Shale characteristics in the southeastern Ordos Basin, China: Implications for hydrocarbon accumulation conditions and the potential of continental shales

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1. Introduction

Marine shale gas has recently gained significant success in the USA, and it has triggered a worldwide fever for shale hydrocarbon resources. In contrast, there has been little work done and less attention paid to continental shale hydrocarbons. Continental shales, characterised by low thermal maturity and a high clay content, which differs from the properties of the marine shale documented in the USA and elsewhere (Curtis, 2002), are widespread in northern China. There is an urgent need to characterise continental shales and evaluate their hydrocarbon potential as a viable resource. The Ordos Basin is a large, hydrocarbon-prolific basin located in the middle of northern China, possessing giant gas fields in the Upper Palaeozoic and oil fields in the Ordovician, Triassic and Jurassic strata (Liu et al., 2012; Tang et al., 2012). In the Triassic Ordos is a typical intra-continental sedimentary basin, which has developed widespread lacustrine shale (F., Wang et al., 2010; Hu et al., 2008; Y. P., Wang et al., 2010) and has been regarded as the most important source rocks for the Triassic oil reservoirs, instead of the hydrocarbon host layers (Hanson et al., 2007; Hu et al., 2008; Li et al., 2012; Liu et al., 2010; Yang et al., 2005). Recently, vertical drills in the upper

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Triassic shales produced two to five tons of oil on average and 1000–3000 m³ of gas per day by fracturing, which inspired oil companies to turn their eyes upon those shale themselves for hydrocarbon resources. Is it possible to find large oil and gas accumulations in these continental shale intervals? In this paper, we re-examined the upper Triassic continental shales in the southeastern Ordos Basin to investigate their geochemical and petrological character and physical properties, and we measured their gas and oil contents to evaluate the hydrocarbon-accumulation conditions and resource potential for continental shales.

2. Geologic setting

The Ordos Basin, 26 × 10⁴ km², is located in the central part of the North China Plate, and it is a large, asymmetric syncline with a broad, gently dipping eastern limb and a narrow, steeply dipping western limb and with the Tianhuan Sag forming the syncline axis (Sun et al., 1989). Tectonically, the basin can be subdivided into six substructures: the Weibei Uplift in the south, the Yimeng Uplift in the north, the Jinxin Fold Belt in the east, the Tianhuan Sag and the western edge thrust belt in the west and the Yishan Slope in the central part (Fig. 1A). The Yishan Slope has a 1–2° dip and covers a large area of the basin (Fig. 1B) where the main locations for petroleum exploration and development in the Ordos Basin are located.

2.1. Tectonics

The Ordos Basin, a typical cratonic basin developed on the base of Archean granulites and the lower Proterozoic greenschists of the North China block (Yang et al., 2005), has experienced four evolutionary stages: the Early Palaeozoic shallow marine platform, the Late Palaeozoic offshore plain, the Mesozoic intracontinental basin and the Cenozoic faulting and subsidence (Yang et al., 2005). The structural...
framework of the basin was largely developed during the Mesozoic, when widespread intra-continental lacustrine shales developed during late Triassic. Since the Late Cretaceous, the Ordos Basin has experienced five events of reformation (Liu et al., 2008; Zhang et al., 2011; Zhao et al., 2011), and the present tectonic situation came into being after the Cenozoic basin general subsidence (Guo, 2006).

2.2. Stratigraphy

The Yanchang Formation, which consists of the upper Triassic strata, topped by the Lower Jurassic Fuxian Formation and underlain by the Middle Triassic Zhifang Formation, can be subdivided into ten members, named Member Chang1 through Chang10 from top to bottom (Fig. 2). All members consist of mudstones, shales and sandstones, among which Member Chang 9, Chang 7 and Chang 4 + 5 are composed predominantly of dark shale, and the other intervals of the Yanchang Formation are composed of sandstones and silt sandstone predominantly interbedded with greyish-green mudstones (Chen, 2004; Guo, 2006; Yang, 2004; Zhang, 2006). Chang 6 is an important exploration target for conventional hydrocarbon accumulations in the basin (Yang, 2004).

