Paleozoic Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah: Multiple Frontier Exploration Opportunities

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Utah Geological Survey

RPSEA Unconventional Gas Project Review Meeting
April 14-15, 2009
Golden, Colorado
Project Goal

Provide basin specific analyses of shale-gas reservoir properties to develop the best local completion practices that can be applied to the emerging Manning Canyon, Delle Phosphatic, and Paradox frontier gas shales.
Mission Statement

The Utah Geological Survey creates, interprets, and provides information about Utah’s oil and gas resources to promote safe, beneficial, and wise use of the land.
Objectives

- Identify and map the major trends for frontier gas shale
- Identify areas with the greatest gas potential
- Characterize the geologic, geochemical, petrophysical, & geomechanical rock properties
- Reduce exploration costs & drilling risk especially in environmentally sensitive areas
- Recommend the best practices to complete & stimulate frontier gas shales to reduce development costs & maximize gas recovery
Project Participants

Utah Geological Survey (Prime Subcontractor)

Halliburton Energy Services

Bereskin and Associates

GeoX Consulting Inc.
Mississippian Manning Canyon Shale

- Mainly claystone with interbeds of limestone, sandstone, siltstone, and mudstone
- Maximum thickness of 2000 ft
- TOC varies from 1% to more than 8%
- Type III (?) kerogen
- In north-central Utah, the Manning Canyon was deeply buried by sediments in the Pennsylvanian-Permian-aged Oquirrh basin and is likely very thermally mature
Organic-Rich Manning Canyon Shale Interbedded with Thin-Bedded Micritic Limestone, Western Provo Canyon, North-Central Utah
Thickness and Distribution of Manning Canyon Shale in Northern Utah and Correlative Formations in Adjacent Areas

Modified from Moyle, 1958
Manning Canyon Shale Stratigraphic Section, Oquirrh Mountains, North-Central Utah

Modified from Moyle, 1959
Average TOC Content Values vs. Thickness for Manning Canyon Shale & Doughnut Formation

Modified from Swetland and others, 1978
Mississippian Delle Phosphatic Shale

- Member of the Chainman Shale, Deseret Limestone, and Little Flat Formation
- Composed of interbedded organic-rich phosphatic shale, siltstone and limestone
- Deposited in a starved basin at the foot of the Paleozoic carbonate ramp
- Typically 100 to 200 ft thick
Location of the Mississippian Delle Phosphatic Member present in the Deseret Limestone and other Mississippian formations

Modified from Sandberg and Gutschick, 1984
Pennsylvanian Paradox Formation

- Cyclic shale units (Gothic, Hovenweep, and Chimney Rock)
- Thinly interbedded, black, organic-rich marine shale
- Dolomitic siltstone; dolomite; and anhydrite.
- Thicknesses of individual shale units generally range in thickness between 10 and 70 ft; the cumulative shale thickness is typically 100 to 200 ft.
- TOC as high as 15%
- Type III and mixed type II-III kerogen
- Naturally fractured (usually on the crest of anticlinal closures), and often overpressured
Pennsylvanian Stratigraphic Chart for the Paradox Basin

Modified from Hite and other, 1984
Massive dark gray or brown dolomitic to silty mudstone of the Chimney Rock shale
Thermal Maturities (Production Index) at the Gothic Shale Interval

Modified from Nuccio and Condon, 1996
Distribution of TOC Values, Northern Paradox Basin

Modified from Schamel, 2006; data from Hite and others, 1984
Project Tasks

• Data compilation from existing wells and publications
• Description & petrophysical, geochemical, & rock mechanical analysis of cores and cuttings
• Outcrop examination & sampling
• Regional mapping (structure, thickness, thermal maturity, & deposition facies maps, burial history plots)
• Best completion practices
# Timing and Major Milestones

<table>
<thead>
<tr>
<th>Technical Tasks</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
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<tr>
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<td>Q3</td>
<td>Q4</td>
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<tr>
<td>Task 1.0. Project Management Plan</td>
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<td>Task 2.0. Technology Status Assessment</td>
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<td>Task 3.0. Technology Transfer</td>
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**Phase I**

| Task 4.0: Data Compilation              | ⬤     | ⬤     | ⬤     |       |       |       |       |       |       |       |       |       |
| Task 5.0: Core and Cuttings Examination and Sample Analysis | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |
| Task 6.0: Outcrop Examination and Sample Analyses | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |

