New Albany Shale Project
Project Update
Presented at RPSEA Unconventional Gas
Project Review Meeting
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New Albany Shale

- Large Geographic Area
- Multiple States
- Complex Geology
- Low Permeability

86 to 160 Tcf New Albany Shale (Gas-in-Place)

Large GIP with Limited Production (.3 Bcf/y) + Technically Complex = R&D Target
New Albany/Antrim Analog

- New Albany Shale is similar to Antrim Shale
- Antrim shale gas rate increased from 130 Bcf/y to 320 Bcf/y after similar GRI project

<table>
<thead>
<tr>
<th></th>
<th>New Albany</th>
<th>Antrim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (ft)</td>
<td>500-2000</td>
<td>600-2200</td>
</tr>
<tr>
<td>Gross Thickness (ft)</td>
<td>180</td>
<td>160</td>
</tr>
<tr>
<td>Pressure (psi)</td>
<td>300-600</td>
<td>400</td>
</tr>
<tr>
<td>TOC (%)</td>
<td>1-25</td>
<td>1-20</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>10-14</td>
<td>8-15</td>
</tr>
<tr>
<td>Gas In Place (Tcf)</td>
<td>86-160</td>
<td>35-76</td>
</tr>
<tr>
<td>Recovery Factor (%)</td>
<td>10-20</td>
<td>20-60</td>
</tr>
<tr>
<td>Gas Rate (Mcfd)</td>
<td>10-50</td>
<td>40-500</td>
</tr>
</tbody>
</table>

New Albany Shale Well Economics
- Horizontal well cost: ~$750,000
- Well depth: 500-2,500 (feet)
- Reserves/well: ~0.7-1.2 (Bcf)
- Peak production: ~200-300 (MMcf/d)
- Time to peak: 6-12 months
- Decline rate: ~5%/year
- Productive life: ~30 years
- Average W.I.: 43%
- IRR: ~45% ($5 gas)

Source: Aurora Oil and Gas Corp.
New Albany Shale

- Large Geographic Area
- Multiple States
- Complex Geology
- Low Permeability

86 to 160 Tcf New Albany Shale (Gas-in-Place)

Illinois Basin

Large GIP with Limited Production (.3 Bcf/y) + Technically Complex = R&D Target
Sensitivity to flush production and price

Economics

**Cash Flow, PV 10%, non-core well, Ft Worth Basin**

IP 600 mcf/d, Drill and complete $1.9 million, $50k G&G, $72k leasehold
Decline rate: 50% year one, 25% year 2, then 10% per year

- $7 flat
- $3.50 yr 1, then $7 flat
- $3.50 yrs 1,2, then $7 flat

PV10 cash flow $430k
PV10 cash flow $94k
PV10 cash flow $-95k

*Prices during flush production are one of the keys to play economics*
New Albany Shale Project

• **Description:** A field-based cooperative research project for identification and characterization of parameters that impede the development of New Albany Shale Gas and to develop techniques to alleviate these impediments

• **Objective:** Develop drilling and completion techniques aimed at improving exploration success ratio, production rate, and ultimate recovery of natural gas from New Albany Shale
New Albany Shale Project

Industry Partners
- Aurora Oil and Gas
- CNXGas
- Diversified Operating
- Noble Energy
- Trendwell Energy
- NGAS
- Atlas America
- Breitburn Energy
- Inflection Energy

Research Team
- GTI
- Amherst College
- Bureau of Economic Geology (BEG)
- Pinnacle Technologies
- ResTech
- Texas A&M
- West Virginia University

In this team effort, the industry partners identify key technical issues to be addressed by the research team and provide data and wells of opportunity for field data acquisition and testing.
New Albany Shale Project

In August 2008, a team of producing and service company partners and research organizations identified and ranked six key technical issues to be addressed by the project.

New Albany Shale Gas Project
Ranked Technical Challenges

- Geo/Geochem: 37%
- FE: 18%
- Res. Eng.: 11%
- Drilling: 11%
- Stimulation: 17%
- General: 6%
New Albany Shale Project

Work, data, and information flow

- Historical and Field Data
- Geology
- Formation Evaluation
- Geochemistry
- Hydraulic Fracturing
- Reservoir Engineering
- Production Data
# New Albany Shale Project

<table>
<thead>
<tr>
<th>Research &amp; Performing Org. and PI</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geochemistry</strong>, Amherst College, Anna Martini; University of Arizona, Jennifer McIntosh; U Mass, Steve Pitsch</td>
<td>Characterization of New Albany gas relative to source and characterization of methanogene bacteria.</td>
</tr>
<tr>
<td><strong>Fracture Modeling</strong>, A&amp;M, Ahmad Ghassemi</td>
<td>Development of a numerical model for prediction of hydraulic fracturing in the presence of sealed and open natural fractures.</td>
</tr>
</tbody>
</table>
# New Albany Shale Project (continued)

