RESERVOIR QUALITY OF THE MESAVERDE GROUP
UINTA AND PICEANCE BASINS
UTAH AND COLORADO

How can rock typing and petrography help us to understand and predict reservoir performance?

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Analysis of Critical Permeability, Capillary Pressure and Electrical Properties for Mesaverde Tight Gas Sandstones from Western U.S. Basins

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Background and objectives
Data set: core description, core plug sampling, KGS lab measurements, log data, legacy core data, thin section petrography
Rock typing, digital rock types
Influence of diagenesis on reservoir quality
Reservoir quality issues (rock type & petrophysics)
Data

- Routine core analysis:
  - Uinta basin - 539 samples, Piceance 629 samples
  - Mercury invasion and imbibition curves for 8 samples
- Core description and petrography:
  - Uinta basin - 7 wells, 1 shallow bore hole, 2060’ core, 26 thin section point counts
  - Piceance basin - 6 wells, 2 shallow bore holes, 1168’ core, 46 thin section point counts
- Log analysis:
  - Modern log suites for 9 wells, various vintages and format for 7 older wells and shallow bore holes
Stratigraphic distribution of cores
Piceance Basin

USGS #1 Book
Cameo outcrop core

Mesaverde
Cameo
Rollins
Cozzette
Corcoran
Stratigraphic distribution of cores, Uinta Basin

Mesaverde

Neslen

Mancos

USGS Book Cliffs outcrop cores
Core Description and digital rock typing

- Standard core description format
  - lithology
  - grain size
  - sedimentary structures
  - bedding and contacts
- 5 digit system to characterize lithofacies
  - basic type (Ss, Ls, coal)
  - grain size/sorting/texture
  - porosity/consolidation
  - sedimentary structure
  - cement mineralogy
<table>
<thead>
<tr>
<th>Grain size/sorting</th>
<th>Visible porosity</th>
<th>Sedimentary struc’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>10xxx Shale</td>
<td>xx0xx 0-2%, unfractured</td>
<td>xxx0x Vert. dike</td>
</tr>
<tr>
<td>11xxx Silty shale</td>
<td>xx1xx 0-2%, fractured</td>
<td>xxx1x Bioturbated</td>
</tr>
<tr>
<td>12xxx V shaly sandstone, siltstone</td>
<td>xx2xx 3-10%, unfrac’d</td>
<td>xxx2x Contorted</td>
</tr>
<tr>
<td>13xxx Shaly sandstone</td>
<td>xx3xx 3-10%, frac’d</td>
<td>xxx3x Discontin. lams.</td>
</tr>
<tr>
<td>14xxx VF sandsone</td>
<td>xx4xx 3-10%, abun fracs</td>
<td>xxx4x Contin. lams.</td>
</tr>
<tr>
<td>15xxx F sandstone</td>
<td>xx5xx &gt;10%, unfrac’d</td>
<td>xxx5x Flaser bedded</td>
</tr>
<tr>
<td>16xxx M sandstone</td>
<td>xx6xx &gt;10%, frac’d</td>
<td>xxx6x Ripple laminated</td>
</tr>
<tr>
<td>17xxx C sandstone</td>
<td>xx7xx &gt;10%, unfrac’d</td>
<td>xxx7x Trough, planar tabular crossbeds</td>
</tr>
<tr>
<td>18xxx VC/Matrix supported cgl.</td>
<td>xx8xx High, weak cons.</td>
<td>xxx8x Planar laminated</td>
</tr>
<tr>
<td>19xxx Conglomerate</td>
<td>xx9xx Unconsolodated</td>
<td>xxx9x Massive</td>
</tr>
<tr>
<td>2xxxx Limestone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30000 Coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05000 Volcanic ash</td>
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</table>
Cement

<table>
<thead>
<tr>
<th>XXXX0</th>
<th>Pyrite</th>
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<tbody>
<tr>
<td>XXXX1</td>
<td>Siderite</td>
</tr>
<tr>
<td>XXXX2</td>
<td>Phosphate</td>
</tr>
<tr>
<td>XXXX3</td>
<td>Anhydrite</td>
</tr>
<tr>
<td>XXXX4</td>
<td>Dolomite</td>
</tr>
<tr>
<td>XXXX5</td>
<td>Calcite</td>
</tr>
<tr>
<td>XXXX6</td>
<td>Quartz</td>
</tr>
<tr>
<td>XXXX7</td>
<td>Authigenic clay</td>
</tr>
<tr>
<td>XXXX8</td>
<td>Carbonaceous</td>
</tr>
<tr>
<td>XXXX9</td>
<td>No pore filling</td>
</tr>
</tbody>
</table>

15277 - Medium sandstone with moderate porosity, unfractured, trough cross bedded, clay cemented
Utility of digital rock typing