3. Samples and experiments

We analysed 33 shale-core samples from 14 wells in the study area. The sample location is shown in Fig. 4. The shale samples were tested for total organic carbon (TOC), rock-eval pyrolysis parameters, maceral composition and XRD analysis and methane-isotherm examination.

The total organic carbon (TOC) was measured by a Leco infrared carbon/sulphur analyser. The gas content was measured by direct methods, according to a procedure similar to the USBM method (Diamond and Schatzel, 1998; Shtepani et al., 2010) and by indirect methods following the sorption-isotherm procedure described in the literature (Gasparik et al., 2012; Krooss et al., 2002). The gas composition was analysed in a GC–MS, and a gas isotopic analysis was performed using a Finnigan Mat Delta Plus GC/IRMS RQ/Y2002-047.

Thin-section investigation, X-ray diffraction (XRD) and QEMSCAN technology were used to analyse the lithological and mineral composition of shale samples. The XRD analysis was performed with a Bruker D8-Discover X-ray diffractometer (XRD). QEMSCAN technology can be used to map the sample surface and contextual information (Gottlieb et al., 2000; Liu et al., 2005); therefore, it was also used to analyse our samples. A combination focused ion beam milling scanning electron microscope (FIB-SEM) was used to investigate the microscopic pores and fractures. The pore structure was measured by a Quadrasorb-SI BET Surface Area and Pore Size Analyser following the method of Gregg and Sing (1982).

4. Continental-shale characteristics

4.1. Shale distribution and sedimentary facies

Outcrops, cores and logging analysis from 33 wells over the study area were employed to map the shale distribution and sedimentary facies. Shales in the members C9 and C7, which were formed by twice-

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<td>300-350</td>
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</table>

Fig. 2: The generalized stratigraphic column of the Triassic in the southeastern Ordos Basin, modified from Yang (2004). The star marked the targeted deep and semi-deep lacustrine organic-matter-rich black shales.
Fig. 3. The loggings correlation through the research area from north to south showing the shale intervals are stable distributed and thin from south to north (the location of the wells and cross section shown as in Fig. 4).
Fig. 4. The sedimentary facies map of the Member C9. The location of cross section of Fig. 3 from Lu67 to Y111 shown as AA′. The sedimentary facies map of the Member C7.
repeated transgressions in the late Triassic (F. Wang et al., 2010; Jian et al., 2010; Y. P., Wang et al., 2010; Yang et al., 2005), cover more than 10,000 km² and are characterised by a black or black–brown colour with horizontal or fine wavy bedding. The shale interval on the top of Member Chang 9, termed the Lijijapan shale, is widespread and thin, ranging from 10 m (33 ft) to 15 m (50 ft) in thickness with an average of 11 m, whereas the shale intervals on the bottom of C7, termed the Zhangjiatan shales, are stable and distributed over the research area ranging from 40 to 100 m (130–328 ft) in thickness with multiple shale layers superimposed vertically, among which a single shale interval on the bottom of C7 is over 60 m (196 ft) thick. All of these shale intervals are thick in the southwest part and thin towards the northeast (Fig. 3). A sedimentary-facies map shows that deep lacustrine developed in the southern part, whereas a distal bar, sub-distributary channel or distributary bay developed in the northern and eastern parts (Fig. 4A and B). Deep and semi-deep lacustrine are favourable deposition environments for developing organic-rich shales.

4.2. Organic geochemical characteristics

4.2.1. Organic-matter abundance

The organic-matter abundance can be measured with total organic content (TOC) (Table 1). The TOC of the C9 shale interval ranges from 0.16 to 6.9 wt.% with an average of 2.18%, and C7 ranges from 0.49 to 6.08 wt.% with an average 2.74 wt.%. The C7 and C9 shale intervals have similar TOC distribution trends over the research region (Fig. 5A and B), with decreasing TOC values from south to north. The high TOC content (TOC) (Table 1). The TOC of the C9 shale interval ranges from 4.2 to 6.08 wt.% with an average 2.74 wt.%. The C7 and C9 shale intervals ranging from 0.49 to 6.08 wt.% with an average of 2.18%, and C7 ranges from 0.49 to 6.08 wt.% with an average of 2.18%. The C7 and C9 ranges from 0.16 to 6.9 wt.% with an average of 2.74 wt.%. The C7 and C9 shale intervals of this region experienced a similar buried and thermal evolution history and possess a similar maturity-variation trend (Fig. 8A and B). The southeastern corner of the research area has a higher maturity level with an Ro of 1.0%–1.5%, which means that this

