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Abstract

Leasing in the Sanford-sub basin began in January 2010; up to three groups were active. No drilling permits were submitted by May 2010. Pipeline build-out continues to provide natural gas for accelerated conversion of coal-fired electric plants by Progress Energy – the major public utility in central- and eastern North Carolina. These pipelines, located near the Sanford sub-basin, provide a ready natural gas market.

North Carolina’s 1945 Oil and Gas Conservation Act, amended in 1988, preceded previous drilling and needs updating to reflect current technology and to provide a framework of modern regulations, bonding, state royalties and permit fees, which are similar to other states. Listening sessions on potential drilling concerns were conducted with interested parties inside both state government and the environmental community.

Progress includes development of an evolving three-dimensional digital subsurface basin model using basin-wide 2D seismic, a Cumnock Fm. (source rock) isopach map, and depth to basement map. Paper petroleum well logs are being converted to digital format. Additional organic geochemical data are being acquired to augment a robust database with thermal maturation and source rock data. Reconnaissance SEM of porosity in the Cumnock Fm. was obtained. The Sanford sub-basin is included in this year’s U.S. Geological Survey’s Mesozoic basin resource assessment.

Potential plays include coal bed methane, shale gas, and possible tight gas sand (strong gas shows noted on well logs and degraded oil in the Sanford Fm. above the Cumnock Fm.). Source rocks below the underlying Pekin Fm. cannot be precluded.

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Selected References


NORTH CAROLINA SHALE GAS -- A PROGRESS REPORT: SANFORD SUB-BASIN, DEEP RIVER BASIN, LEE, CHATHAM AND MOORE COUNTIES

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Basin and Source Rock Overview

- Eastern North American Triassic rift lacustrine basins related to the opening of the Atlantic
- Deep River Basin – 150-mile-long northeast trending half-graben (rift basin) with a steeply dipping eastern border fault.
- ~7,000+ feet of Triassic strata; paleo-equatorial location.
- Fresh water, shallow lake deposits similar to African rift valley lakes – aerated; current action, no deep water shales; cyclic sedimentation with wet- and dry cycles.
- ~59,000-acres with inferred %Ro≥0.8.
- Total petroleum system containing:
  - Source rock,
  - Seal, and
  - Traps / reservoir.
- Relatively untested exploration area; leasing underway (6,000 acres since January 2010).
Multidisciplinary techniques

- LiDAR (fractures and structure),
- Seismic interpretation (depth to basement and isopach of source rock thickness),
- GIS (digital platform for data integration, display and analysis),
- Organic geochemistry (TOC, maturation),
- XRD (clays and rock brittleness for fracking), some SEM (porosity); limited petrophysics,
- Molecular gas analysis (BTU, composition, stable isotopes for nitrogen, carbon and deuterium),
- Core logging and interpretation, data mining to recover historic technical data,
- Geologic mapping to outcrop scale, petrography, and
- Conversion of paper logs and seismic sections to digital products for use with digital seismic software.
USGS/NCGS Resource Assessment

- **Current focus:** Rigorous, science-based assessment of technically recoverable natural gas.
- **Assessments units (AU’s):** Developed for:
  - Coal bed methane (CBM),
  - Shale gas,
  - Tight gas.
- **Methodology:** Numeric, conservative approach to be computed by the U.S. Geological Survey (FORSPAN Model – USGS OFR–03–384) [used for continuous accumulations of petroleum].
- **Completion target date:** Spring 2011.
- **Publication date:** Sometime in 2011.
LiDAR is an important exploration tool – when combined with geologic maps

Sanford sub-basin, Lee Co., NC
Generalized cross section

SANFORD SUB-BASIN OF THE DEEP RIVER BASIN

Pekin Formation
Cumnock Formation
Sanford Formation
Jonesboro fault zone

NW
A

vertical scale = horizontal scale

5 km

Mostly fluvial, red and brown clastic rocks
Lacustrine gray and black fine-grained clastic rocks
Red, brown, and gray conglomerate and sandstone
Major normal faults

~7,000 feet deep

Generalized lithologies and stratigraphy.