<table>
<thead>
<tr>
<th>Research &amp; Performing Org. and PI</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fracture Diagnostics</strong>, Pinnacle Technologies, Steve Wolhart</td>
<td>Fracture design, Seismic and Tiltmeter fracture diagnostic surveys.</td>
</tr>
<tr>
<td><strong>Reservoir Engineering</strong>, Texas A&amp;M, Tom Blasingame, Christine Economides</td>
<td>Production data analysis focused on horizontal and hydraulically fractured wells of New Albany Shale.</td>
</tr>
<tr>
<td><strong>Best Practice Analysis</strong>, West Virginia University, Shahab Mohaghegh</td>
<td>Development of a fractured reservoir model for determination of best drilling and completion methods.</td>
</tr>
</tbody>
</table>
Albany Shale Project

Primary Project Areas and Producer Participants

- Trendwell
- Vigo
- Noble
- Energy
- Sullivan
- Aurora
- Oil&Gas
- Knox
- Deka
- Exploration
- Jackson
- Developing
- Area
- CNXGas
- Webster
- NGAS
- Muhlenberg
- Christian
- NGAS
- Christian

Albany Shale Project Map with highlighted areas and participants.
Field Data Acquisition: Reverse VSP Survey

- 3-C Surface Geophones
- Z-Trac Downhole Source
- New Albany Shale
A Fully Integrated Project  (Example: Fracturing)

Fig. 24 Simulation results of Case 1: (a) $\sigma_x/\sigma_y = 1.0/1.0$; (b) $\sigma_x/\sigma_y = 2.0/1.0$; (c) $\sigma_x/\sigma_y = 1.0/2.0$. 

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Hydraulic fracture
Natural fault

L = 0.15

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A Fully Integrated Project

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Hydraulic Fracture Treatments
Pumping Phase

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BEG

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Pinnacle
A Fully Integrated Project (Reservoir Engineering)

WVU: Geostatistical & AI approach

A&M: Analytic approach
New Albany Shale Project (Geochemistry)

> 32 water samples from New Albany and 11 samples from Antrim wells collected. Sample collection continues.

> Data from Antrim Shale suggests 10% reduction in production decline rate due to ongoing biogenic methane generation.

> Water analysis completed, DNA sequencing continues.

> Results of water analysis will be also used for characterization of produced water.
# New Albany Shale Project
## (Project Schedule)

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
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<tbody>
<tr>
<td>Project Year</td>
<td>Year 1 (Aug 08 - Jul 09)</td>
<td>Year 2 (Aug 09 - Jul 010)</td>
</tr>
<tr>
<td>Project Management Plan</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Technology Status Assessment</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Technology Transfer Plan</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Data Gathering (existing data)</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Geology</td>
<td>⬤</td>
<td>⬤</td>
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<tr>
<td>Geochemistry</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Formation Evaluation</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Reservoir Engineering</td>
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<tr>
<td>Fracture Modeling</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Hydraulic Fracturing &amp; Diagnostics</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Best Practice Analysis</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Environmental and Carbon Management</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Field Data Acquisition and Field Verification</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Coordination, Integration, Tech Transfer</td>
<td>⬤</td>
<td>⬤</td>
</tr>
</tbody>
</table>

- ⬤ Major Field Events (Fracture diagnostic surveys, coring and logging, well testing)
- ⬤←→ Intermittent Events (Data gathering, field data acquisition)
- ⬤←←→ Continuous Events (Analytical work and interpretation)
Summary of results to date

> Geologic Studies

   – Steep, partly or completely sealed fractures are likely most important for completions
   – Calcite-sealed fractures form weak planes (reactivation likely)
   – More complex fracture fill gives stronger planes (reactivation less likely)
   – Site-specific fracture characterization of the well experiment is critical
   – Present day $S_{Hmax}$ is generally ENE across region

> Geochemical

   – Sample from 43 wells collected and analyzed, DNA sequencing began
   – It appears that biogenic methane production has slowed production decline rate by 10% in Antrim shale
Summary of results to date

> Formation Evaluation
  – Reviewed available core, geochem and rock eval data, developed protocols, characterized discrepancies between isotherm and canister results leading to future development of corrections for isotherm results
  – Performed log analysis on several NAS logs

> Hydraulic Fracturing
  – Continued the development of analytic model for fracture propagation
  – Designed and forward modeled tiltmeter response to N2 fracturing
  – Performed forward modeling and analysis on results from different fracture treatments
Summary of results to date

> Reservoir Engineering
  – Developed base model for geostatistical/AI production simulation
  – Investigated various analytic methods and identified the power law exponential decline analysis technique most appropriate for NAS.