4.2.2. Organic-matter type

The classification of the organic matter based on the H/C and O/C atomic ratios can determine the type of hydrocarbon product of kerogen (Table 1). The elemental composition analysis results show that, in general, the O/C ratio is between 0.03 and 0.15 and H/C is between 0.5 and 1.5. A van Krevelen diagram indicates that most of the kerogen is type II, either type II1 or type II2 (Fig. 6).

The maceral composition in the polished rock surface in reflected light was also examined to classify the kerogen type (Table 1). Several maceral types were observed in the samples, including amorphous, alginite, resinite, sporopollen, cutinite, vitrinite and inertinite. Amorphous and alginite, derived from marine or lacustrine subaquatic muds, represent kerogen type I, ranging from 2.0% to 24.7% of the total mineral composition. Resinite, sporopollen and cutinite were combined into liptinite for consideration with a range of 12 to 15%. Vitrinite and inertinite, derived from the continental material input and able to act as an indicator for kerogen III, represented less than 1%. A ternary diagram of the maceral composition derived from (Hou and Zhang, 2003) indicates that the shale samples from the C7 and C9 shale intervals are predominantly type II (Fig. 7).

4.2.3. Thermal maturity

Thermal maturity provides an indication of the maximum palaeotemperature reached by a source rock, which determines the type and quantity of the hydrocarbon product from kerogen. The vitrinite reflectance of the C9 and C7 shale intervals ranges from 0.65 to 1.5% Ro and 0.5%–1.3% Ro, respectively (Table 1). The C9 and C7 shale intervals of this region experienced a similar buried and thermal evolution history and possess a similar maturity-variation trend (Fig. 8A and B). The southeastern corner of the research area has a higher maturity level with an Ro of 1.0%–1.5%, which means that this
Fig. 5. Maps showing the weight percent of TOC content in the Member C9 (A) and C7 (B). Contour interval, 0.5 wt.%. TOC. TOC content value trend is familiar between the Member C9 and C7, but the C7 is higher than that for the C9. See Table 1 for the rock-eval pyrolysis data.
region has already reached the wet-gas window, whereas the wide middle and eastern part is still in the oil window with 0.6–1.0% Ro.

4.3. Mineral composition and physical properties

4.3.1. Lithology and mineral composition

Thin-section investigation shows that strong heterogeneity of the lithology exists within the shale intervals. The combination patterns of detrital grains and the mud matrix or organic matter include: 1) detrital grains in shales that are lamellae interbedded with an organic-rich matrix (Fig. 9A), 2) detrital grains floating among a clay and organic-matter matrix (Fig. 9B), 3) detrital grains and the clay matrix mixed homogenously (Fig. 9C) and 4) detrital grains and the clay matrix mixed with a crumb structure (Fig. 9D). Various lithological combination patterns may lead to dissimilar rock mechanics, which impact the response of shale intervals to hydraulic fracturing (Enderlin et al., 2011).

The X-ray diffraction (XRD) analysis result shows that the C7 and C9 shale intervals are quite rich in clay minerals (Table 2). For certain samples, the clay mineral content ranges from 20 to 58% with an average of 43.8%, and the brittle mineral content accounts for ~30 to 60%. Among brittle minerals, quartz and feldspar dominate (including potassium and plagioclase), accounting for 24–34% and 10–25%, respectively; a small amount of carbonate minerals and pyrites also present in a number of samples. Clay minerals are essentially composed of illite, mixed illite/smectite and chloride; the illite content dominates, even up to more than 60% of clay minerals for certain samples.

