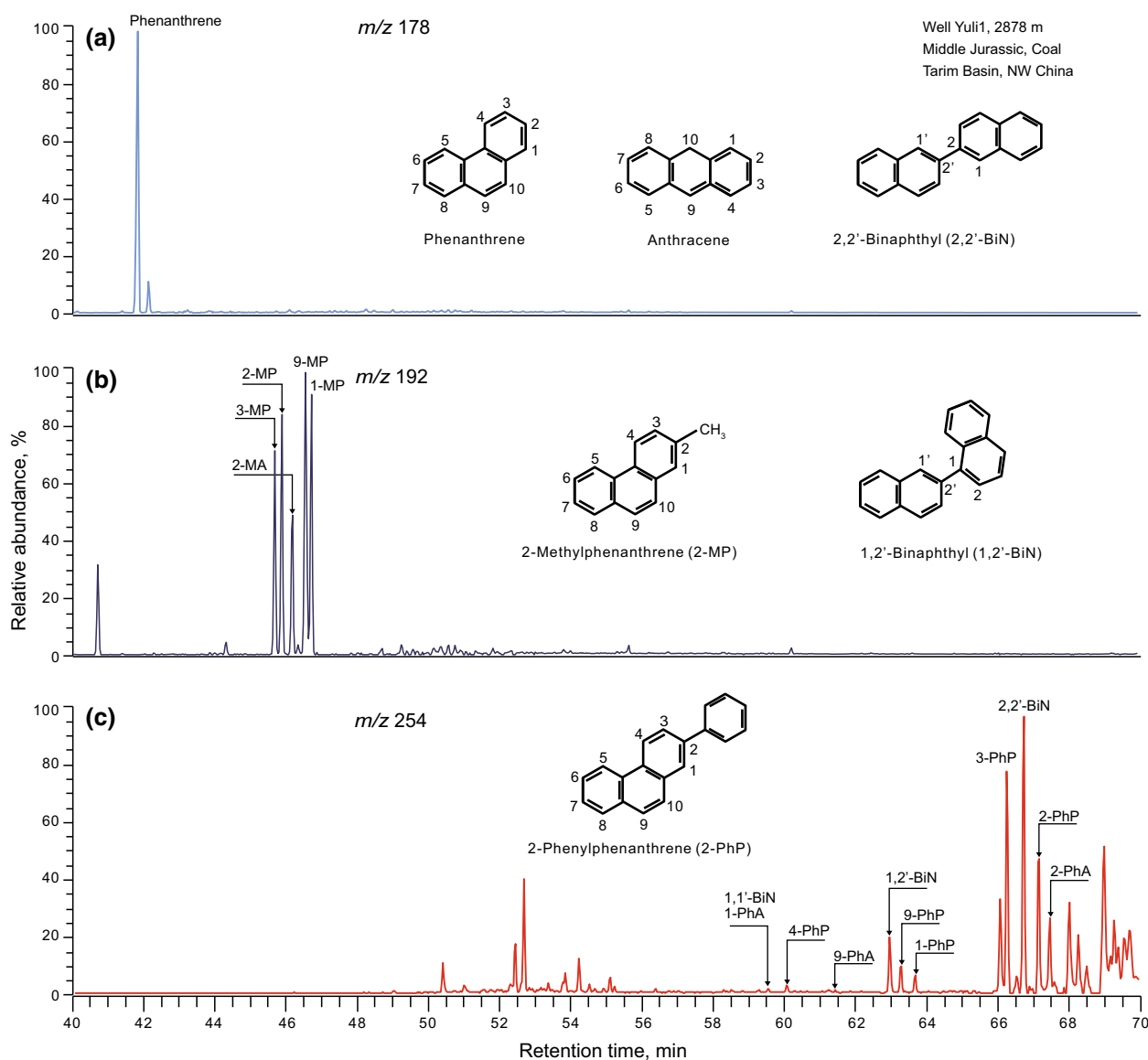
n.d.: no data

(ADBT/ADBF) versus pristane/phytane ratio (Pr/Ph) provides a powerful and convenient way to infer crude oil source rock depositional environments and lithologies (Radke et al. 2000). The oils from Ordovician reservoirs in the Tabei Uplift were characterized by lower Pr/Ph ratio and higher ADBT/ADBF ratio (Table 1), and the data points were plotted in Zone 1A of the cross-plot of ADBT/ADBF versus Pr/Ph ratios, indicating their marine carbonate origin (Fig. 5).

