Abstract

In this paper, shale oil is defined to be the mature oil that is stored in organic-rich shale stratum with nano-sized pore-throats, and it is a very promising exploration field in future. Based on the data of thin sections, Field Emission-SEM, Nano-CT, EDS, Mercury injection, N2 adsorption and production data, we carried out the preliminary research on the potential of shale oil in the Ordos Basin. This study is trying to determine whether terrestrial shales can be reservoirs and whether the commercial oil production is available in such shales.

The samples are black shale and dark grey mudstones developed in the semi-deep to deep lacustrine facies, with I-type and III-type kerogen. The thickness of shale with TOC higher than 2% and Ro higher than 0.7% is 21-36m, and the exploration area can reach 20,000 km². EDS data indicate that total percentage of brittle minerals is 45~59%, with quartz>20%, feldspar=10%~15%, calcite minerals=5~18%, pyrite+hematite=5~18%, which is similar to the mineral composition of gas shale in North America. With such high content of brittle minerals, Upper Triassic shale is prone to generate artificial fractures after hydro-fracturing. FE-SEM data indicate that intra-feldspar pores, inter-chlorite pores, inter-pyrites pores and parallel bedding fractures dominate the storage space. Organic matter (OM) pores are limited, and most of them are located between organic matters and surrounding matrix. Nano-CT data indicate that connected pores account for around 60% of whole space. The porosity of the samples is 0.6%~3.5%, and permeability is 0.00072~0.0023mD. The pore-throats in Upper Triassic shale are continuously distributed, ranging from less than 10nm to 15μm. The percentage of pore-throats with radius less than 1000 nm is 96.5%, among which pore-throats with radius less than 100 nm is more than 60%. Thus, nanometer-scale pore-throats dominate the reservoir spaces of Upper Triassic shale, which may be the fundamental reason for the special characteristics of unconventional tight reservoirs. The oil testing indicates that oil production can reach 20.4 tons per day for a well with three perforated intervals. Moreover, the API of crude oil is 35-58°, and the viscosity is 0.7-5 kcP.

This study may be helpful in knowing more about the potential of terrestrial shale/mudstone oil, and providing references for the unconventional petroleum exploration in the Ordos Basin.
Reference Cited


Website

Preliminary Research on Reservoir Potential of Terrestrial Shale in China

Caineng ZOU, Songtao WU
Z. Yang, R. K. Zhu, S. Z. Tao, X. F. Zhai

RIPED, PetroChina

May 22th, 2013
Shale gas: Big success in North America

- >22 basins
- >40,000 shale gas wells
- 2009: $878 \times 10^9 \text{m}^3$
- 2011: $1,700 \times 10^9 \text{m}^3$
- >22 countries invested

From Navigant Consulting, Inc. 2008
What does shale gas tell us?

source + seal < shale = source + seal + reservoir

Marine facies shale

Commercial production of natural gas

Terrestrial shale ??

Commercial production of oil ??
# Shale Oil: Self-sourced system without migration

<table>
<thead>
<tr>
<th>Shale Oil</th>
<th>Tight Sand Oil</th>
<th>Near-Sourced System</th>
<th>Short Distance Migration</th>
<th>Industrial Breakthrough</th>
</tr>
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<td>Tight Limestone Oil</td>
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</tr>
</tbody>
</table>

(Zou, 2013)
What to do?

1. Choose samples
   - Mineralogy
   - Pore-throat system
   - Physical property

2. Evaluate reservoir potential
   - Important source rocks
   - Oil window
   - Mineralogy
   - Pore-throat system
   - Physical property

3. Get the conclusions with uncertainties listed

Methods

- TOC
- Rock Eval
- SEM, Nano-CT
- Mercury injection
- \( N_2 \) adsorption
- GRI
Part 1

