Recent Significant Discoveries in Mature Basins – Take Offshore Bohai Bay Basin as an Example*

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Search and Discovery Article #10342 (2011)
Posted July 31, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011.

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Abstract

The Bohai sea area is the offshore part of the Bohai Bay Basin. The drilling of the first new field wildcat dated back to 1966 and the discovery peak occurred during 1995-2000 when a number of major heavy oil fields with an initial oil in place of over 100 million tons had been found. They include PL19-3, QHD32-6, CFD11-1, BZ25-1S fields. By the end of 2004, about 2.7 billion cubic meters of oil in place had been found in the offshore Bohai Bay Basin. With increasing exploration maturity, however, it has become more and more difficult to make new significant discoveries. Maintaining a highly efficient and sustainable petroleum exploration venture have met serious challenges.

Since 2005, systematic studies of effective source kitchens, high-quality reservoirs distribution and oil/gas migration patterns indicated that the Tan-Lu strike-slip fault zone and the slopes surrounding the Bozhong depression were the prospective areas for petroleum enrichment. The exploration in the offshore Bohai Bay basin entered a new exploration phase which was characterized by exploration for oil and gas in multiple stratigraphic intervals and targeting multiple types of traps. The exploration focused on traps rich in oil and gas and meanwhile the prospectivity of the areas surrounding these traps were quickly and thoroughly assessed.

The JZ25-1, JX1-1, BZ28-34, KL10-1 trends and the eastern plunging end of the Shi-Jiu-Tuo arch were selected for drilling. The exploration results proved that all the five trends are petroleum enrichment belts. The fields newly found in the trends led to the second peak of petroleum discovery in the offshore Bohai Bay basin. About 1.6 billion cubic meters of oil in place had been discovered in five years. Recent discoveries have been made in new plays and new domains which include the Neogene lithologic traps, steep slope zones of depressions, and fault transfer zones. The occurrence of second discovery peak indicates that new exploration ideas and technological innovations have played an important role in petroleum exploration in mature
basins. Exploration in China's offshore areas and similar basins may take lessons and guidance from the successful exploration practice in the offshore Bohai Bay Basin.
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4-12-2011
Introduction to Bohai Offshore

Bohai Offshore

- Exploration Area: 44,000 km²
- 15 sags and 13 Uplifts
- 650 Exploration and appraisal wells
- 4.9 Billion m³ oil equivalent found
  - Mainly in Liaodongwan and Bozhong area
  - Estimated resource 13~14 Billion m³

Bohai bay basin:
1. Coverage 200,000 km².
2. Estimated Oil and gas resources:
   - 30 Billion tons and 2.6 Trillion m³;
3. Discovered oil and gas:
   - 10 Billion tons and 0.3 Trillion m³
Cenozoic basin deposits include: 1. the pre-Tertiary Basin basement; 2. Tertiary rifting deposits and, 3. Depression deposits composed of Neogene and Quaternary.
**Petroleum Systems**

1. **Source rocks**
   Paleogene 3rd members of Dongying and Shahejie Fms;

2. **Reservoirs:**
   Fluvial, deltaic sandstones in all stages; burial hills;

3. **Peak hydrocarbon expulsion**
   At Neogene Guantao Fm

4. **Hydrocarbon distribution**
   Mainly in Bozhong and Liaodongwan areas.
1. 1966 ~ 1994: Targeting at burial hill and Paleogene, small size reserves found.
2. 1995 ~ 2005: Many Heavy Oil fields found under the concept of Sags delineation and uplifts exploration
3. 2005 ~ present: continuously discovered light oil and field with the concept of “all round exploration”.

Forty Four Years Exploration : Concept Shift Lead to Success

- ①开始下海起步阶段 (1966 ~ 1979)
- ②对外合作阶段 (1980 ~ 1984)
- ③高效自营勘探 (1985 ~ 1988)
- ④成效欠佳的低迷阶段 (1989 ~ 1991)
- ⑤中小油气田群勘探 (1985 ~ 1988)
- ⑥新近系大发现阶段 (1995 ~ 2001)
- ⑦立体勘探阶段 (2002 ~ 2010)
Improved Understanding and Discoveries in the past five years
1. The relationship between the Hydrocarbon accumulation and Paleogene effective reservoirs development with the strike slip faults system.

2. Middle - deep reservoirs predication based on the Hydrocarbon accumulation mode in the steep slope area of prolific basin.