Oils from Jurassic and Paleogene reservoirs in the Kuqa Depression and oils from Cretaceous reservoirs in the Tabei Uplift have relatively higher Pr/Ph values and very low ADBT/ADBF values. All these data points fall into

Zone 3 (Fig. 5), suggesting the mudstone lithology of their source rocks. On the basis of oil-to-source correlation results, all these oils were derived from Mesozoic lacustrine mudstone source rocks (e.g., Song et al. 2015).

Selected Mesozoic mudstones from the Kuqa Depression and the Tabei Uplift were also analyzed. All rock samples have relatively higher Pr/Ph ratios and quite low values of ADBT/ADBF. The points also fall into Zone 3, indicating their lacustrine mudstone lithology (Fig. 5). The coal sample from Well YL1 in the eastern Tarim Basin has very high Pr/Ph ratio, which falls into Zone 4 (fluvial/deltaic carbonaceous shale and coal zone).



**Fig. 2** Identification of phenanthrene ( $m/z$  178), methylphenanthrene and methylanthracene ( $m/z$  192), and phenylphenanthrene, phenylanthracene, and binaphthyl isomers ( $m/z$  254) in sedimentary rocks and their chemical structures

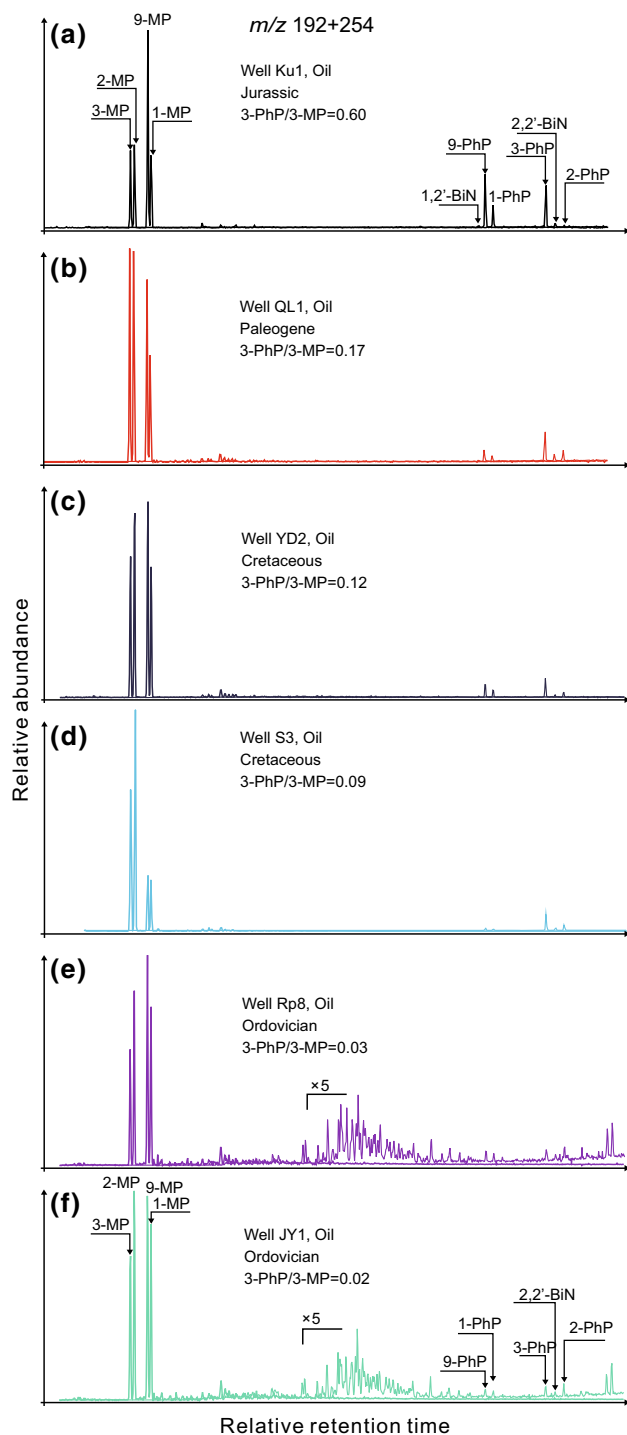
Therefore, the relative abundances of alkylated dibenzothiophenes to alkylated dibenzofurans and pristane to phytane confirm that the oils in the Ordovician reservoirs are of marine carbonate origin and the oils from Mesozoic and Paleogene sandstone reservoirs in the Kuqa Depression and Tabei Uplift of the Tarim Basin are of lacustrine mudstone origin.