QEMSCAN technology was used to map the sample surface, the textural properties and the contextual information (Gottlieb et al., 2000; Liu et al., 2005). The QEMSCAN analysis results show that the clay minerals are the dominant minerals (over 60% of the bulk mineral composition) and are distributed in a lamellar structure with brittle-mineral intervals (Fig. 10).

4.3.2. Pore types and fractures

The pore types within the shales were classified into interparticle (interP) mineral matrix pores, intraparticle (intrap) mineral pores and intraP organic-matter (OM) pores (Loucks et al., 2012). All of these types of pores are present in the C7 and C9 shale intervals. The organic matter tends to mixed together with clay minerals, shown as the dark area in photographs (Fig. 11A, B, C, E, F).

OM pores, nearly occurring as intraP pores, are quite developed in the samples with Ro 0.96%, although restricted to a limited area, which might be the residue of an organic clay that experienced thermal alteration and had its hydrocarbons expelled (Fig. 11A, B).

Previous works show that the pore is more developed with higher maturity (Curtis et al., 2012). Woodford Shale develops pores only with a vitrinite reflectance higher than 0.90% Ro, whereas in our research area, the samples with lower maturity (Ro 0.72%) have already developed plenty of pores within the organic-rich matrix.

The matrix pores are well developed, mostly as interP pores, usually occurring around or between grains, regardless of their maturity (Fig. 11C and D), and they may play a larger role for hydrocarbon storage than the OM pores. Fishman also reported that mineral pores can play a more important role in gas storage (Fishman et al., 2012).

A low-pressure N2 sorption measurement (BET surface analysis) can provide a quantitative description of the size distribution of pores and their contributions to the volume. The BET surface analysis shows that the majority of the pores in the C7 and C9 shale samples are between 3 and 5 nm wide (Fig. 12), which makes them mesopores by IUPAC pore-size classification (Adesida, 2011; Rouquero et al., 1994). Such pores are so small that they are even invisible in the FIB-SEM micrographs (pores with widths of dozens to hundreds of nanometres can be seen in the FIB-SEM images, Fig. 11B), but they may provide the main compartments for hydrocarbon storage in shale intervals.

Tectonically induced fractures are not well developed due to gentle structural deformation (Zhu et al., 2013), but millimetre- or nanometre-scale micro-fractures have still developed, which were observed in thin sections, SEM and QEMSCAN photographs (Fig. 10). The micro-fractures mostly originates from diagenesis and are easy to recognise because they often occur along the lithological transition zone in horizontally laminated or banded zones, extending far and straight, which is in contrast to the fractures derived from desiccation/drying, which extend zigzag and often occur in groups and clusters (Loucks et al., 2009).

4.3.3. Porosity and permeability

The porosity of the C7 and C9 shales was measured by experiments and logging analysis. The porosity calculated from acoustic logging ranges from 3 to 8% for the C9 shale interval and 3 to 6% for the C7 shale interval. The permeability is quite low, ranging from ~0.001 to 0.01 md. This physical-property data of the C7 shale interval is reasonable compared with that of the adjacent tight-sandstone reservoirs within Member C7, with a porosity of 0.8%–12% with an average of 7.2% and a permeability 0.01–1.35 md with an average of 0.18 md (Yang et al., 2013).
Fig. 8. The isoreflectance maps (% Ro) for Member C9 (A) and C7 (B). Contour interval, 0.1% Ro.
4.4. Oil and gas yield and origin

4.4.1. Gas content

There were only six samples available for gas-canister desorption from well LP171 and Wan 169, located in the southwestern corner of the research region (Table 3). The result shows that the gas yield ranged from 1.15 to 3.49 m$^3$/t rock ($R^2 \approx 0.9$), which is higher than the range of 0.4 to 2.0 m$^3$/t reported in the New Albany Shale (Strapoc et al., 2010). Actually, the GOR to the west of our research area amounts to 80–120 m$^3$/t (Deng et al., 2011).

These samples were also run in the laboratory-derived sorption isotherm under dry conditions. The Langmuir equations were employed to calculate the Langmuir volume ($V_L$) and the Langmuir pressure ($P_L$) (Table 1). The $V_L$ ranges from 1.56 to 6 m$^3$/t, concentrating by ~3–5 m$^3$/t, which suggest that the shale intervals in C7 and C9 have quite a strong gas-absorption capacity, much higher than that reported in North of the Border, Canada (1.5 m$^3$/t with 5–10 wt.% TOC) (Ross and Bustin, 2007).

