Visualization and Quantification of Deeply Buried Paleokarst Reservoirs in Tahe Oilfield, Tarim Basin, China*

Fei Tian¹, Qiang Jin¹, Yang Li², Hong-fang Zhang², and Xun Kang¹

Search and Discovery Article #20257 (2014)**
Posted July 24, 2014

*Adapted from poster presentation given at 2014 AAPG Annual Convention and Exhibition, Houston, Texas, April 6-9, 2014
**AAPG©2014 Serial rights given by author. For all other rights contact author directly.

¹School of Geosciences, China University of Petroleum, Qing Dao, China (upc_tianfei@126.com)
²China Petroleum and Chemical Corporation, Sinopec, Beijing, China

Abstract

Mapping and quantify 3-D construction of the paleokarst reservoirs is a challenge in deeply buried (>5500m) heterogeneous carbonate system, as their irregular geometry and complex filling materials. Well-logging constrained acoustic impedance seismic dataset and seismic attribute analysis combined with 3-D visualization technology provide a significant amount of visible information about paleokarst reservoirs’ features in Tahe oilfield, Tarim basin. This paper describes an integrated approach to visualize and quantify the paleokarst reservoirs. First, caves’ recognize equation is developed using conventional well-logging data, which is demarcated from core and image logs with a cave resolution of approximately 0.5 m. Second, time-depth conversions for 97 wells are identified one by one, and the recognition results in the signal wells are tied to seismic dataset. Third, after determining the cutoff values of the host rocks and the caves in acoustic impedance, the impedance inversion volume can recognize the spatial construction of the paleokarst reservoirs effectively. Forth, the 3-D mapping and visualization of the paleokarst reservoirs are achieved by tracing the distribution of caves. Fifth, based on the 3-D ‘geobody’ and karst genetic theory, comparing with spatial geometry of the Mammoth Cave, the Tahe paleokarst reservoirs are divided into epikarst, vadose and runoff zones. Additionally, the genetic types of them are identified, i.e. chamber caves, main channel, branch channel etc. Using 3-D visualized geobody, the length, width, area, volume of different genetic types are calculated, and the chamber caves and main channels are pointed out as prior targets for hydrocarbon exploration. Using 3-D visualization technology, the spatial construction of paleokarst reservoirs is delineated; combined with the karst hydrodynamics theory, vertical zones and genetic types of the reservoir are divided; the entrances, exits, collapses and relative high points of the cave
systems are identified; the quantification of each genetic type is calculated from line, area to volume. All achievements above provide detailed information of the reservoir for structural model, geological model, hydrocarbon exploration and can be applied to other similar paleokarst oilfields.
Visualization and Quantification of Deeply Buried Paleokarst Reservoirs in Tahe Oilfield, Tarim basin, China

Fei Tian¹, Qiang Jin¹, Yang Li², Hong-fang Zhang², Xun Kang¹

¹China University of Petroleum, School of Geosciences, Qingdao, 266555, China; ²China Petroleum and Chemical Corporation, Beijing 100728, China E-mail: upc_tianfei@126.com

Paleokarst
- Developing near the surface of unconformity
- World-class hydrocarbon reservoirs
- Irregular geometry and complex filling materials
- Four zones: epikarst, vadose, runoff, phreatic

Paleokarst Oilfields in China
- Naxi Gasfield
- Weiyuan Gasfield
- Renqiu Oilfield
- Shengli Oilfield
- Changqing Oilfield
- Tarim Oilfield
- Tahe Oilfield

Geological background of Tahe Oilfield
- In northern Tarim Basin, Northwest China
- Three main kast reservoir formations: Lianglitage, Yijianfang, Yingshan

Characters of Fracture-Caves
- Outcrop observation
- Sinkhole
- Main channel
- Branch channel
- Tip channel
- Multi-layers caves
- Fractures developed around caves
- Multi-types of fills in the cave
- There are many cave players
- Results of multi-stages karstification

Cave fills in core
- Clastic sediment
- Breccias
- Chemical fills

Fracture-cave combination

Fractures in core
- High angle
- Medium angle
- Low angle
- High density
- Low density

Visualization of paleo cave (Zeng, 2011)

Block diagram of karst terrain (Loucks, 1999)