> Water Management
  – Scheduled for the second year

> Background and Field Data Acquisition
  – Established access to HPDI database on over 250 wells in Kentucky
  – Acquired and distributed 39 datasets from producing members
  – Surveyed a Reverse VSP and determined the local velocity anisotropy for determination of fracture orientation.
Natural Fracture Study

Implications for development of effective drilling and completion technologies

Julia F. W. Gale
Stephen E. Laubach

Bureau of Economic Geology, Jackson School of Geosciences,
The University of Texas at Austin, USA
Fracture Attribute Characterization

- Orientation
- Number of sets
  - Relative timing
- Intensity
- Spatial distribution
  - Regional, local
- Openness/mineral fill
- Connectivity
- Height
  - Mechanical layer thickness
Core and Outcrop Locations

Map from Schieber and Lazar, 2004
Steep Sealed Fractures

4 in diameter cores
Fault Surfaces
Compacted Veins

Blocher Member, Stop 1

Illinois Basin

View: West
Small Compacted Vein

Example in core, depth 2,804 ft
Polyphase Cement

Anschutz Corp. #16-19 Voelkel, Dubois Co., 2106 ft
Origin of Opening-Mode Fractures

> Regional, burial plus gas generation
> Differential compaction
> Regional, tectonic paleostress
> Local effects of major faults and folds
> Stress release during uplift

Structure Map from Comer (2006)
Example (Barnett, Permian Basin)

- Compacted fractures
- Fractures with fibrous cement and petroleum inclusions
- Cracking to gas
Jointed pavements, Ohio River at New Albany, looking west.
Bedrock Joint Orientations, Indiana
Comer et al. (2006)

- Conjugate sets
- Sullivan Co. ENE set dominant
- Pike Co. Highly variable
- Subsurface fractures commonly do not match joint orientation
In Situ Stress (controls hydraulic fracture orientation)

Mid-Plate Compression Province, but local variation
Need to establish $S_{H_{\text{max}}}$ carefully
Natural fractures NW-SE (orthogonal to $S_{H_{\text{max}}}$)
Secondary set ~ E-W
Data from 3 cored wells Hamilton-Smith et al (2000)
Active tectonics

Earthquakes along Wabash Valley Fault System (normal faults)
18th April 2008 Magnitude 5.2

McBride and Nelson (1999)
Subcritical Crack Index & Network Geometry

Geomechanical modeling: J. Olson

Map views of fracture pattern models

n=5

n=20

n=80
Barnett Shale samples give $n > 100$

- Large fractures clustered
- Mechanical layer thickness ~ 100s ft
- Cluster spacing several 100 ft

Samples from NAS cores, Sullivan Co.

- Noble Solsman 1-32H; 2 samples
- Noble Osburn Trust 1-11H; 1 sample
Subcritical Crack Index Testing

Fractures in Noble Solsman 1-32H core

- Apparent concentration of fractures

Clustered

or

Stratabound
Weakly bonded fracture cement

Nobel Solsman 1-32H
2568.8 ft
Conclusions

>Natural fractures common; diverse origins
  ─ Steep, partly or completely sealed likely most important for completions
  ─ Calcite-sealed fractures weak planes (reactivation)
  ─ More complex fracture fill stronger planes (reactivation less likely)

>Different origins yield different attributes
  ─ Subcritical index for spacing
  ─ Location of well experiment critical
    > Sullivan/Pike Co. area near Wabash Valley Fault System
    > Christian Co. area near Rough Creek Graben (E-W)
    > Present day SHmax ENE across region (need local confirmation)
Formation Evaluation: Integrate Core-Geochem-Logs

> April 15, 2009
Characterize the Resource

> Core and Geochem
  - Porosity, Sw, Sg, So, K matrix
  - TOC, S1, S2, S3, Tmax, Ro, HI, OI (Maturity)
  - Isotherm – Adsorbed Gas
  - Canister – Total Gas

> Log Data
  - Kerogen, Pyrite, Qtz, Clay, Other, and Porosity
  - Correlate Rhob and other to TOC – Geochem
  - Free and Adsorbed Gas

> Integrate Log Based Models & Producibility
Previous Core and Log Data Studied

> Producibility Consortium Feb. 1999
> Client logs and core (circa 1970s) 3 well W. KY.
> Noble logs and Conventional Core 2006 (2 wells)
> CNX well logs and 25 Rotary SWC, 1 well W. Ky.
> Trendwell Energy – 2 wells- log, core data and gas analysis
> Recently received – approximately 30 Ngas well logs – W. Ky.
Typical Rhob – TOC correlation