- Excellent match with GR log traces
- Precise depth shifting of core analysis data
- Track statistical distribution of lithofacies, sampling and core analysis data
- Provides quantitative variables for multivariate analysis
Grain densities of the Mesaverde Group

Percent of Basin Population

Grain Density (g/cc)

Green River
Piceance
Powder River
Uintah
Wind River
Washakie
Sand Wash

2.58-2.60
2.60-2.62
2.62-2.64
2.64-2.66
2.66-2.68
2.68-2.70
2.70-2.72
2.72-2.74
Utility of digital rock typing, continued

- Differences in detrital composition of sediment, depositional environment, burial history and diagenesis among basins requires separation of basins for assessment of reservoir quality.
- Rock types are not restricted to a specific depositional environment.
Phi/K Crossplot Mesaverde, Piceance Basin

Ambient Permeability, in mD

Ambient Porosity, percent
Phi/K Crossplot Mesaverde, Piceance Basin

Ambient Permeability, in mD

Ambient Porosity, percent

14XXX
Porosity Distribution in the Mesaverde Group

Mesoporosity

Intergranular pores, primary and secondary

Moldic pores (partly and completely dissolved feldspars, carbonate and volcanic rock fragments)

Microporosity

Pore-lining and pore-filling clay cement

Intragranular micropores (altered VRF, clay pellets, shale rock fragments, clay and carbonaceous matrix)

Fractures

Macroscopic and microscopic (primarily crushed feldspars or chert, separations at quartz overgrowth boundaries)
Porosity Distribution
Mesaverde Uinta and Piceance

BP + BC Mesopor

Moldic Mesopor

BP + WP Micro
Mesaverde Group
Uinta and Piceance Basins

Permeability, in md

Percent Microporosity of Total Pores
Porosity Distribution in the Mesaverde Group

Type I
Conventional porosity – Primary intergranular and modified intergranular (e.g. quartz overgrowth cement, secondary intergranular), no clay cement, Mesoporosity >> Microporosity, low Swi, Phi=high, K=high

Type II
Moldic– May include primary intergranular and secondary intergranular Trace to absent clay cement, Mesoporosity >> Microporosity, Low to moderate Swi, elevated Snwr, Phi=high, K=moderate

Type III
Restricted intergranular– Clay-lined pores and pore throats, some moldic and clay-filled intergranular microporosity, moderate to common clay cement, Microporosity > Mesoporosity, Moderate to high Swi, elevated Snwr, Phi=moderate, K=low
Porosity Distribution in the Mesaverde Group

Type IV
Microintergranular– Clay-filled intergranular pores, moderate to common clay cement, Microporosity >> Mesoporosity, High Swi, High pore entry pressure, Phi=moderate to low, K=low to extremely low

Type V
Nanointergranular– Typical of mudstones, clay-sized intergranular, common clay or carbonaceous material, Microporosity only, high Swi, extremely high pore entry pressure, Phi=moderate to low, K=low to extremely low
Type I (moderate compaction)

Porosity consists of moderately connected primary and secondary intergranular mesopores and traces of pore-lining chlorite clay containing microporosity.

Quartz cement and ferroan calcite are sparse.

Lack of pore-lining clay cement reduces Swi and improves relative permeability.

Barrett Last Dance 43C, 3544.9'
Rock type 16277
11.4% 2.65 g/cc Ka=0.8716 mD
Type II

Porosity consists of poorly to moderately connected moldic and secondary intergranular mesopores with traces of pore-lining ML/IS(?) clay containing microporosity.

Quartz cement is prominent, ferroan calcite is sparse.

Pore-lining clay cement causes elevated Swi and reduced relative permeability.

Williams PA 424, 6148.8’ 15276
9.9%  2.66 g/cc  Ka=0.0237 mD
Type III

Porosity consists of clay-lined intergranular pores, pore throats are occluded by clay cement, which causes elevated Swi and reduced relative permeability.

Inhomogeneous packing and over-sized intergranular pores indicate the development of secondary intergranular porosity.

Williams PA 424, 4600.3′ 15297
12.2% 2.65 g/cc Ka=0.0178 mD
Type IV

Porosity consists almost entirely of sparse, poorly connected, clay-filled intergranular microporosity.

Quartz cement is prominent, ferroan calcite is sparse.

Pore-filling clay cement causes elevated Swi and reduced relative permeability.

Williams PA 424, 4686.4′ 15286
7.9%  2.65 g/cc  Ka=0.211 mD
Conclusions

- Rock typing is a useful tool for lithofacies analysis and directing statistical sampling.
- Grain size and shale content are the primary controls on reservoir quality.
- Matrix porosity in the Mesaverde Group consists of both primary and secondary intergranular, moldic, and clay-filled microporosity.
- Porosity type and distribution of clay cements help explain the variation of permeability for a given value of porosity.
- Microfracturing on the scale of individual grains, overgrowth partings, and mesofractures are also present.
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