#### 4.3 Distribution of PhPs and MPs in oils and source rocks

Most of the phenylphenanthrene isomers were detected in oils from wells Ku1, QL1, YD2, and S3 (Fig. 3a–d). They are present in differing abundance in these oils. The isomer of 2,2'-biphenyl is typically present in quite low

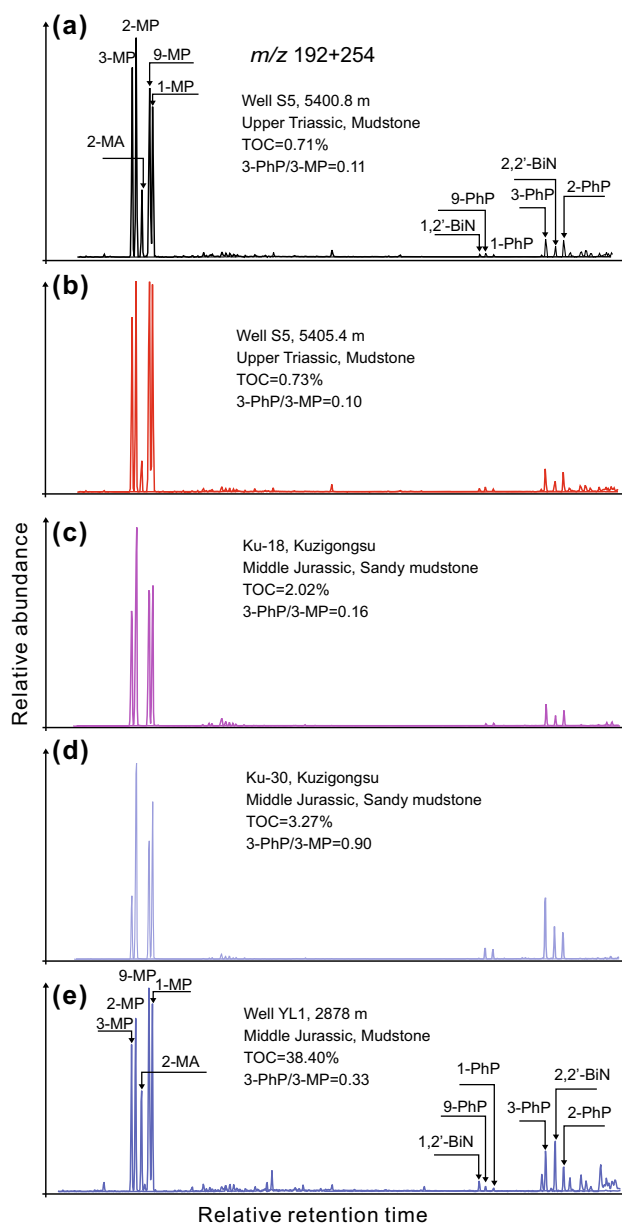
concentrations, and 1,2'-biphenyl is commonly absent or under detection limit. The 3-PhP is the dominant compound among all PhP, PhA, and BiN isomers in  $m/z$  254 mass chromatograms. The concentrations of PhPs are generally lower than those of their methylated counterparts—MPs in all oils. Here we defined 3-PhP/3-MP to indicate the relative abundance of PhPs to MPs. The oils from wells Ku1, QL1, YD2, and S3 have 3-PhP/3-MP ratios higher than 0.10. However, oils from Ordovician reservoirs in the Tabei Uplift, including Ha6, Repu, Xinken, Jinyue, and Tuofutai blocks, have extremely low concentrations of phenylphenanthrenes with 3-PhP/3-MP ratios lower than 0.10 (Fig. 4e, f; Table 1).