From Olsen and others, 1991
## Stratigraphy

<table>
<thead>
<tr>
<th>SUPERGROUP</th>
<th>Group</th>
<th>Deep River basin</th>
<th>Dan River basin</th>
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<td>Sub-basins</td>
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<td>CHATHAM</td>
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<td>Sanford Formation</td>
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<td>Cumnock Formation</td>
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<td>Cumnock coal bed</td>
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<td>Gulf coal bed</td>
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<td>Pekin Formation</td>
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<td>Dan River</td>
<td>Group</td>
<td>Stoneville</td>
<td>Cow Branch</td>
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<td>Formation</td>
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- **Cumnock Formation** found 2009

**Key:**
- Conglomerate, sandstone, and mudstone
- Sandstone, mudstone, coal, and carbonaceous shale
- Gray mudstone and sandstone, with thin coal beds
- Conglomerate, fanglomerate, sandstone, and mudstone

From Reid and Milici, 2008
Drill Hole : USBM DH-2
NCGS No.: CH-C-1-45
Box No. : 118
From : 1423 feet to 1440 feet

Drill Hole : USBM DH-2
NCGS No.: CH-C-1-45
Box No. : 119
From : 1440 feet to 1449 feet
**Light Detection and Ranging (LiDAR) – Operational Theory**

- NC has complete LiDAR coverage (~49,000 sq. miles)
- Remote Sensing Technology similar using laser light pulses instead of sound waves or radio waves.
- Always combined with IMU (Inertial Measurement Unit) & Airborne GPS.
- Produces a data point cloud.
- Can also provide data based on the nature of the reflected light pulses (Intensity)
- Can fly day or night (but not in rain or through cloud cover)
- Large land areas can be covered relatively quickly
- Useful for areas where ground access is limited, prohibited or too risky for field crews.
Hillshade LiDAR – shows trends of dikes, fractures and beds
LiDAR fracture patterns can be traced to outcrops, and possibly to drill core.
Seismic Line 113

Bobby Hall #1
TD = 4,6100 ft

Elizabeth Gregson #1
TD = 4,120 ft

~7,100 feet
Alluvial fan system from southeastern highland

Preliminary depth to basement map, Sanford sub-basin. Elevation in meters below the surface. Northing and eastings are in meters; original data were in State Plane NAD83 meters. Depth is in meters. From: Reid, Jeffrey C. and Taylor, Kenneth B., 20100623, Assessment of continuous resources in Mesozoic basins (preliminary). North Carolina Geological Survey, Raleigh, NC.
Source rock is Cumnock Fm. – up to 200+ meters thick

Preliminary isopach map of the Cumnock Formation; original data were in State Plane NAD83 meters. Thickness is in meters. Northings and eastings are in meters; original data were in State Plane NAD83 meters. Depth is in meters. From: Reid, Jeffrey C. and Taylor, Kenneth B., 20100623, Assessment of continuous resources in Mesozoic basins (preliminary). North Carolina Geological Survey, Raleigh, NC.
Gas and oil shows

- Eleven of 28 drill holes (including old coal holes) with gas, oil or both and some ‘asphalt’ shows.
- Coal mines with underground oil shows; multiple fatal methane gas mine explosions (mines long closed).
- Two shut-in wells with significant pressure (March 2009) – failed nitrogen frac jobs.
  - Butler #3 (upper left) – with pressure of 900 psi; initial flow rate: unknown;
  - Simpson #1 (lower half) – with pressure of 250 psi; initial flow rate: 3,000 mcfd; settled at 231 mcfd; well flared; and
  - Butler #1 (upper right) – well flared; small amount high paraffin, low flow temp. oil (hand warming) recovered.

‘Black band’ rock - nitrogen source rock
- Nitrogen, phosphorous, oil and iron compounds (local fertilizer);
- Retorted (1927) produced 3.6 to 12.4 gallons of oil per ton;
- 18” thick interval between upper and lower Cumnock coal benches (could be packed off); and
- Formed from carbon and iron-rich muds in coal-forming swamp with restricted accumulation of plant material.
~59,000 acres within solid line with inferred %Ro ≥ 0.8 (from NCGS OFR-2010-07).
Degraded oil in the Sanford Formation at shallow depth and above the Cumnock Formation.
Quartz+feldspar content indicates “fracability”.

Clays are subequal chlorite + illite; very minor kaolinite + mixed I/S

Some calcite veins observed

Diagram showing Cumnock Fm. brittleness
Porosity – SEM

CH-C-1-45 (BDMDH-1): Cumnock Fm. depth = 1,454.5 feet
LE-OT-1-82: Cumnock Fm. depth = 842 feet (DP-1)
Organic geochemistry

- Sediments are predominantly gas prone with some oil shows; robust database ~400 analyses.
- TOC data exceeds the conservative 1.4% threshold necessary for hydrocarbon expulsion.
- Organic matter derived from terrestrial Type III woody (coaly) and from Type II material; Type I (algal material) likely present.
- Thermal alteration data (TAI) and vitrinite reflectance data (%Ro) indicate levels of thermal maturity suitable to generate hydrocarbons.