TOC vs OB Rhob
For NABS

\[ y = -26.799x + 73.164 \]

\[ R^2 = 0.8897 \]
Adsorbed Gas from Isotherms

Methane Adsorption Isotherm For Two Sullivan County, Indiana Wells, New Albany Shale

Gas Contents are Normalized to TOC = 10%

V = 259.6*P/(P+2608.5)
# Stress Profile

<table>
<thead>
<tr>
<th>LITHOLOGY</th>
<th>TOC</th>
<th>RHOB</th>
<th>DTS</th>
<th>DTC</th>
<th>VP- VS</th>
<th>VP/VS</th>
<th>PR</th>
<th>STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>30</td>
<td>240</td>
<td>40</td>
<td>1.5</td>
<td>2.0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>240</td>
<td>40</td>
<td>25K</td>
<td>(ft/s)</td>
<td>0</td>
<td>3000</td>
</tr>
</tbody>
</table>

![Graph showing stress profile](image-url)
Geochem Log
Matrix Permeability

Matrix Permeability Measured on Crushed Chips with In-Situ Fluids with Two New Albany Shale Wells, Indiana

Free Gas, %BV

Matrix Perm, Nanodarcies
Future work

> Matrix gas permeability
  – Resolve different lab results

> Isotherm and Canister Gas Content
  – Heavy components in gas - resolve observed discrepancies
  – Create pseudo isotherm

> Improve Log Analysis
  – Determine water salinity from core
  – Calibrate log results to match core analyses
  – Explore method to distinguish gas from oil in bulk volume hydrocarbon determination
Future Work (Cont’d)

> Identify natural fractures and spacing
  – Image logs
  – Integrate with core work
  – Integrate with well testing and reservoir simulation

> Finalize integrated models – tie them to:
  – Producibility
  – Effective completions
  – Economic operations
Fracture Design & Diagnostics
New Albany Shale Project

April 15, 2009

Steve Wolhart
Pinnacle

steve.wolhart@pinntech.com
Overview

> Ultra low permeability reservoir that requires stimulation to be economic

> Stimulation can be either natural (open natural fractures), induced (hydraulic fracture) or combination

> Contact maximum amount of the reservoir for production performance – network size & density
Objective & Scope

> Hydraulic fracturing has been a key driver for shale plays
  – Barnett, Marcellus, Fayetteville, Woodford, Bakken, Huron, etc.

> Objective: Better understand & improve stimulation in the NAS
  – Horizontal or vertical wells?
  – Nitrogen, slickwater, etc?

> Hydraulic Fracture Diagnostics
  – Surface Tilt – hydraulic fracture azimuth & dip, coverage along the lateral & fracture complexity
  – Microseismic – hydraulic fracture azimuth, fracture height, fracture length, coverage along the lateral & complexity
  – Hydraulic Fracture Engineering
New Albany Shale Challenges

> Reservoir Characterization
  - Shale thickness & composition
  - Bounding rock layers
  - Natural fractures – density, orientation & mineralization
  - Faulting, karsts, formation dip & structural influences

> Reservoir pressure (low P* & large volumes of induced water are not compatible)

> Presence of (movable) water
  - Within or above/below NAS?
Albany Shale Project

> Extensive HF mapping in many shale plays
  — Hundreds of wells and thousands of frac stages have been mapped in various shale plays in the US and Canada

> Limited HF in the NAS
  — Handful of wells (IN & KY)
  — All horizontal wells
  — Cemented & un-cemented
  — Detailed results confidential
Uncemented Liner

Observation well

Map View
Cemented/Perforated

Map View

Observation well
2000/5000 Bbl Slickwater Fracs

Uncalibrated model
30 bpm
1,000/2,500 Mscf N2 Fracs

Uncalibrated model
30 Mscf/min
Summary

> Still early in the completion/stimulation review
> Stimulated reservoir volume & network complexity matter
> Horizontal wells – contact open natural fractures & efficiently contact more reservoir
> Uncemented liners – poor coverage with untreated sections along the lateral
> Evaluate diversion strategy
  ─ More stages
  ─ Consider OH packer systems
  ─ Time-related diversion also promising
Summary

>Cemented/perfed – difficulty pumping large, high rate frac jobs

>Azimuth – varied but not significant

>Frac height & payzone coverage
  — Varied based on shale thickness
  — Stratigraphic position lateral – h/frac height/best pay/water

>Frac half length - significant variation in half lengths
  — Impact drainage area & well spacing

>Cautious about pumping large volumes of water
  — N2, foam or N2/hybrids
Future Work

> Field Data Acquisition

> Microseismic & surface tiltmeter mapping
  - Azimuth, height, length, complexity, reservoir volume contacted, etc.

> Use results of geology, geochemistry & formation evaluation studies to better understand hydraulic fracture geometry

> Integration with best practices, fracture modeling & reservoir engineering