3. Hydrocarbon accumulation and entrapment modes in the extremely shallow lacustrine and lacustrine deltaic deposition systems.
Reservoir is key to Deep Prospect Exploration

Most of the discoveries are the results of integrated studies of the above three aspects, of which reservoir analysis is the key.
Five Over 100 MM Tons Light Oil Field Groups Found in the Past 5 Years

1. Five light oil fields groups each over 100 million tons have been discovered in the past 5 years. Among them, 16 over 30 million m³ and 3 over 100 million tons: JX1-1, KL 10-1 and JZ 25-1

2. 85% of the newly discoveries are of light oil, contrast to before 2005, the 85% reserve is heavy oil.

Reserves distribution of moderate-large fields discovered in the past 5 years

- **1.** Extension-strike slip
- **2.** Steep slope
- **3.** Extremely shallow delta

- Other 4%
- 25%
- 44%
- 27%
27 wells had been drilled in the past 20 years, and only 3 fields found. Does it still has potential? If yes, where?

JZ 25-1 Oil field: Liaoxi Area Exploration
The objective is the S3 sandstone, however, drilling indicates the mudstone overlaps on the Mesozoic strata, therefore, the post drilling analysis speculate no sediments deposits downslope and reservoir is key element for future exploration.
JZ 25-1 Oil Field: Geological Model

Is this model correct?
New Sand Deposition Model in Lacustrine Rift Basin

In lacustrine rift basin, sand deposition is controlled by four factors: from source to sink system.

1. Effective Material Source (Source system): Providing source
2. Long-time eroded gully (Transportation system): Providing the effective transportation pathway
3. Slope break (Sink system): Location of sediments depositing
4. Base level of deposition (Time system): Deposition time of the sediments

Source-Gully-Slope-Level control

Sand deposition is controlled by the joint working of the above four factors. If we can find the coexistence of effective source and sink place, we could find sand reservoir.
Effective sources include obvious (long time eroded and very easy to identify) and unobvious sediments source, and the latter is very important for identifying effective sand from a lean sand setting.

**Unobviousness means:**

**Unobvious Time:** In a third order sequence, the source location occurred a early erosion (providing source) and later deposition (can’t providing source).

**Unobvious space:** Source location move with the strike slip movement

**Identification method:** Paleotopography reconstruction
Previously: The S3 mudstone deposits overlap on Mesozoic strata. No reservoir occurred downslope due to no sediments (sand) source.

Present
There are sediments sources distributed on Liaoxi low uplift through paleotopography reconstruction based on the thoroughly analysis of high resolution sequence stratigraphy.
Dynamic source:
Source area changes in different deposition stages in a sequence. In the low standing period, erosion (source) area increases as the lake surface down, and in the high standing period, the erosion area reduces or disappears with the surface rise.
The erosion areas of JZ 25-1 in LST and HST during the third member of Shahejie Fm.
Sink System: Sediments Deposits Along the Basin Margin Faults
Source-Sink System in JZ 19 and JZ25 Areas

Lake transgressive deposition sequence distribution of JZ 19-25 area in the middle sections of the third member of Shahejie Formation
Evidence 1: Distribution of ZTR Index

Resistant mineral content increases with transporting distance increase.

Z—zircon, T—tourmaline, R—rotite

<table>
<thead>
<tr>
<th>Well</th>
<th>Interval</th>
<th>Avg. ZTR%</th>
</tr>
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<tbody>
<tr>
<td>JZ19-2-1</td>
<td>S3</td>
<td>71.5</td>
</tr>
<tr>
<td>JZ25-1-3</td>
<td></td>
<td>33.1</td>
</tr>
<tr>
<td>JZ25-1-4</td>
<td></td>
<td>24.0</td>
</tr>
<tr>
<td>JZ25-1-5</td>
<td></td>
<td>29.9</td>
</tr>
</tbody>
</table>
Evidence 2: Heavy Mineral Difference Indicates Multiple Source Suppliers

The third member of Shahejie Fm in JZ 19 and JZ 25 areas have significant difference in heavy mineral contents, indicating the sediments soured from different regions.
Dynamic Source Concept Continuously Proved By Drilling

The LST reservoir prediction of the third member of Shahejie Fm in JZ 20-2N were proved true by drilling.
Area is 3000k², and 530 million m³ oil equivalent discovered by over 90 wells through 2005, Main Problem is the discovered fields reservoir is very thin and discontinuous. Does it still have huge potential? Where the potential is?
 Depositing features of lake shrinking:

1. Big lake coverage but average water depth less than 9m,
2. Relative stable tectonic setting and a flat fluvial topography (no slope break).
3. High frequent interactions of fluvial and lake.

