Concepts, Geological Characteristics and Evaluation Techniques for Continuous Petroleum Accumulations in China*

Cai-neng Zou¹, Shi-zhen Tao¹, Xiao-hui Gao¹, Ying Li¹, Zhi Yang¹, Yan-jie Gong¹, Jin-hua Jia¹, Da-zhong Dong¹, Xin-jing Li¹

Search and Discovery Article #10246 (2010)
Posted June 28, 2010

*Adapted from oral presentation at AAPG Convention, New Orleans, Louisiana, April 11-14, 2010

¹Research Institute of Petroleum Exploration & Development, PetroChina, Beijing, China (zcn@petrochina.com.cn)

Abstract

USGS presented the concept "continuous-type petroleum accumulations" for the purpose of resource assessment. And we have further studied the concepts, geological characteristics and evaluation techniques for continuous petroleum accumulations based on many cases in China basins:

1) Continuous petroleum accumulations are those oil or gas accumulations that exist in large spatial dimensional unconventional reservoir systems and are continuously distributed in "non-closed traps". "Continuous" stresses the continuous distribution of hydrocarbon in dimensions, and "petroleum accumulation" refers to the places where petroleum accumulated. Tight sandstone oil/gas, carbonate cavity reservoirs, coal-bed methane, shale oil, shale gas and gas hydrate all belong in the category of continuous petroleum accumulations;

2) Geological characteristics: (1) largescale continuous distribution, but local enrichment, (2) mainly unconventional reservoirs in large dimensions, (3) non-closed traps with indistinctly defined boundaries, large reservoir space, (4) in-source or near-source distribution, (5) no migration or mainly primary migration, (6) accumulated mainly by diffusion, limited role of buoyancy, (7) non-Darcy infiltration flow, (8) weak fluid differentiation, diverse oil or gas saturation, and complex distribution of oil, gas and water;
3) Techniques for continuous petroleum accumulations require more attention than conventional accumulations in many aspects, such as seismic reflectance, logging identification, oil or gas test measurement, reservoir transformation, exploitation evaluation, recovery improvement, assorted techniques, and so on;


Continuous petroleum accumulations have been one of the most important fields for theory and technology research, and for the following exploration and exploitation. By the end of 2008, the continuous oil accumulations and continuous gas accumulations had reached 47% and 56% of the total geological reserves in China respectively, and the exploration potential will be greater in the future.
Concepts, Geological Characteristics and Evaluation Techniques for Continuous Petroleum Accumulations in China

Zou Caineng, Tao Shizhen, Yuan Xuanjun, Zhu Rukai, Hou Lianhua, Jia Jinhua, Wang Lan, Gao Xiaohui, Zhang Xiangxiang, Yang Chun, Yang Zhi, Li Ying, etc.

Research Institute of Petroleum Exploration & Development, CNPC
April, 2010
AAPG U.S.A.

Caring for energy, caring for you
Outline

Ⅰ. Basic Concept of Continuous Oil and Gas Plays

Ⅱ. Geological Features of Continuous Oil and Gas Plays

Ⅲ. Assessment Technology of Continuous Oil and Gas Plays
I. Basic Concept of Continuous Oil and Gas Plays

Oil and gas exploration and its theoretical research has undergone four stages:

- **First stage:** Oil & Gas Seepage
- **Second stage:** Anticlinal Trap Theory
- **Third stage:** Conventional Trap Oil/gas Reservoirs
- **Fourth stage:** Unconventional Oil/gas plays
Based on whether trap configuration is obvious or not: there are 2 types of reservoirs (conventional and unconventional).

**Conventional trap oil/gas reservoirs:** anticlinal reservoir, etc. This type of reservoir experienced long-distance secondary migration, accounts for 10-20% of the total resource.

**Unconventional oil/gas plays:** there are 2 types (continuous and discontinuous).

**Continuous:** shale gas, tight gas sands, etc., which experienced primary migration and short-distance secondary migration, and accounts for 40-50% of the total resource.

**Discontinuous:** fracture-cavity interconnected carbonate oil/gas plays, etc., which experienced short-distance secondary migration, and accounts for 20-30% of the total resource.
I. Basic Concept of Continuous Oil and Gas Plays

"Concept of Continuous Oil and Gas Plays": Unconventional oil and gas is distributed in large-scale unconventional reservoir rock continuously. It is distinctly different from the traditional typical discrete conventional trap oil/gas reservoirs.

"Continuous": Emphasize on the continuous or quasi-continuous distribution of oil/gas.