No samples are available for canister desorption in the middle and eastern part of the research region, but the GOR of this area, ranging

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### Table 2

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<th>Pla. (wt.%)</th>
<th>Cal. (wt.%)</th>
<th>Dol. (wt.%)</th>
<th>Pyr. (wt.%)</th>
<th>Sid. (wt.%)</th>
<th>Kao. (wt.%)</th>
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<td>C 9</td>
<td>5</td>
<td>43.60</td>
<td>26.00</td>
<td>4.20</td>
<td>19.00</td>
<td>1.00</td>
<td>9.00</td>
<td>1.00</td>
<td>5.33</td>
<td>0</td>
<td>15.20</td>
<td>36.60</td>
<td>48.20</td>
<td>16.00</td>
</tr>
<tr>
<td>LP180</td>
<td>1612.85</td>
<td>C 9</td>
<td>1</td>
<td>62.00</td>
<td>34.00</td>
<td>4.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16.00</td>
<td>33.00</td>
<td>51.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Zheng061</td>
<td>535.14</td>
<td>C 7</td>
<td>1</td>
<td>53.00</td>
<td>24.00</td>
<td>4.00</td>
<td>19.00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>31.00</td>
<td>37.00</td>
<td>32.00</td>
<td>25.00</td>
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<tr>
<td>Liu016</td>
<td>4745.74</td>
<td>C 7</td>
<td>5</td>
<td>39.60</td>
<td>30.40</td>
<td>5.40</td>
<td>14.00</td>
<td>3.00</td>
<td>7.50</td>
<td>6.00</td>
<td>7.25</td>
<td>0</td>
<td>16.80</td>
<td>41.00</td>
<td>42.20</td>
<td>15.00</td>
</tr>
</tbody>
</table>

N, number of core samples; Str., strata; I/M, mixed illite and smectite; Pot., potassium; Pla., plagioclase; Cal., calcite; Dol., dolomite; Pyr., pyrite; Sid., siderite; Kao., kaolinite; Chlor., chloride; Ratio, ratio of I/M.
from 40 to 50 m$^3$/t (Deng et al., 2011), suggests that the gas content of the middle and eastern part of the research region can be quite low.

### 4.4.2. Oil production

In the western part of the research area, vertical wells were drilled at Member C7 and C9 and produced an oil average of 1–4 m$^3$ and liquid at 2–10 m$^3$ per day after reservoir stimulation. The oil from the C7 shale is typically normal black oil with an average density of 0.84–0.85 g/cm$^3$ and a viscosity 5.8–6.12 mPa s at the surface conditions.

No horizontal wells have been drilled yet, although the horizontal wells in the neighbouring area produced up to 20 m$^3$ of oil per day on average by hydraulic fracturing (Yang et al., 2013), which suggests that the research area is a favourable area for producing commercial oil.

### 4.4.3. Gas and oil origin

Gas samples were collected from the desorption canister. The gas-composition analysis shows that the light-hydrocarbon gas content accounts for 75–90% in volume, among which the methane content comprises 50–87%, ethane approximately 12–16% and the heavier...
gas less than the gas content (Table 4). The carbon isotopic analysis provides information about the gas origin. The carbon isotope of methane ($\delta^{13}C_{1}$) ranges from $-55$ to $-35\%$, and the ethane ranges from $-39.7$ to $-37.5\%$, which indicates that the gas is thermogenic and cogenerated with oil according to the natural-gas-origin isotopic template established by Dai (2000) (Fig. 13).