Selected Mesozoic lacustrine mudstones were also investigated to analyze the distribution patterns of PhPs and



**Fig. 3** Distribution of methylphenanthrenes ( $m/z$  192), phenylphenanthrenes ( $m/z$  254), and their isomers in selected oils from the Tarim Basin

MPs in sedimentary rock extracts. Most of the PhP isomers and 2,2'-BiN were detected in all rocks in this study. For the lower thermodynamic stability, PhAs and 1,1'-BiN are generally below detection limit in this study. The ratio of 3-PhP/3-MP in Mesozoic lacustrine mudstones is from 0.11 to 1.44, which is consistent with oils from wells Ku1, QL1,

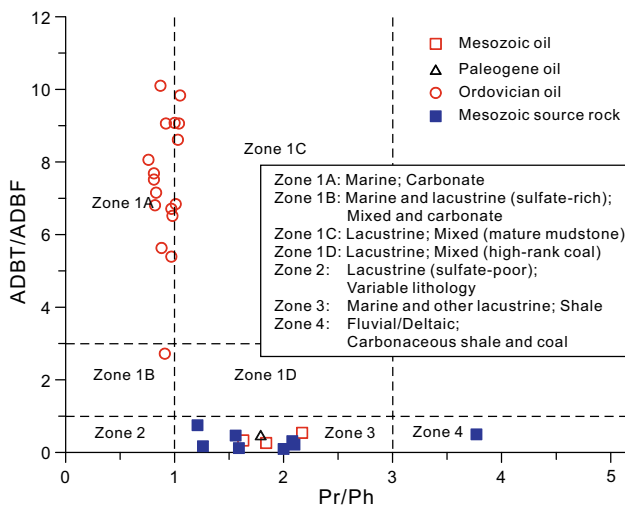


**Fig. 4** Distribution of methylphenanthrenes ( $m/z$  192), phenylphenanthrenes ( $m/z$  254), and their isomers in Mesozoic source rocks in the Tarim Basin

YD2, and S3. Therefore, the occurrence and distribution of phenylphenanthrene and methylphenanthrenes in Mesozoic oils and source rocks further confirmed their genetic affinity.

#### 4.4 Effect of environment and lithology on the distribution of MPs and PhPs

Much work has been done on the occurrence and distribution of methylated phenanthrenes. For example, Alexander et al. (1995) demonstrated that the sedimentary methylation process can form some alkylphenanthrene isomers. Due to the ubiquitous occurrence, the methylphenanthrenes appear to

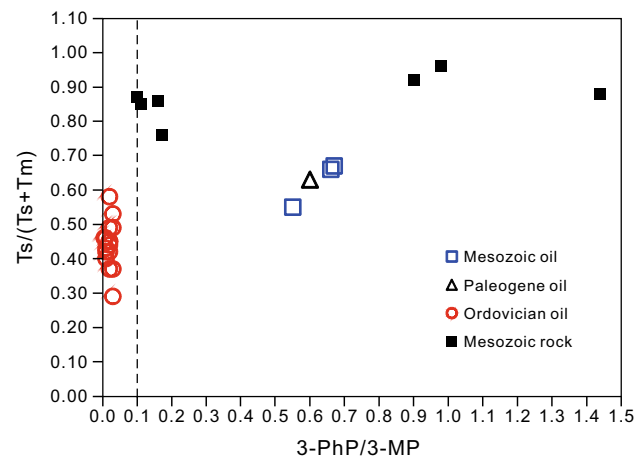


**Fig. 5** Cross-plot of alkyldibenzothiophene/alkyldibenzofuran ratio (ADBT/ADBf) versus pristane/phytane ratio (Pr/Ph) showing crude oil source rock depositional environments and lithologies (after Radke et al. 2000)

have limited depositional environment and lithology significance. They are effective molecular markers for thermal maturity assessment (e.g., Radke et al. 1982; Boreham et al. 1988; Voigtmann et al. 1994; Szczerba and Rospondek 2010).