**Phase II**

| Task 7.0: Determination of Best Completion Practices | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |
| Task 8.0: Regional Correlation, Mapping, and Depositional History Determination | ⬤     |       | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |
| Task 9.0: Final Interpretations and Recommendations | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |
Value of the Research – Project Problems

- Reservoir quality and the basic rock mechanic data so important to successful completions are virtually unknown for the Manning Canyon, Delle Phosphatic, and Paradox shale.
- Numerous cores and cuttings are available at the Utah Geological Survey’s Utah Core Research Center, but very few have been described in detail or have had reservoir analysis.
- Existing published maps and information on the distribution and thickness of these rocks is poor and often incorrect.
- The vertical succession and regional correlation of the Manning Canyon and Delle Phosphatic units have not been interpreted in a sequence stratigraphic framework.
Value of the Research – Project Problems

• The source potential of the Manning Canyon and Delle Phosphatic units is poorly understood and the burial history appears complex and probably varies widely from deep burial in the Permian Oquirrh basin (>10,000 ft of overlying Pennsylvanian and Permian strata) to shallower burial along the Paleozoic shelf of central Utah.

• In central Utah it is unknown if the formation is Doughnut or a tongue of the Manning Canyon.

• The following issues need to be addressed in determining best completion practices:
  – horizontal versus vertical wells,
  – fracturing techniques,
  – acidization, and
  – perforation method.
Value of the Research – Project Impacts

- Addresses the information needs of oil and gas exploration companies both large and small.
- Results will be used to identify favorable target areas to acquire leases and begin active exploration of shale-gas reservoirs.
- Exploration and service companies can use results as a basis for evaluating leases and development strategies.
- Best local completion practices developed by the project can be applied to the emerging Manning Canyon, Delle Phosphatic, and Paradox frontier gas shale where operations encounter technical, economic, and environmental challenges.
• Halliburton in designing best practices for proper stimulation and completion of each of the potential shale-gas reservoirs will provide a wealth of engineering information generally not available to the small operator.
• Reduces development costs, maximize gas recovery, and make results available to the petroleum industry (both large and small operators).
Planned, drilling, or completed shale-gas well
Technical Overview – Status of Current Technology

Petrophysical, Geochemical, and Rock Mechanical Analysis

• Core descriptions will involve a foot-by-foot examination and photography of slabbed sections. A subsequent electronic column or coregraph will be generated.

• Traditional petrography, X-ray diffraction/fluorescence, SEM, and petrophysical techniques.

• Standard TOC and vitrinite reflectance techniques.

• Rock mechanics testing includes extensive use of tight-rock analysis (TRA) provides: (1) bulk density, (2) grain density, (3) bound and mobile water and hydrocarbon saturations, (4) total porosity, (5) gas-filled porosity, and (6) pressure decay permeability.
Technical Overview – Status of Current Technology

Petrophysical, Geochemical, and Rock Mechanical Analysis

• This technique has been effectively utilized for many previous shale studies and appears very valuable in correlation of core to open-hole log data and potential production rates, and can be used to estimate ultimate reserve numbers.

• Triaxial and acoustic testing on core plugs under in-situ conditions for shale units will formalize the relationships developed to delineate facies-dependent correlations for Young's modulus, Poisson's ratio, and resulting degree of hydraulic fracturing.

• These data will be critical in determining the best completion practices for these potential shale-gas reservoirs.
Regional Correlation, Mapping, and Depositional History Determination

- Regional mapping will include structure, thickness, thermal maturity, and deposition facies maps of key shale-gas reservoirs.
- Regional cross sections and burial history plots for key shale-gas reservoirs will also be constructed.
- These products require the use of various commercially available computer mapping, log correlation, and basin modeling programs (currently licensed to the UGS) and will depend on and incorporate data collected during the first year of the project.
Best Practices

• Drilling (horizontal vs. vertical), fracturing, acidization, perforation, etc., based on geochemical and petrophysical information compiled by the UGS.
• Halliburton will draw on its significant experience with shale-gas completions from established shale-gas reservoirs elsewhere in the U.S. (Barnett Shale, Woodford, etc.).
<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Description</th>
<th>Planned Date</th>
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<tbody>
<tr>
<td>1</td>
<td>Project Management Plan</td>
<td>completed 10/08</td>
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<tr>
<td>2</td>
<td>Technical Status Assessment</td>
<td>completed 11/08</td>
</tr>
<tr>
<td>3</td>
<td>Monthly status reports. Template will be provided by RPSEA and available on RPSEA web site.</td>
<td>Monthly</td>
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<tr>
<td>4</td>
<td>A final report on the results of the Defined Effort. Template will be provided by RPSEA and available on RPSEA web.</td>
<td>06/11</td>
</tr>
<tr>
<td>5</td>
<td>Bibliography of published stratigraphic definition, petrologic, rock mechanics, geochemical, and geochronology analysis.</td>
<td>03/31/09</td>
</tr>
<tr>
<td>6</td>
<td>Well database of significant penetrations, tops, formation tests, completion information, production, and other reservoir data.</td>
<td>03/31/09</td>
</tr>
<tr>
<td>7</td>
<td>Megascopic description of slabbed core (including photography and tying to geophysical well logs).</td>
<td>12/31/10</td>
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## Project Deliverables