"Oil and Gas Plays": Referring to the area where oil/gas accumulated.
Outline

Ⅰ. Basic Concept of Continuous Oil and Gas Plays

Ⅱ. Geological Features of Continuous Oil and Gas Plays

Ⅲ. Assessment Technology of Continuous Oil and Gas Plays
In general, average pore throat radius <1μm, porosity <10%, permeability <1md, TOC >1%, Ro >0.7%, and pressure difference between source rock and reservoir >10MPa are favorable for forming continuous oil/gas plays.
### Geological Features of Continuous Oil and Gas Plays

#### 7 types of continuous oil/gas plays in China:

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Low porosity and permeability sandstone oil/gas plays</td>
<td>Paleozoic gas of Sulige Gasfield and Mesozoic oil of Longdong Oilfield in Ordos Basin, Mesozoic sand oil and tight sand gas in Songliao Basin, upper Triassic gas of Xujiahe Formation in Sichuan Basin, etc.</td>
</tr>
<tr>
<td>2</td>
<td>Fracture-cavity-pore interconnected carbonate oil/gas plays</td>
<td>Ordovician oil &amp; gas in Lunnan Oilfield, Tarim Basin; Lower Paleozoic gas in Ordos Basin, etc.</td>
</tr>
<tr>
<td>3</td>
<td>Fracture-cavity interconnected volcanic rock oil/gas plays</td>
<td>Volcanic oil/gas plays in Songliao and Junggar Basin, etc.</td>
</tr>
<tr>
<td>4</td>
<td>Coalbed methane</td>
<td>Coalbed methane in Qinshui Basin, Ordos Basin, etc.</td>
</tr>
<tr>
<td>5</td>
<td>Mud shale oil &amp; gas</td>
<td>Paleozoic shale gas in Sichuan Basin, Cretaceous shale oil of Qingxi Oilfield in Jiuquan Basin, etc.</td>
</tr>
<tr>
<td>6</td>
<td>Biogas</td>
<td>Quaternary biogas in Qaidam Basin, etc.</td>
</tr>
<tr>
<td>7</td>
<td>Gas hydrate</td>
<td>South China Sea, etc.</td>
</tr>
</tbody>
</table>
## Geological Features of Continuous Oil and Gas Plays

### 10 differences between continuous oil/gas plays and conventional trap oil/gas reservoirs:

<table>
<thead>
<tr>
<th>No.</th>
<th>Characteristics</th>
<th>Continuous unconventional oil/gas play</th>
<th>Conventional trap oil/gas reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distribution</td>
<td>Large-scale continuous distribution in basin center and slope area, enrichment in local area</td>
<td>Discrete trap, non-continuous distribution</td>
</tr>
<tr>
<td>2</td>
<td>Reservoir features</td>
<td>Mainly large-scale unconventional reservoir rock</td>
<td>Conventional reservoir rock</td>
</tr>
<tr>
<td>3</td>
<td>Source and reservoir</td>
<td>Mainly self-generation and self-preservation</td>
<td>Diverse source-reservoir relationships</td>
</tr>
<tr>
<td>4</td>
<td>Trap features</td>
<td>Non-enclosed trap, nor obvious boundaries</td>
<td>Conventional enclosed trap with obvious boundaries</td>
</tr>
<tr>
<td>5</td>
<td>Migration</td>
<td>Primary migration or short-distance secondary migration</td>
<td>Long-distance secondary migration</td>
</tr>
<tr>
<td>6</td>
<td>Accumulation mechanism</td>
<td>Mainly depend on diffusion, with limited buoyancy in oil/gas accumulation</td>
<td>Depending on buoyancy in oil/gas accumulation</td>
</tr>
<tr>
<td>7</td>
<td>Seepage properties</td>
<td>Mainly non-Darcy flow</td>
<td>Darcy flow</td>
</tr>
<tr>
<td>8</td>
<td>Fluid properties</td>
<td>Bad fluid differentiation, no uniform oil/water or gas/water contacts and pressure system, oil &amp; gas saturation varies greatly, usually forming the coexisting miscible oil-gas-water system</td>
<td>Top oil &amp; gas, bottom water, with obvious oil/water or gas/water contacts</td>
</tr>
<tr>
<td>9</td>
<td>Resource properties</td>
<td>Low resource abundance, reserves assessed by well-control blocks</td>
<td>Reserves assessed by trap elements</td>
</tr>
<tr>
<td>10</td>
<td>Production techniques</td>
<td>Special production practice, need of pertinency techniques</td>
<td>Mainly conventional techniques, easy to exploit</td>
</tr>
</tbody>
</table>
Geological Features of Continuous Oil and Gas Plays

- Extensive continuous distribution in basin center and slope area, forming giant oil/gas region.

