THE MARCELLUS SHALE GAS PLAY
Water-Resource Issues

John H. Williams
New York Water Science Center
Troy, New York

https://profile.usgs.gov/jhwillia/
Water Resource Issues

- Drill cuttings
- Frac flowback
- Faults and fractures
- Methane migration
Horizontal wells target basal Marcellus Shale
High TOC and elevated radioactivity in basal Marcellus Shale

<table>
<thead>
<tr>
<th>Location of the Core</th>
<th>Uranium Content (ppm)</th>
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</thead>
<tbody>
<tr>
<td>Allegheny, NY</td>
<td>8.9 – 67.7</td>
</tr>
<tr>
<td>Tompkins County, NY</td>
<td>25 – 53</td>
</tr>
<tr>
<td>Livingston County, NY</td>
<td>16.6 – 83.7</td>
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</tbody>
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Levanthal and others (1981)
Uranium & Thorium to Radium & Radon
Radioactive Decay Series

EXPLANATION
- Alpha decay
- Beta decay
- Radioisotope and half life
High TOC and abundant pyrite in basal Marcellus Shale

Lash and Engelder (2009)
Drill Cuttings

- Elevated uranium and abundant pyrite in high-TOC black shale
- Multi-horizontal well site will generate more than 500 times the volume of shale cuttings than single-vertical well site

Core of target interval

Drill cuttings
Drilling Fluids and Cuttings

Lined pit

Mixed with sawdust

Closed-loop system

Offsite disposal in landfill
Flowback

Contains elevated TDS, chlorides, barium, and radioisotopes whose concentrations increase during the flowback period approaching formation brine.
Ra-226 increases relative to Ra-228 in the later higher TDS flowback consistent with a U-rich source for the water such as the Marcellus shale (Engle and others, 2011)
Municipal wastewater treatment plants not designed to handle flowback chemistry

Limited number of disposal wells in Ohio

Reuse flowback, onsite treatment for solids / blend with 70 % freshwater
Microseismic Mapped Frac Tops and Bottoms
Marcellus Shale

Fisher (2010)
Onondaga Limestone
Tully Limestone
Marcellus Shale
Burkett Shale

Deep-seated fracture zone

Upper Devonian bedrock containing freshwater aquifers above sandstone gas reservoirs.

Seismic data courtesy of Shell Appalachia
Avoid Hydraulic Fracturing across Structures
Methane in Water Wells
Marcellus/Utica Gas-Play Area

Osborn and others (2011)
Marcellus Gas-Well Construction

2,500 – 4,000 feet
Directional rig for drilling horizontal leg

Top-set rig for drilling vertical surface- and intermediate-cased interval
Wellheads of first two of six horizontal wells
Good Zonal Isolation

- Conductor Pipe
- Surface Casing
- Production Casing
- Fresh Water Aquifer Zone
- Intermediate Producing Zone
Poor Zonal Isolation

Pressure builds up

Conductor Pipe

Surface Casing

Production Casing

Fresh Water Aquifer Zone

Shallow Producing Zone

Intermediate Producing Zone

Target Producing Zone

Casing

Cement

Formation

Southwestern Energy®
Geophysical Logs and Base of Freshwater Aquifer

Log data courtesy of Shell Appalachia
Shale Gas Development
Best practices based on state-of-the-art technology and science

- Geophysical logging to delineate base of freshwater aquifers
- Surface casing/cement deep enough to protect freshwater aquifers
- Intermediate and production casing/cement/packers to prevent upward migration of gas
- Cement-bond logging and pressure testing to ensure good seals
- Drilling and frac fluid storage in tanks and offsite burial of drill cuttings
- Avoid hydraulic fracturing near structures
- Microseismic monitoring of hydraulic fracs
- Reuse of frac fluid reduces freshwater resource impacts and disposal issue
- Water-well sampling before and after drilling/hydraulic fracturing operation
“ZEALOUS FOR THE MARCELLUS”