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Description</th>
<th>Planned Date</th>
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<tbody>
<tr>
<td>8</td>
<td>Petrographic Report - thin section and scanning electronic microscopy; X-ray diffraction; plug analysis for porosity and permeability, capillary pressure/mercury injection, and palyomorph/microfossil age dating.</td>
<td>12/31/10</td>
</tr>
<tr>
<td>9</td>
<td>Geochemical Report - total organic carbon and vitrinite reflectance analysis.</td>
<td>12/31/10</td>
</tr>
<tr>
<td>10</td>
<td>Rock Mechanics Report - micro probe, triaxial tests, scratch tests, and tight rock analysis.</td>
<td>12/31/10</td>
</tr>
<tr>
<td>11</td>
<td>Outcrop Report – measured sections and selected petrographic analysis of selected samples</td>
<td>12/31/10</td>
</tr>
<tr>
<td>12</td>
<td>Best Completion Practices Report</td>
<td>06/11</td>
</tr>
<tr>
<td>13</td>
<td>Structure, thickness, thermal maturity, and depositional facies maps; regional cross sections; and burial history plots of key shale gas reservoirs.</td>
<td>12/31/10</td>
</tr>
<tr>
<td>14</td>
<td>Map of significant play areas “sweet spots” for each of the emerging Paleozoic shale-gas reservoirs.</td>
<td>12/31/10</td>
</tr>
<tr>
<td>15</td>
<td>Formal publications of project work and results in various professional journals and/or geological society guidebooks.</td>
<td>06/30/11</td>
</tr>
<tr>
<td>16</td>
<td>The UGS will provide technical results containing details and data to be utilized for determination of program impact as requested by RPSEA.</td>
<td>06/30/11</td>
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</tbody>
</table>
Progress to Date

Data Compilation (Task 4)

- A well database has been developed that includes well location, operator, formation top depths, cuttings and core collections, well log types, formation tests, completion and production information.
- Compiled available geochemical analysis (published and in the UCRC files) such as TOC, S_1, S_2, S_3, Tmax, HI, OI, S_2/S_3, and PI.
- Downloading well logs tiff images pertinent to the Manning Canyon Shale, Gothic shale, and Delle Phosphatic Member.
- An assessment has been conducted of the Paradox Formation and Manning Canyon Shale cores and well cuttings that are included in the UGS’s Core Research Center (UCRC) collection.
- Additional critical cores needed for study that are stored in other facilities are being acquired.
Progress to Date

Core & Cuttings Examination & Sample Analysis (Task 5)

• Developing detailed descriptions and photography of existing slabbed core
Dolomitic silty mudstone with wavy to planar lamination.
Progress to Date

Core & Cuttings Examination & Sample Analysis (Task 5)

- Detailed descriptions and photography of existing slabbed core
- General petrographic analysis of thin sections (shale matrix composition, secondary cements, clays, pore types, and natural fractures if present)
- Scanning electron microscopy

Chimney Rock Shale
Mule 31-K well, San Juan County, Utah

Dolomitic mudstone with euhedral crystals of dolomite

Organic rich mudstone with terrigenous clastics
Progress to Date
Core & Cuttings Examination & Sample Analysis (Task 5)

- Developing detailed descriptions and photography of existing slabbed core
- General petrographic analysis of thin sections (shale matrix composition, secondary cements, clays, pore types, and natural fractures if present)
- Scanning electron microscopy
- X-ray diffraction and fluorescence
Progress to Date

Core & Cuttings Examination & Sample Analysis (Task 5)

- Developing detailed descriptions and photography of existing slabbed core
- General petrographic analysis of thin sections (shale matrix composition, secondary cements, clays, pore types, and natural fractures if present)
- Scanning electron microscopy
- X-ray diffraction and fluorescence
- Geochemical analysis
  - TOC
  - Vitrinite reflectance
  - CO2 adsorption isotherm depending on result of TOC

