Successful Cases Analysis of Complex Carbonate Logs

Interpretation of PetroChina

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- Evaluation of Inhomogenous Lacustrine Carbonate Reservoir
- Identifying the reservoir nearby the borehole and fluid type interpretation
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Background Introduction

- PetroChina got a series success in deep-buried carbonate within last 10 years.
- Carbonate reservoir is characterized by ultra-low $\Phi/K$ with fracture and dissolved pore-cave as favorable target.
• Advanced and applicable logging technology, as FMI/LithoScanner/CMR, provided perfect solution for carbonate reservoir evaluation.
• Win-win cooperation between PC and SLB has been in steady advance.
Part I. Evaluation of Inhomogenous Lacustrine Carbonate Reservoir

- Yingxiongling area, located in west of Qaidam, northwest of China
- Pay zone is $E_3^2$, deposited in saline lake
- Complex lithology and pore-space hinder log interpretation
Part I. Evaluation of Inhomogenous Lacustrine Carbonate Reservoir

- Pore space includes intercrystalline pores, dissolved pore, cave & fracture.
- The productivity depends mainly on total porosity and fracture porosity.
- Determining porosity and valuable pay zone is of great importance.

Permeability

Low \(\rightarrow\) High

- Intercrystalline pores
- Micro-fracture
- Dissolved pore
- Intergranular pore

Nanometer size

2\(\mu\)m

fracture
Part I. Evaluation of Inhomogenous Lacustrine Carbonate Reservoir

- LithoScanner provides detailed elements & mineral profile
- Based on $\rho_{ma}$ from LithoScanner, the accuracy of $\phi_e$ is improved greatly.
Part I. Evaluation of Inhomogenous Lacustrine Carbonate Reservoir

- The formation with block structure in FMI image is high-yield layer usually.
- Heavily laminated formation is dry zone.

heavily laminated

4034-4044m, dry

weak layered

4450-4460m, Oil 8m³/d

block with dark blobs

4073-4083m, Oil 55m³/d
### Part I. Evaluation of Inhomogenous Lacustrine Carbonate Reservoir

- By FMI image scaled with core, favorable reservoir is discriminated.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Core</th>
<th>FMI image</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>block with dark blobs</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td>dark blobs means dissolved pores and cave, accompanied by fractures</td>
</tr>
<tr>
<td>heavily laminated</td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td>well layered with constant dip, no cave and fractures</td>
</tr>
<tr>
<td>weak layered</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td>layered with thick lamina, accompanied by fractures</td>
</tr>
<tr>
<td>Tight</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td>Anhydrite gathering or fast deposition.</td>
</tr>
</tbody>
</table>
Further, reservoir is classified into 3 types according to image spectrum.

- **Type I:** $m \geq 4$, $V \geq 12$
- **Type II:** $m \geq 4$, $9 \leq V < 12$
- **Type III:** $m \geq 4$, $5 \leq V < 9$

Pay zone: $3\% \leq \Phi < 6\%$, $FVPA \geq 0.03\%$

4090-4098m, Oil $24.68m^3/d.$
Part I. Evaluation of Inhomogenous Lacustrine Carbonate Reservoir

- FMI/LitoScanner/CMR+ items have been introduced into this area in large-scale.
- Application of SLB technology improves the interpretation coincidence rate.
- Cooperation between Petrochina & Schlumberger is win-win.
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- Traditionally, remote acoustic reflection wave logging is based on reflected P-wave.
- The answer is uncertain in distance and direction only by P-wave from mono-pole.
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- Different type of noise is summarized and corresponding solution is provided for cleaning image.

<table>
<thead>
<tr>
<th>Noise</th>
<th>Noise Type</th>
<th>Response</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>relevant</td>
<td>borehole wave</td>
<td>$\Delta t$ is constant</td>
<td>F-K filtering</td>
</tr>
<tr>
<td></td>
<td>Bad channel</td>
<td>borehole radius increase</td>
<td>Bad channel identification &amp; resorting</td>
</tr>
<tr>
<td></td>
<td>interface reflected wave</td>
<td>Great change in GR log</td>
<td>median filtering</td>
</tr>
<tr>
<td>irrelevant</td>
<td>circuit noise</td>
<td>Signal with low frequency and large amplitude (&lt;1.5kHz)</td>
<td>Digital bandpass filtering</td>
</tr>
<tr>
<td></td>
<td>Multiple wave</td>
<td>obvious trailing in direct wave</td>
<td>deconvolution</td>
</tr>
<tr>
<td></td>
<td>others</td>
<td>Discrete noise</td>
<td>Superposition denoising</td>
</tr>
</tbody>
</table>
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- By noise suppression step by step, accurate reflected S-wave image is obtained.
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- Based on clean image we can define reflector and find reservoir behind the borehole.
- Then by sidetracking and we got oil & gas production.
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- From FMI, 192 Rt logs are obtained and then Rt is converted into Rwa.
- From the distribution of Rwa we can infer the fluid type.

\[
\overline{R_{wa}} = \frac{\sum_{i=1}^{n} R_{wai} P_{R_{wai}}}{\sum_{i=1}^{n} P_{R_{wai}}}
\]

\[
\sigma_{R_{wa}} = \sqrt{\frac{\sum_{i=1}^{n} P_{R_{wai}} (R_{wai} - \overline{R_{wa}})^2}{\sum_{i=1}^{n} P_{R_{wai}}}}
\]
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- From the Rwa spectrum analysis, some difficult zones are interpreted successfully.
Part II. Identifying the reservoir nearby the borehole and fluid type interpretation

- By FMI scaling, criteria for pay zone interpretation is defined and the coincidence rate of carbonate reservoir is improved greatly.
Part III. Case of Carbonate Gas Reservoir filled with Asphaltum

- GuanWuShan Formation is typical of dissolution cave filled with 2 types of asphaltum
- DTC/DTS and Rt increase with the existence of asphaltum
• Φ/K/T2 test before & after solution of asphaltum show that both pore size and connectivity are affected by the asphaltum.
• Φe from T2 may be related to the volume of asphaltum.
• $e$ from conventional logs is too large, and needs correction
• LithoScanner provides accurate volume of asphaltum and make the correction possible.
Based on CMR, it is also possible to determine the volume of asphaltum and also the effective porosity.

\[ V_{\text{asph.}} = \Phi_{\text{conv.}} - \Phi_{\text{eT2}} \]
Part III. Case of Carbonate Gas Reservoir filled with Asphaltum

- Qualitatively, it is also possible to identify asphaltum zone by conventional logs: low GR, AC is reverse to RT
Reservoir quality in PetroChina’s domestic exploration and production area become continuous deterioration, so that need to use advanced well log techniques, which include LithoScanner, CMR-NG and ultra high temperature high pressure wirelog equipment, to deeply evaluate these complex reservoirs.
Thanks