Triassic rift / lacustrine oil and gas in North Carolina and south-central Virginia: An unexplored US East Coast fairway
North Carolina (NC) - Overview

• NC is a highly technical and modern society right in the heart of the U.S. East Coast.
• NC is in the middle of a major unexplored rift / lacustrine oil and gas fairway stretching from Florida to NJ and until now, virtually no one has realized it.
• NC is right next to the NY market and can economically access the Marcellus generated oil field service industry in Appalachian basin.
• NC has spent a lot of time and effort getting the “social license” to drill and frack straightened out.
East Africa rift size compared to Eastern U.S. Mesozoic basins

Right: From Milici and others, 2012. Figure scales about equal.
Estimated technically recoverable resources (ETRR): N.C. and VA results (Milici and others, 2012)

Deep River basin AU:

<table>
<thead>
<tr>
<th>Gas (BCFG)</th>
<th>NGL (MMBNGL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F95</td>
<td>F50</td>
</tr>
<tr>
<td>779</td>
<td>1,527</td>
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</table>

Dan River – Danville basin AU:

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<thead>
<tr>
<th>Gas (BCFG)</th>
<th>NGL (MMBNGL)</th>
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</thead>
<tbody>
<tr>
<td>F95</td>
<td>F50</td>
</tr>
<tr>
<td>17</td>
<td>42</td>
</tr>
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Cumberland-Marlboro AU:

- Not assessed
- Aeromagnetic anomaly to be drilled by the NC Geological Survey

Note 1: M* = Mean
Note 2: Mean of 3.86 TCF for all East Coast Mesozoic basins; Deep River basin ~ 40% of the ETRR.
East Coast USA Mesozoic basins: Common characteristics

• Basin evolution:
  – Formed: along the continental margin from regional uplift, extension (deep rifting), and crustal thinning from the early Atlantic opening.
  – Rifting: started about 227 mya – Middle Triassic – Carnian time.
  – Basin fill (fluvial to lacustrine environments): boulder beds, coarse-grained fluvial to deltaic sandstones, red siltstone, mudstones, gray and black shales.
  – Rifting ended: in Jurassic accompanied by regional volcanism and intrusion of diabase dikes and sills (CAMP).

• Hydrocarbon potential:
  – Source rocks: gray and black shales and coal beds.
  – Kerogen: derived from vascular plants and algae => gas and oil.
  – Thermal maturation: Wide range from immature to dry gas.
  – Potential reservoirs: Continuous accumulations in wide range of lithologies (boulder conglomerates, very coarse sandstones to mudstone, shale and coal).
  – Seals (potentially): shale beds interbedded with coarser strata.

Adapted from Milici and others, 2012, and NCGS contributions
<table>
<thead>
<tr>
<th></th>
<th>Deep River Basin</th>
<th>Dan River Basin</th>
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</thead>
<tbody>
<tr>
<td><strong>Sub-basins</strong></td>
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<tr>
<td>Wadesboro</td>
<td>Sanford</td>
<td>Durham</td>
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<td></td>
<td>Sanford Fm.</td>
<td>Sanford Fm.</td>
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<td></td>
<td>Cumnock Fm.</td>
<td>Cumnock Fm.</td>
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<tr>
<td>Pekin Fm.</td>
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<tr>
<td></td>
<td></td>
<td>Pine Hall Fm.</td>
</tr>
</tbody>
</table>

**NEWARK SUPERGROUP**

**Chatham Group**

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

**Triassic stratigraphy and lacustrine strata (gray and green colors)**

* Very thin coal in North Carolina only

**Dan River Group**

- **Stoneville Fm.**
- **Eden Mbr.**
- **Dry Fork Mbr.**
- **Walnut Cove Mbr.**

**Dan River Group**

- **Pine Hall Fm.**

* Gray shale beds in Wadesboro sub-basin
Cumnock Fm. - TOC / Potential source /reservoir rock

**TOC Sanford sub-basin, Deep River basin = 1.96%, N = 353.**

**TOC Cow Branch Mbr. = 3.55%, N = 122; Eden Mbr. = 1.38%, N=42 – Dan River-Danville basin.**

Drill Hole : BMDH 2
NCGS No.: CH–C–1–45
Box No. : 118
From : 1423 feet to 1440 feet

Drill Hole : BMDH 2
NCGS No.: CH–C–1–45
Box No. : 119
From : 1440 feet to 1449 feet
Shows
- green circle = oil
- red circle = gas
Generalized lithologies and stratigraphy.

From Olsen and others, 1991
Deep River basin seismic line 113 – half graben

Green = reflectors
Red = faults
Yellow = lacustrine intercepts
Organic source material – Mostly Type 3 and some Type 1 – Deep River basin
Kerogen type and maturity (Tmax) – multiple wells: Sanford sub-basin

**%Ro = 1.25%, N = 42 as of August 2012**
Maturation: Most data plots in the oil and condensate windows + dry gas

Wells / core holes

Oil - Butler #1
Depth 3,000 ft

Oil-saturated sands above the source rock

Simpson #1 flare
Sanford sub-basin, Deep River Basin
Other (brittle minerals) - clays - carbonate (N=101)

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

Mostly quartz+feldspar

Some calcite veins observed
High pressure mercury porosity and permeability (MICP) results
Porosity examples – reservoir characterization

Top - V.R. Groce #1, depth 2,407 feet. Field of view shows intergranular pores associated with clay minerals and contacts with rigid grains.

Bottom - BMDH 2, depth 1,163 feet. Evidence of “organic porosity”. The sample has 2.3% TOC and 6.4% Hg porosity. Intergranular porosity (green arrows) associated with Mg chlorite. Sample is chlorite/illite mud rock with prominent phosphate “complexes”. Organic porosity occurs both within and along the margins of organic matter (OM; blue arrows).

(Left) - Backscatter electron image; OM is black. Clays have typical platy appearance; chlorite is the lighter shade of gray.

(Right) - Secondary electron image; pores marked by arrows - these are of variable size (nanometer range is typical). Gray fleck in OM are occluded clay.
North Carolina - Summary

• Two continuous gas assessment units (AUs).
• Age: Late Triassic (Carnian).
• Source rocks: Freshwater lacustrine shales deposited near/at the paleo-equator.
• Continental rift basins formed from Permian to Early Jurassic extension and breakup of Pangea.
• Both North Carolina basins were assessed by U.S. Geological Survey (Fact sheet 2012-3075) – URL http://pubs.usgs.gov/fs/2012/3075/.
• Industry interest; some leasing – available open ground.
• Horizontal drilling and fracking legalized in 2012; new state permitting rules required by October 2014.
• First permits anticipated to be issued in March 2015.
• With new completion technology, these deposits may become economically viable.
For further information

**Geological research** (list of all oil and gas publications) about the Triassic strata and reservoir characterization in North Carolina are on the Internet at URL: [http://portal.ncdenr.org/web/lr/oilandgasresearch](http://portal.ncdenr.org/web/lr/oilandgasresearch),

**Draft rules** are available on the Internet at URL: [http://portal.ncdenr.org/web/mining-and-energy-commission/home](http://portal.ncdenr.org/web/mining-and-energy-commission/home)

**Drill site** in Deep River basin: flat, relatively featureless, and lots of secondary roads. Typical terrain in these prospective basins – perfect for exploration!

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V.R. Groce #1 well pad - 1974