5. Discussion

5.1. TOC and absorbed gas in place

The gas content is well correlated with the TOC content, which has been well documented by previous studies (Ross and Bustin, 2007, 2009; Zhang et al., 2012). Minimal gas content data from canister desorption is available, but the Langmuir volume ($V_L$) from the sorption isotherm versus the TOC content shows that the gas-absorption capacities of shales are roughly related to the TOC content, although the correlation coefficients ($R^2$) vary greatly from $-0.2337$ (C7) to $-0.958$ (C9) (Fig. 14). With more sorption-isotherm data, the empirical relationship between the TOC content and $V_L$ would more reliable, and it would enable us to obtain a more precise model for the estimation of absorbed gas.

5.2. Thermal maturity and hydrocarbon product of kerogen

The thermal maturity level of the C7 and C9 shale intervals is still in the oil-wet-gas window, and the maturity decreases from west to east, which suggests that the hydrocarbon product might change from wet
natural gas via oil-gas coproduction in the middle part to oil predominance in the eastern part of the research area.

The southwestern corner of the research area has a relatively high thermal maturity, ranging from 1.0 to 1.5% Ro, which is comparable to the maturity level of the Barnett shale, Fort Worth Basin, where the regions with Ro more than 1.0% are potential areas, particularly the area with Ro 1.3–1.7%, which is the highest potential area for gas production (Montgomery et al., 2005). Therefore, we can expect that the southwestern corner of our research area might have high potential as a shale-gas resource. This appears to be true by the latest successful drilling and gas production testing from the C7 and C9 shale intervals in Well LP 177.

The eastern part of the research area, still in the oil window with Ro 0.5–1.0%, has a lower gas content and produces light-normal oil, properties which are similar to those of the Bakken formation, Williston Basin, where the oil density ranges from 0.7 to 0.85 m³/g (Price and Schoell, 2005) and the shale thermal maturity ranges from 0.6 to 1.0% (Flannery and Kraus, 2006). These comparisons provide evidence to predict the shale-oil potential of the eastern region. In reality, there already a large number of vertical wells producing oil from Chang 6 in the middle and eastern part of the research area (Deng et al., 2011).

5.3. Mineral composition and fracability prediction

The mineral composition of the continental shales in the C7 and C9 shale intervals have significant differences from the shales documented in the USA (Chalmers et al., 2012; Clarkson et al., 2013). The C7 and C9 shale intervals have a much higher clay-mineral content than Barnett shales (clay content of 36.3%), approximately close to that of Haynesville, Woodford and Marcellus (43%–45.8%) (Chalmers et al., 2012).

The brittleness of shales is a very important factor for predicting rock fracability (Breyer et al., 2011; Britt and Schoellfier, 2009), which is related to the lack of clay constituents of shales. Ductile rocks, such as Fort Simpson shales and the upper black shale member, which have clay contents in the range of 26 to 88%, will present production challenges (Ross and Bustin, 2008). Therefore, the clay content of the C7 and C9 shale intervals ranges from 20% to 58%, which might lead to significant challenges for successful development.

6. Conclusions

Geochemical, petrologic and hydrocarbon-composition analyses show that continental shale is significantly different in its petrologic and mineral composition from marine shales in the USA but that it can also have considerable hydrocarbon potential.

(1) The Upper-Triassic Chang 9 (C9) and Chang 7 (C7) are continental, organic-rich shales in the Ordos Basin, developed in the deep to semi-deep lacustrine, covering over 10,000 km² with a stable thickness distribution (50–115 m in thickness). The continental shales are predominantly characterised by kerogen type II, with a high TOC content (2.0–3.0%) and a relatively low thermal maturity (vitrinite reflectance, 0.75–1.5% Ro).

(2) Continental shales have strong heterogeneity of lithological combination, with low to ultra-low porosity (less than 8%) and permeability (less than 0.01 md). Nanometre-scale pores and micro-fractures are well developed. Mesopores may provide the main compartments for hydrocarbon storage in the continental shale intervals.

(3) Oil and gas is coproduced from the C7 and C9 shale intervals, and the hydrocarbon product changes from predominantly gas via oil-gas coproduction in the middle part to oil predominance in the eastern part of the research area.