Gothic shale kerogen type determination from TOC and Rock-Eval pyrolysis data
Progress to Date

Core and Cuttings Examination and Sample Analysis (Task 5)

- Tight rock analysis
  - continuous strength profile (scratch testing)
  - bulk density (including fracture volume), grain density, gas-filled porosity determination, fluid saturation (oil, water and clay-bound water saturation), and effective total inter
- pulse or pressure decay permeability
- capillary pressure/mercury injection analysis

TSI Test System

Typical scratch testing results

Gothic shale capillary pressure/mercury injection
Skyline #27-43 Mustang, 6028 ft.
Progress to Date

Core and Cuttings Examination and Sample Analysis (Task 5)

- Completion quality analysis/mechanical properties
  - Analysis of anisotropic properties from multistage compression testing, using multiple regression numerical analysis
  - 3 sample multi-stress path testing suite for analysis of anisotropic properties and in-situ stress
  - Unconfined compression strength test with evaluation of elastic parameters of Young’s modulus and Poisson’s ratio
  - Pre and post-test CT-scanning on individual plugs prepared for laboratory testing

Gothic shale Young’s Modulus and Poisson’s Ratio

Gothic shale compressive strength analysis
Gothic, Chimney Rock, and Hovenweep Shale Core at the UCRC
Manning Canyon/Deseret Cuttings at the UCRC
Progress to Date

Outcrop Examination and Sample Analyses (Task 6)

• Examined and collected samples from outcrops of the following sites:
  – Gothic shale of the Paradox Formation in San Juan Canyon, southeastern Utah
Gothic Shale in San Juan River Canyon, Honaker Trail, Southeastern Utah
Outcrop Examination and Sample Analyses (Task 6)

- Examined and collected samples from outcrops of the following sites:
  - Gothic shale of the Paradox Formation in San Juan Canyon, southeastern Utah
  - Manning Canyon Shale at Provo and Soldier Canyons, the Lake Mountains, and Mount Nebo, north-central Utah

Manning Canyon Shale in Provo Canyon, North-Central Utah
Outcrop Examination and Sample Analyses (Task 6)

• Examined and collected samples from outcrops of the following sites:
  – Gothic shale of the Paradox Formation in San Juan Canyon, southeastern Utah
  – Manning Canyon Shale at Provo and Soldier Canyons, the Lake Mountains, and Mount Nebo, north-central Utah

• Began preparing samples for analysis including microfossil age dating

• Began digitizing geophysical well logs for comparison to outcrop localities
Progress to Date

Regional Correlation, Mapping, and Depositional History Analysis (Task 8)

- Constructed regional structural contour and isopach maps of the Gothic, Chimney Rock, and Hovenweep shales of the Paradox Formation from the UGS dataset
- Produced burial history plots for the Manning Canyon Shale in central Utah
Combined Structural Contour and Isopach Maps
Technology Transfer

- Technical Advisory Board
- Geologic Society Meeting Exhibit Booths
- Publications
- Technical Presentations
- Core Workshop
- Field Review
- Project Web Page
  (http://geology.utah.gov/emp/shalegas/index.htm)
Technical Advisory Board

- Shell E & P Company
- Sinclair Oil and Gas Company
- Encana Oil and Gas USA, Inc.
- Bill Barrett Corporation
- CrownQuest Operating, LLC
- ST Oil Company
Upcoming Project
Technical Presentations

Shale Gas and Shale Oil Resources of the Paradox Basin, Colorado and Utah, by Steve Schamel

Gas Shale Characteristics from the Pennsylvanian of Southeastern Utah, USA, by S. Robert Bereskin and John McLennan

American Association Petroleum Geologists
Annual Convention
June 9, 2009, Denver, Colorado
Shale-Gas Resources

Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah

Funded by Research Partnership to Secure Energy for America

Project Summary || Map || Reports || Presentations || Contact

Project Summary
- Executive Summary (pdf)

Area Map

Red dots: planned, drilling, or completed shale-gas well. From Potential Shale-Gas Resources in Utah poster (see below)

Reports (pdf)
- Proposal (2MB)

Poster Presentations (pdf)
Potential Shale-Gas Resources in Utah
  - Poster (7MB)

Contact
For more information on this project, contact Tom Chidsey, 801-537-3364, email: tomchidsey@utah.gov or Roger Bon, 801.537.3363, email: rogerbon@utah.gov.
Technical Issues – Problems Encountered