Diagram of distribution model of continuous oil/gas plays in China
The distribution area of continuous oil/gas plays of depression basins has reached 3-10 $\times 10^4$ km$^2$. 

The gas pools of upper Triassic Xujiahe Formation in Sichuan Basin distribute continuously with area of 10 $\times 10^4$ km$^2$.

The oil pools distribute continuously in mid-south Ordos Basin, area reaches 3 $\times 10^4$ km$^2$.

The gas pools distribute continuously in mid-north Ordos Basin, area reaches 3.5 $\times 10^4$ km$^2$.

In the central depression of Songliao Basin, the oil and gas pools distribute continuously with area of 3.6 $\times 10^4$ km$^2$. 

Extensive continuous distribution in basin center and slope area, forming giant oil/gas region.
Continuous tight sand gas in Ordos Basin: Average single well production rate of 1,760 wells is $1.13 \times 10^4$ m$^3$ per day.

Continuous tight sand oil in Ordos Basin: Average single well production rate of 2,118 wells is 2.8 ton per day.

Extensive continuous distribution in basin center and slope area, forming giant oil/gas region.

The depositional systems and gas pools distribution of He 8 Formation in Ordos Basin

The depositional systems and oil pools distribution of Yanchang Formation in Ordos Basin
Large-scale low and ultra-low porosity and permeability unconventional reservoir rock (Φ: <10%, K: < 1md)

Reservoir physical property statistics of He 8 Formation of Sulige in Ordos Basin

<table>
<thead>
<tr>
<th>Region</th>
<th>Debris dissolution pore (%)</th>
<th>Intergranular dissolution pore (%)</th>
<th>Intercrystal pore (%)</th>
<th>Others (%)</th>
<th>Even Porosity (%)</th>
<th>Even Permeability (mD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Sulige</td>
<td>44.7</td>
<td>13.1</td>
<td>24.8</td>
<td>17.4</td>
<td>8.8</td>
<td>0.83</td>
</tr>
<tr>
<td>Central Sulige</td>
<td>43.7</td>
<td>15.9</td>
<td>20.7</td>
<td>19.7</td>
<td>8.6</td>
<td>1.51</td>
</tr>
<tr>
<td>West Sulige</td>
<td>45.9</td>
<td>15.1</td>
<td>21.5</td>
<td>17.5</td>
<td>8.3</td>
<td>0.98</td>
</tr>
<tr>
<td>Gaoqiao</td>
<td>47.5</td>
<td>14.2</td>
<td>18.4</td>
<td>19.9</td>
<td>8.4</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Reservoir physical property statistics of Chang 8 Formation in Ordos Basin

<table>
<thead>
<tr>
<th>Region</th>
<th>Target Formation</th>
<th>Porosity (%)</th>
<th>Permeability (mD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jiyuan</td>
<td>Chang 8</td>
<td>8.7</td>
<td>0.72</td>
</tr>
<tr>
<td>Xifeng</td>
<td>Chang 8</td>
<td>11.0</td>
<td>1.50</td>
</tr>
<tr>
<td>Huaqing</td>
<td>Chang 8</td>
<td>8.9</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Average porosity: 8.5 ̴, average permeability: 0.98 md
No obvious trap boundaries and seals, depending on reservoir-fracture interconnection to form continuous oil/gas plays.

<table>
<thead>
<tr>
<th>Guangan 111</th>
<th>Guangan 109</th>
<th>Guangan 104</th>
<th>Guangan 2</th>
<th>Guangan 103</th>
<th>Guangan 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas: 0.4×10⁴ cbm/day</td>
<td>Gas: 0.1×10⁴ cbm/day</td>
<td>Gas: 1.6×10⁴ cbm/day</td>
<td>Gas: 4.2×10⁴ cbm/day</td>
<td>Water: 9.4 cbm/day</td>
<td></td>
</tr>
<tr>
<td>Water: 12.5 cbm/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas: 4.4×10⁴ cbm/day</td>
<td>Water: 15 cbm/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- Porosity: 6%
- Porosity: 8%
- Porosity: 10%

Profile of upper Triassic gas play, Xujiahe Formation, Sichuan Basin
Bad fluid differentiation, oil & gas saturation varies greatly, usually forming the coexisting miscible oil-gas-water system.
Mainly primary migration or short-distance secondary migration, characterized by non-Darcy flow.