Here we use 3-PhP/3-MP to show the abundance of phenylphenanthrenes relative to methylphenanthrenes in oils and sedimentary organic matter. The abundance of parent phenanthrene may be different for the differences in the input of organic matter in source rocks and/or thermal maturation level of sedimentary organic matter. As proposed by previous studies (Marynowski et al. 2001; Rospondek et al. 2009), the phenylation of phenanthrene is mainly associated with an oxidizing depositional environment. Therefore, an oxic to suboxic environment may favor the formation of phenylphenanthrenes. The cross-plot of  $Ts/(Ts + Tm)$  versus 3-PhP/3-MP is used here to investigate the effect of the depositional environment and lithology on the distribution patterns of MPs and PhPs. The  $Ts/(Ts + Tm)$  ratio ( $18\alpha$ -22,29,30-trisnorneohopane/( $18\alpha$ -22,29,30-trisnorneohopane +  $17\alpha$ -22,29,30-trisnorhopane)) depends on both source and maturity (Moldowan et al. 1986). It is a reliable maturity indicator when assessing oils from a common source of consistent organic facies (Peters et al. 2005). This ratio increases with the increasing maturity. It is sensitive to clay-catalyzed reactions. For example, oils from carbonate source rocks appear to have low  $Ts/(Ts + Tm)$  ratios compared with those from shales (e.g., Rullkötter et al. 1985).

Here we found that oils from Ordovician reservoirs have relatively lower  $Ts/(Ts + Tm)$  values (<0.50) and very low 3-PhP/3-MP ratios (<0.10). In contrast, the Mesozoic and Paleogene oils from wells Ku1, QL1, S3, and YD2 and Mesozoic lacustrine mudstones have higher  $Ts/(Ts + Tm)$



**Fig. 6** The cross-plot of  $Ts/(Ts + Tm)$  versus 3-PhP/3-MP ratio provides a useful way to infer the depositional environment and lithology of oils and related source rocks.  $Ts$ — $C_{27}$  18 $\alpha$ -22,29,30-trisnorneohopane;  $Tm$ — $C_{27}$  17 $\alpha$ -22,29,30-trisnorhopane

(>0.55) and 3-PhP/3-MP ratios (>0.10) (Fig. 6). The higher  $Ts/(Ts + Tm)$  ratios for Mesozoic oils and source rocks are mainly attributed to a suboxic depositional environment and clay-rich lithology, because Ordovician oils sourced from Paleozoic marine source rocks have generally higher maturation levels than those from the Mesozoic lacustrine source rocks.

The  $C_{30}$  diahopane in sedimentary rock extracts and oils may be derived from bacterial hopanoid precursors that have experienced oxidation and rearrangement by clay-mediated acidic catalysis. Therefore, the presence of a significant amount of  $C_{30}$  diahopane indicates bacterial input to sediments containing clays deposited under oxic or suboxic environments (Peters et al. 2005). In this study, the  $C_{30}$  diahopane is generally present in very low concentration in Ordovician oils (with  $C_{30}$  diahopane/ $C_{30}$  hopane ratios lower than 0.20). While Mesozoic and Paleogene oils from wells Ku1, QL1, S3, and YD2 and Mesozoic lacustrine mudstones have higher  $C_{30}$  diahopane/ $C_{30}$  hopane ratios (Table 1). Therefore, our study suggests that the presence of a significant amount of phenylphenanthrenes is generally related to clay-enriched sediments deposited under suboxic conditions.

## 5 Conclusions

Phenyl phenanthrenes and their isomers have been detected in oils and source rocks from the Tarim Basin, NW China. 3-phenylphenanthrene (3-PhP), 2-PhP, and 1,2'-binaphthyls (1,2'-BiN) are typically predominant compounds among all isomers. The abundances of phenylphenanthrenes are extremely low in Ordovician oils in the Tabei Uplift of the Tarim Basin. The Mesozoic oils from wells QL1 and

Ku1 from the Kuqa Depression and wells S3 and YD2 from the Tabei Uplift have relatively higher concentrations of phenylphenanthrenes.

The ratio of 3-PhP/3-MP (3-phenylphenanthrene/3-methylphenanthrene) is used to indicate the relative abundances of phenylphenanthrenes to methylphenanthrenes. We discovered that oils from marine carbonate source rocks have a very low ratio (<0.10). However, oils of lacustrine mudstone origin and related source rocks have relatively high 3-PhP/3-MP ratios, associating with higher Pr/Ph, Ts/(Ts + Tm) and C<sub>30</sub> diahopane/C<sub>30</sub> hopane values.

The occurrence and distribution of phenylphenanthrenes in oils and sedimentary rock extracts in the Tarim Basin clearly show an environment dependence. Relatively higher abundance of phenylphenanthrenes (3-PhP/3-MP higher than 0.10) generally suggests clay-enriched sediments under suboxic depositional environment. Certainly, further work is needed to investigate whether this is valid in other basins.

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