Block diagram of karst terrain (Loucks, 1999)
Conventional Recognize Methods

Abnormal Drilling 3-D Seismic Reflection

Image logging Conventional Logging

Breccia Sedimentary Unfill-Sedimentation

Branch channel Tip channel Branch channel

Low angle Fractures Net-like Fractures Fracture-Cave Combination

New parameters

Shale Content

Absolute of DLL

Cave Recognition

Multi-parameters standard-weighted method

Fill types Dividing Section

Unfill section \( \text{DEN}<2.61, R_{\text{LLS}} > 50 \), \( V_{\text{sh}} < 15\% \)

Sedimentary

\( \text{DEN}<2.61, R_{\text{LLS}} > 50 \), \( V_{\text{sh}} > 15\% \)

\( 2.61 \leq \text{DEN} < 2.68 \)

\( 2.68 \leq \text{DEN} < 2.71, V_{\text{sh}} > 15\% \)

\( 2.71 \leq \text{DEN}, V_{\text{sh}} > 8\% \)

Fractures Recognition

\[ \text{Fracture Porosity} = \frac{A_1}{R_{\text{LLS}}} + \frac{A_2}{R_{\text{LLD}}} + \frac{A_3}{R_{\text{LL}}}, \] \[ P > 0.3 \text{ is case section} \]

Fracture-Cave combination

Recognition Results of Core and FMI Section

Tip channel (0.5m) in well S74

Caves in well S75

Low density fractures

High density fractures

Fracture-cave combination

High angle fractures in well S75

Low angle fractures in well S74

High angle fractures in well S75
Recognition Results of Fracture-cave

- Fractures
  - Low angle
  - High density
- Fills
  - Sedimentary
  - 7 cycles + Breccias
  - 4 cycles

Chamber cave (74m) in Well TK409

- Fractures
  - High angle
  - Low density
- Fills
  - Sedimentary
  - Breccias
- Chemical fills

4 cycles

Main channel (6m) in Well TK411

- Fractures
  - High angle
  - High density
- Fills
  - Breccias
- Chemical fills

3 cycles

Tip channel (0.3m) in Well TK421

- Chemical fills

3 cycles

Branch channel (1-1.3m) in Well TK633

Time-Depth Calibration

Table 1 Caves recognition results in seismic data

<table>
<thead>
<tr>
<th>Well NO.</th>
<th>Cave A</th>
<th>Cave B</th>
<th>Cave C</th>
<th>Distance to T74</th>
<th>FMI</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>T615</td>
<td>5534</td>
<td>5554</td>
<td>20.5</td>
<td>13.1</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>T615</td>
<td>5631</td>
<td>5639</td>
<td>8.6</td>
<td>110.3</td>
<td>x</td>
<td>√</td>
</tr>
<tr>
<td>T615</td>
<td>5696</td>
<td>5675</td>
<td>6.3</td>
<td>148.6</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5624</td>
<td>5627</td>
<td>3.2</td>
<td>103.6</td>
<td>x</td>
<td>√</td>
</tr>
<tr>
<td>T615</td>
<td>5555</td>
<td>5558</td>
<td>2.8</td>
<td>34.5</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5677</td>
<td>5679</td>
<td>2.0</td>
<td>156.4</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5561</td>
<td>5563</td>
<td>1.9</td>
<td>40.6</td>
<td>x</td>
<td>√</td>
</tr>
<tr>
<td>T615</td>
<td>5567</td>
<td>5569</td>
<td>1.7</td>
<td>46.6</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5572</td>
<td>5574</td>
<td>1.6</td>
<td>51.5</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5685</td>
<td>5686</td>
<td>1.4</td>
<td>164.0</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5529</td>
<td>5530</td>
<td>1.2</td>
<td>8.4</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5566</td>
<td>5567</td>
<td>0.6</td>
<td>45.4</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5570</td>
<td>5570</td>
<td>0.4</td>
<td>49.5</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5563</td>
<td>5581</td>
<td>18.2</td>
<td>44.1</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5603</td>
<td>5611</td>
<td>7.9</td>
<td>84.4</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5558</td>
<td>5561</td>
<td>3.1</td>
<td>39.3</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5589</td>
<td>5591</td>
<td>2.4</td>
<td>69.9</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5556</td>
<td>5557</td>
<td>1.1</td>
<td>37.0</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5528</td>
<td>5529</td>
<td>0.9</td>
<td>9.9</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5540</td>
<td>5541</td>
<td>0.7</td>
<td>21.9</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5530</td>
<td>5531</td>
<td>0.6</td>
<td>11.8</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5543</td>
<td>5544</td>
<td>0.6</td>
<td>24.8</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>T615</td>
<td>5525</td>
<td>5526</td>
<td>0.3</td>
<td>6.8</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