Modified from Reid and Milici (USGS OFR 2008-1108)
• Distribution of TOC data in wells in the Sanford sub-basin
• A threshold of 1.4% TOC is considered necessary for hydrocarbon expulsion
• From Reid and Milici, 2008
Hydrogen and oxygen indices from Rock-Eval pyrolysis in relation to primary kerogen type.

The organic material in these formations was derived from Type II and Type III matter; Type I likely present.
Kerogen conversion and maturity ($T_{\text{max}}$) – Multiple wells

**Production Index ($P_{\text{I}}$)**

- **Immature**
- **Oil Window**
- **Condensate-Wet Gas Zone**
- **Dry Gas Window**

**Maturity (based on $T_{\text{max}}$, °C)**

- **Low Level Conversion**
- **Intensive Generation, Expulsion**
- **High Level Conversion**
- **Overmature**

**Stained or Contaminated**
%Ro – All data, Sanford sub-basin

Estimated maximum erosion is ~3,000 ft

Observed variations are:
• V.R. Groce #1: -1,800 ft
• Butler #3: -1,000 ft
• Simpson #1: -3,000 ft (maximum observed)

Dummitt-Palmer #1 (CBM) – “near dikes” and “overcooked” (updip, basin edge)

Bobby Hall #1

After Dow, 1977 (method)
## Gas composition and BTU (C1 = methane)

<table>
<thead>
<tr>
<th>Well</th>
<th>PSI</th>
<th>C1 %</th>
<th>N2 %</th>
<th>CO2</th>
<th>C2H6</th>
<th>BTU (Dry)</th>
<th>Comment</th>
<th>∆N Per mill</th>
<th>∆C Per mill (C1)</th>
<th>∆D Per mill (C1)</th>
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<tr>
<td>Butler #3 - 2009</td>
<td>900</td>
<td>48.78</td>
<td>45.60</td>
<td>3.86</td>
<td>3.86</td>
<td>605</td>
<td>Small amounts other gases</td>
<td>-3.32</td>
<td>-45.11</td>
<td>-178.5</td>
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<td>Simpson #1 - 1998</td>
<td>640-680</td>
<td>70.07</td>
<td>29.603</td>
<td>0.117</td>
<td>0.117</td>
<td>712.920</td>
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<tr>
<td>Simpson #1 - 2009</td>
<td>~250</td>
<td>51.65</td>
<td>45.49</td>
<td>1.89</td>
<td>1.89</td>
<td>577</td>
<td>Small amounts other gases</td>
<td>-3.23</td>
<td>-51.41</td>
<td>-174.8</td>
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<td>Dummitt-Palmer #1 – 1991 - Cumnock</td>
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<td>96.95</td>
<td>2.4</td>
<td>0.24</td>
<td>0.24</td>
<td>986.25</td>
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<td>Dummitt-Palmer #1 – 1991 – Gulf coal</td>
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<td>96.40</td>
<td>3.05</td>
<td>0.16</td>
<td>0.16</td>
<td>976.45</td>
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<td>Dummitt-Palmer #1 – 1991 – Black shale</td>
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<td>88.40</td>
<td>10.85</td>
<td>0.17</td>
<td>0.17</td>
<td>908.95</td>
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</table>

**Note** – ∆C and ∆D for light gases (ethane, propane, iso-pentane and N-butane along with specific gravity for 2009 analyses – not shown because of space)
Cross plot of $\Delta D$ methane (deuterium isotopes for methane, $\%$) vs. $\Delta^{13}C$ methane (carbon isotopes for methane, $\%$) showing fields for bacterial gas, associated gas, postmature dry gas etc., from Ellis et al., 2003. Reprinted with permission from the Oil & Gas Journal (from Janell Edman, RMAG, August 2007).
Summary

- ~56,000 prospective acres for exploration with inferred %Ro ≥ 0.8.
- Mesozoic rift basin with depth of 7,000+ feet.
- 800-foot thick organic shale section with two coal beds.
- Gas prone section based on organic chemistry and maturation and two shut-in wells with pressure.
- Centrally located in state.
- Environmental and permitting issues.
Acknowledgements

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