Modern analogue  Deposition mode  Sand deposition
Expanding stage: the delta develop as lobes and clusters, with a wide front, interdistributary deposits occurred between the lobes.

Shrinking stage: the delta develop as dendritic, vascular, the levee act as deposition frame, which is 3~4 times wider than the channels.

Poyang Lake: Analogue of Extremely Shallow Delta
1. Long Time Lake Environment

Later Oligocene to Quaternary Bozhong Depression gradually Became Depositing Center
2: Mudstone Color: Lacustrine Environment

①—Light green, greyish green mudstone
②—gray green, purple mudstone
③—Brown mudstone and varicolored soiled mudstone (fluvial)
3. Deposition Structure: Lacustrine Deposition

- River Mouth Bar
  - Rolling bedding
  - Horizontal bedding
- Shallow lacustrine mud
- PL19-3-6ST 1166-1166.5m

- PL19-3-6ST 1040-1043m
  - Submerged distributary channel
  - Lag-boulder clay
  - Channel lag-boulder clay
4. Shallow Water Fossils

Abundant Shallow water fossils like Bivalve, Gastropod are found in the core.

BZ29-4.5井，N_{2+1}-
(1726.8～1727.0m)

(鉴定单位：南京地质古生物所)
5. Paleo-water Depth

<table>
<thead>
<tr>
<th>Lake</th>
<th>Avg. Water depth (m)</th>
<th>Max Water depth (m)</th>
<th>Area (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dongting</td>
<td>6.39</td>
<td>23.5</td>
<td>2625</td>
</tr>
<tr>
<td>Poyang</td>
<td>8.4</td>
<td>25.1</td>
<td>3283</td>
</tr>
<tr>
<td>Huanghekou</td>
<td>6~9</td>
<td>&gt;16</td>
<td>2570</td>
</tr>
<tr>
<td>Bozhong</td>
<td></td>
<td></td>
<td>8660</td>
</tr>
</tbody>
</table>

Modern analogues:
- Shallow water
- + large coverage

![Dongting Lake](image1)
![Dongting Lake](image2)
![Poyang Lake](image3)
![Poyang Lake](image4)
1. Depositional facies features:
   A. submerged distributary channel relatively developed
   B. Single river mouth sand bar relative thin
      • Deposition sequence discontinuous
      • Foreset underdeveloped
      • Delta-like sand body deposited

2. Well logs features:
   Flat-funnel-spike-bell-serrate
Identification Feature 1: Vertical Sequence

Lakeward

Foreset under-developed

progradation

Normal delta
Identification Feature 2: Horizontal Features

- **Shallow water delta front sand**
  - Wave dominated
- **Shallow water delta front sand**
  - Fluvial dominated
- **Meandering sands**
  - Fluvial dominated

A/S (accommodation/supply) decreases with fluvial strengthen
Two Extremely Shallow Delta Models in Bohai Offshore

**Mode 1—Sand bar type**
- A/S increase with the lake surface rise
- Depositional frame is sand bar, later might be sand spit, with a wide swamp front
- The sand deposited in the distributary channels is very little but has a good connection

**Mode 2—Channel type**
- A/S decrease with the lake surface rise
- Depositional frame is natural levee, the thickness of the sand deposited in the distributary channels is thinner than that of the levee
- Submerged distributary channels long and narrow developed.
BZ 28-2 South Oil field: A Sand Bar Type Shallow Delta

The field has about 70 million m$^3$ oil. Wells indicate the reservoir sands are more continuous than that of the meanderings river.
Discoveries of the Past 5 years Using Shallow Delta Model in Huanghekou Area

Four moderate-large fields and many small fields, about 290 million m³ oil equivalent, have been discovered in the past 5 year under the instruction of geological model.
Conclusions

- Instructed under improved geological understandings, 5 light oil fields groups, each over 100 million tons, have been discovered in the past 5 years. 85% of the newly reserves is light oil, similar to the heavy oil proportion before 2005.

- Sand deposition is controlled by the joint working of four factors: the Source-Gully-Slope-Level. Effective sources include obvious and unobvious sediments source, and the latter is very important for identifying effective sand from a lean sand setting.

- Extremely shallow water delta deposits during lake shrinking. Two type of models are identified. For the sand bar type, sand deposited in the distributary channels is very little in content but has a good connection. Four moderate-large fields and a number of small fields, about 290 million m3 oil equivalent, have been discovered in the past 5 year with the instruction of shallow water delta model.