### Table 3
Canister gas yield, lost gas calculated from liner fit.

<table>
<thead>
<tr>
<th>No.</th>
<th>Well</th>
<th>Strata</th>
<th>Depth (m)</th>
<th>Wight (kg)</th>
<th>Gas yield (cm³)</th>
<th>Gas content (m³/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LP171</td>
<td>C7</td>
<td>1730.00</td>
<td>3.30</td>
<td>4909.86</td>
<td>1.64</td>
</tr>
<tr>
<td>2</td>
<td>LP171</td>
<td>C7</td>
<td>1780.00</td>
<td>0.60</td>
<td>1790.18</td>
<td>2.98</td>
</tr>
<tr>
<td>3</td>
<td>LP171</td>
<td>C9</td>
<td>1862.00</td>
<td>0.50</td>
<td>1742.57</td>
<td>3.49</td>
</tr>
<tr>
<td>4</td>
<td>Wan 169</td>
<td>C7</td>
<td>973.00</td>
<td>0.55</td>
<td>613.36</td>
<td>1.15</td>
</tr>
<tr>
<td>5</td>
<td>Wan 169</td>
<td>C7</td>
<td>977.40</td>
<td>0.23</td>
<td>767.60</td>
<td>3.41</td>
</tr>
<tr>
<td>6</td>
<td>Wan 169</td>
<td>C7</td>
<td>976.70</td>
<td>0.26</td>
<td>804.50</td>
<td>2.93</td>
</tr>
</tbody>
</table>

* Gas yield includes lost gas, desorbed gas and remaining gas.

### Table 4
Gas composition and isotopic analysis result for samples from Well LP171.

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Strata</th>
<th>Depth (m)</th>
<th>Gas composition (%)</th>
<th>Carbon isotope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C7</td>
<td>1730</td>
<td>0.23  1.07 75.38 12.81 7.29 0.58 1.73 0.26 0.34 0.3 52 39.7 34.3 32.6</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>C7</td>
<td>1730</td>
<td>1.09 0.95 76.03 12.05 6.86 0.55 1.63 0.24 0.32 0.27 51.9 39.6 34.3 32.7 32.4 31.9</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C7</td>
<td>1730</td>
<td>0 1.25 76.84 12.09 6.84 0.54 1.61 0.24 0.32 0.26 51.6 39.5 34.1 32.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>C7</td>
<td>1780</td>
<td>1.48 0.6 76.16 12.35 6.46 0.58 1.51 0.25 0.32 0.27 51.3 39.4 34 32.7 31.8 32.1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>C7</td>
<td>1780</td>
<td>0 1.15 75.95 13.54 6.85 0.59 1.35 0.2 0.21 0.15 50.6 39.1 33.8 32.1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>C7</td>
<td>1780</td>
<td>0 0.85 70.48 16.15 9.36 0.72 1.83 0.24 0.24 0.12 48.9 38.9 34.1 32.7 32.3 32.3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>C9</td>
<td>1862</td>
<td>0 0.39 70.00 16.02 9.86 1.02 2.06 0.29 0.26 0.08 51.1 38.9 33.8 35.0 32.4 31.9 31.1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>C9</td>
<td>1862</td>
<td>4.75 0.32 69.06 13.76 8.73 0.54 1.85 0.27 0.23 0.08 50.7 37.5 33.3 32.1 32.0 28.3</td>
<td></td>
</tr>
</tbody>
</table>

N₂—nitrogen; C₁—methane; C₂—ethane; C₃—propane; iC₄—iso-butane; nC₄—n-butane; iC₅—iso-pentane; nC₅—n-pentane; C₆+—heavy hydrocarbon with carbon number is more than six.
According to Dai (2000).

(5) The continental shale intervals of C7 and C9 are rich in clay-

The highly mature shales in the southwestern corner of the re-

coproduced oil and gas to predominantly oil with the decreasing

(4) The research region, possessing high gas contents and gas-absorption

capacities, have a high potential for shale-gas exploration. The

(5) The continental shale intervals of C7 and C9 are rich in clay-

Fig. 13. The gas isotopic composition and gas origin analysis plate. The isotopic plate ac-

cording to Dai (2000).

Fig. 14. The cross plots of TOC content versus the Langmuir volume ($V_L$).

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Fig. 14. The cross plots of TOC content versus the Langmuir volume ($V_L$).