Source rock migration analysis of Ordos Basin

Su76, 3226.94m, fluorescence x25

Su121, 3732.43m, fluorescence x50

Su6-j1, 3328.38m, upper is single polar x50, lower is fluorescence x50

Oil/gas in micro-fracture charging channels presents fluorescence color of yellow, yellow green and brown.
Geological Features of Continuous Oil and Gas Plays

Continuous shale gas reservoir rock develop pore space in Sichuan Basin

illitic interlayer gap, 1534m, $S_1$, Wei 201 well, Sichuan Basin

Quartz grows on the grain boundary of pyrite. Wei 201 well, $P_1$, Sichuan Basin
Outline

1. Basic Concept of Continuous Oil and Gas Plays
2. Geological Features of Continuous Oil and Gas Plays
3. Assessment Technology of Continuous Oil and Gas Plays
1. Unconventional resources dimensional prediction and assessment methods
2. High resolution large-area seismic data acquisition technique
3. Sequence stratigraphy industrial application technology
4. Gravitational-magnetic-electrical volcanic reservoir prediction technology
5. Pre-stack seismic reservoir fluid prediction technology
6. Fracture-cavity characterization technology of carbonate reservoir rock
7. Drilling technology such as horizontal drilling, multi-lateral drilling, etc.
8. Stimulation technology, such as coiled tubing fracturing, etc.

......
Matching rate reaches 90%:
Continuous gas play dimensional distribution simulation technology applied in Sichuan Basin

Hechuan 1 Block, Sichuan Basin
Proved reserve: $1.166 \times 10^8 \text{m}^3$
Simulation result: $0.985 \times 10^8 \text{m}^3$
Matching rate reaches 88%: Pre-stack seismic gas zone detection technology applied for upper Triassic tight gas of Xujiahe Formation in Sichuan Basin.

Figure of gas saturation of Xujiahe 4 Formation in Guang’an region, Sichuan Basin.

Daily natural gas production rate: $2.02 \times 10^4$ m$^3$
After fracturing, the single well daily natural gas production rate of upper Triassic tight gas sands of Xujiahe formation in Sichuan Basin is more than 10-20 times of the natural gas production before fracturing.

<table>
<thead>
<tr>
<th>Well No.</th>
<th>Target Formation</th>
<th>Testing production($10^4m^3/d$)</th>
<th>Before fracturing</th>
<th>After fracturing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangan 002-35</td>
<td>Xu 6</td>
<td>2.19</td>
<td></td>
<td>18.76</td>
</tr>
<tr>
<td>Guangan 002-39</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>21.28</td>
</tr>
<tr>
<td>Guangan 002-29</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>11.25</td>
</tr>
<tr>
<td>Guangan 002-32</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>23.12</td>
</tr>
<tr>
<td>Guangan 002-33</td>
<td>Xu 6</td>
<td>0.47</td>
<td></td>
<td>14.8</td>
</tr>
<tr>
<td>Guangan 002-X45</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>13.29</td>
</tr>
<tr>
<td>Guangan 002-X22</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>8.78</td>
</tr>
<tr>
<td>Guangan 002-25</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>30.03</td>
</tr>
<tr>
<td>Guangan 002-X34</td>
<td>Xu 6</td>
<td>3.05</td>
<td></td>
<td>20.38</td>
</tr>
<tr>
<td>Guangan 002-X36</td>
<td>Xu 6</td>
<td>0.65</td>
<td></td>
<td>39.39</td>
</tr>
<tr>
<td>Guangan 002-27</td>
<td>Xu 6</td>
<td>0.1</td>
<td></td>
<td>18.04</td>
</tr>
</tbody>
</table>
Conclusions and Outlook

- Continuous oil/gas play has no obvious trap boundaries and has large distribution area. Its huge reserve make it the future strategic alternative area worldwide.

- The proved reserves of oil/gas in place of continuous plays account for 47% and 56% of the total reserves respectively in China.

- The perspective resources of continuous natural gas in China is 10 times of conventional natural gas resource (of which coalbed methane is $40 \times 10^{12} m^3$, tight sand gas is $30 \times 10^{12} m^3$, shale gas is $100 \times 10^{12} m^3$, and gas hydrates is $500 \times 10^{12} m^3$).
Unconventional resources

nothing is impossible

¢ Thank you for your attention
¢ Welcome you all to visit RIPED for technical exchanging and future cooperation
Zou Caineng

Organization: Research Institute of Petroleum Exploration & Development, CNPC
Position: Vice President and Chief Geologist
Professional Title: Research Professor, Supervisor of PhD student
Speciality:
Geological concept and techniques research on litho-stratigraphic oil/gas reservoirs,
Concept and techniques research on continuous oil/gas plays,
Research on oil/gas exploration areas and target evaluation in China
Program: Chief scientist of “Lithologic-stratigraphic oil/gas accumulation rule, key technology and target evaluation” in China
Publications: Published more than 80 papers and 9 monographs
Address: No.20 Xueyuan Road, Beijing, P. R. China
E-mail: zcn@petrochina.com.cn