Choose Sample
**Samples: Chang 7 shale in the Ordos Basin**

**Location**

- North-Central China
- 2nd largest basin in China
<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Thickness (m)</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chang 1 Member</td>
<td>Tșy1</td>
<td>100–240</td>
<td></td>
</tr>
<tr>
<td>Chang 2 Member</td>
<td>Tșy2</td>
<td>40–45</td>
<td></td>
</tr>
<tr>
<td>Chang 3 Member</td>
<td>Tșy3</td>
<td>45–50</td>
<td></td>
</tr>
<tr>
<td>Chang 4+5 Member</td>
<td>Tșy4</td>
<td>90–100</td>
<td></td>
</tr>
<tr>
<td>Chang 6 Member</td>
<td>Tșy5</td>
<td>85–110</td>
<td></td>
</tr>
<tr>
<td>Chang 7 Member</td>
<td>Tșy6</td>
<td>35–45</td>
<td></td>
</tr>
<tr>
<td>Chang 8 Member</td>
<td>Tșy7</td>
<td>20–30</td>
<td></td>
</tr>
<tr>
<td>Chang 9 Member</td>
<td>Tșy8</td>
<td>25–35</td>
<td></td>
</tr>
<tr>
<td>Chang 10 Member</td>
<td>Tșy9</td>
<td>240–280</td>
<td></td>
</tr>
</tbody>
</table>

**Upper Triassic: Yanchang Formation**

- **Mudstone**
- **Silty Mudstone**
- **Muddy siltstone**
- **Siltstone**
- **Fine-grained sandstone**
- **Coal**
- **Gritstone**
- **Medium-grained sandstone**
- **Carbonaceous Mudstone**

**Lithology**

- **Shale**
- **Mudstone**
- **Muddy Siltstone**
- **Sandstone**
**Samples:** Chang 7 shale in the Ordos Basin

**Lithology:** black shale, mudstone, silty mudstone

**Location:** semi-deep/deep lacustrine

Core photos

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**Location:** semi-deep/deep lacustrine
Part 2

Evaluate reservoir potential
Mineralogy: High brittle mineral content

Quartz + Feldspar + Carbonate: 45~59%, avg. = 53%
3-element texture: Q+F+C—CM—OM+P
Mercury injection data: nanometer-scaled pore-throats dominate

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>TOC (%)</th>
<th>$S_1+S_2$ (mg/g)</th>
<th>Ro (%)</th>
<th>$\Phi$ (%)</th>
<th>K (mD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S001</td>
<td>5.60</td>
<td>6.85</td>
<td>0.73</td>
<td>0.6</td>
<td>0.00072</td>
</tr>
<tr>
<td>S002</td>
<td>14.30</td>
<td>22.95</td>
<td>0.97</td>
<td>2.3</td>
<td>0.0023</td>
</tr>
</tbody>
</table>
N₂ adsorption: nanometer-scaled pore-throats dominate

(Sample No. = 7)
Nanometer-scaled Pore system

Pore Types

- Inter-particle Pores
- Intra-particle Pores
- OM Pores

D: 30~200nm
Nanometer-scaled Pore system
Nanometer-scaled Pore system

Nano-CT: medium connectivity with some isolated pores
Comparable with Bakken & Eagle Ford
Rough resource estimation: $>1.0 \times 10^9$ t

Favorable Shale Oil Play

- Kerogen type: I & II$_A$
- $R_o$: 0.7%-2.0%
- TOC: $>2.0\%$
- Thickness: $>10$ m

Area: $20 \times 10^3 \text{ km}^2$

$Q = Sh\rho q$

$Q$—shale oil resources, t
$S$—effective area, m$^2$
$h$—effective thickness, m
$\rho$—shale density, $10^3 \text{ kg/m}^3$
$q$—total shale oil content (per unit weight of shale), %
Part 3
Conclusions & Uncertainties
Conclusions & Uncertainties

Chang 7 shale has the potential to act as oil reservoir

- High brittle mineral content (avg.=53%) is favorable for fracturing
- Nanometer-scaled (3~200nm) pore-throat system with relatively good connectivity
- Relatively high porosity & permeability

Some problems remain to be answered:

1. Fluid flow mechanism + HC occurrence;
2. Abnormal low pressure;
3. OIP evaluation;
4. Reservoir simulation

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