- : recognized, x : unrecognized, =: uncertain

Optimization of Seismic Data

- TK730-T615 amplitudes profile
- Root mean square profile
- Wave impedance profile

- Comparison of different attribute seismic profiles
- Wave impedance inversion reflects caves better
- The larger and more continuous caves were chosen
  We trace their center to interpret the karst construction

Applied in the Area of Well T615
Visualization and Quantification

Table 2: Statistics of paleokarst reservoirs of Well T615 area in run-off zone 1

<table>
<thead>
<tr>
<th>Cave Type</th>
<th>Number</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Area Ratio</th>
<th>Volume (m³)</th>
<th>Volume Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber caves</td>
<td>4</td>
<td>80410</td>
<td>60330</td>
<td>421425</td>
<td>10.88%</td>
<td>20367000</td>
<td>18.57%</td>
</tr>
<tr>
<td>Main channel</td>
<td>1</td>
<td>7080</td>
<td>130720</td>
<td>1776600</td>
<td>45.86%</td>
<td>57574000</td>
<td>52.49%</td>
</tr>
<tr>
<td>Branch channel</td>
<td>8</td>
<td>29001800</td>
<td>30420</td>
<td>1675575</td>
<td>43.26%</td>
<td>31741000</td>
<td>28.94%</td>
</tr>
</tbody>
</table>

Table 3: Statistics of paleokarst reservoirs of Well T615 area in run-off zone 2

<table>
<thead>
<tr>
<th>Cave Type</th>
<th>Number</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Area (m²)</th>
<th>Area Ratio</th>
<th>Volume (m³)</th>
<th>Volume Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber caves</td>
<td>4</td>
<td>60240</td>
<td>00240</td>
<td>213477</td>
<td>4.72%</td>
<td>90167000</td>
<td>4.16%</td>
</tr>
<tr>
<td>Main channel</td>
<td>3</td>
<td>14002200</td>
<td>130560</td>
<td>2170800</td>
<td>54.27%</td>
<td>76587000</td>
<td>57.85%</td>
</tr>
<tr>
<td>Branch channel</td>
<td>5</td>
<td>4061500</td>
<td>60230</td>
<td>204850</td>
<td>41.02%</td>
<td>46793000</td>
<td>35.34%</td>
</tr>
</tbody>
</table>

Geological Model

Discussion and Conclusion

- Demarcated from core and image logging information, we optimize DEN, CNL, Vsh, CLLS and AC and build a cave recognition equation, of which the coincidence of small cave (H < 1 m) is greater than 81%; next, we optimize CLLS, Vsh and AC×Rmf and build a fracture and protoconduit recognition equation, the coincidences of which are greater than 82%.

- After detailed time-depth conversions for each of the 97 wells in Ordovician strata, the interpretation results of single wells are demarcated on the acoustic impedance inversion volume. In certain wells, which are demarcated by well-logging, the resolution of the volume is approximately 3 m, and the descriptions of the paleokarst between wells are also reliable.

- This method is applied in the area of Well T615, and the construction of paleokarst in this area is interpreted. The run-off zone has developed 2 layers of caves. The length, width, area, volume of different genetic types are calculated, and the chamber caves and main channels are pointed out as prior targets for hydrocarbon exploration.

- The major contribution of this integrated method of combining cores, well logs and acoustic impedance inversion volume is to detect precisely and analyze the construction of paleokarst reservoirs in three-dimensional space.

- Analyzing the genetic relationships and control factors of the geological concept model including epikarst zone, the vadose zone and the run-off zone is the next study objective.

- Our study provides a reliable and precise description of the construction of deeply buried paleokarst reservoirs and maybe applied to similar subsurface paleokarst systems in other areas.

Acknowledgements

Special thanks to China national basically research program-2011CB201001, Tahe Oilfield Sinopec for providing data. We also thank numerous colleagues.

References