Field Test of an Alternative Hypothesis for Stray Gas Migration from Shale Gas Development

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Presentation for GWPC Stray Gas Forum
July 25, 2012  Cleveland, Ohio
Northeastern PA: A Poster Child for Stray Gas

- New Year's morning, 2009: a well vault explodes in Norma Fiorentino's front yard in Dimock, PA
- Nine other wells in Dimock had high methane levels
- Also high amounts of Al & Fe
- Odors, foam, orange color
- White flakes and other solids
- 20 families affected
- Popular assumption: gas was from the Marcellus Shale
- Was this really the explanation?

Aquifers:
- Pleistocene glacial till
- Upper Devonian bedrock:
  - Catskill Formation
  - Lock Haven Formation
    - Bradford Sands (gas)
  - Brallier Formation
- Low matrix permeability, fractured
Fractured Aquifers

• Fractured aquifers have high hydraulic conductivity, and lower overall porosity compared to aquifers with significant matrix porosity (Freeze and Cherry, 1979).

• The amounts of water stored per unit bulk volume (storativity) are lower in fractured aquifers than in aquifers with significant matrix porosity.

• The smaller volumes of groundwater contained in fractured aquifers respond quickly to changes in pressure head, and flow rapidly.

• Contaminant transport through fractured aquifers can occur with very little diffusion (F&C, 1979).

• Transient flow can be introduced to the fractures by a short-term pressure gradient.
Appalachian Basin Devonian Shales

**DISCUSSION**

East-west section shows a westward transition from shelf sandstones (B0 to D3), through slope turbidites (Bralier and Chagrin), to distal and basin sill water, black and gray shales.

Section based on 27 wells projected from cross section network prepared for the Eastern Gas Shales Project. Facies geometry from cross section network also used to delineate lithologic units. Horizontal datum is approximately the top of the Devonian System.

Prepared by W. A. Pryor and Paul Edwin Potter, H. N. Fisk Laboratory of Sedimentology, University of Cincinnati (EY-76-C-05-5201) for E. G. S. F. December 1979
Catskill Formation: Upper Devonian fractured, interbedded sandstone and mudstone, northern equivalent of the Hampshire Formation, cross bedded, fluvial and alluvial plain deposit.
Lock Haven Formation: Upper Devonian gray interbedded shale, siltstone, sandstone, and minor conglomerate. Sandstone described as lenticular and cross-bedded. Unit is a fossiliferous marine deposit.
Stray Gas as a Groundwater Contaminant

• How is the gas related to the other water quality problems (taste, color, odors, minerals, clarity, etc.)
• Two aspects of contaminants: **source vs. transport**
• **SOURCE:** What is the origin of the gas?
  • Biologic/biogenic: aerobic digestive processes, or anerobic metabolic decay processes
  • Geologic/thermogenic: Which geologic unit in particular? Can gas chemistry tell different units apart?
  • Some combination of sources
• **TRANSPORT:** How does the gas get from the source to the discharge point?
  • Upward migration (buoyancy)
  • Entrainment in groundwater flow gradient
  • Some combination of upward and lateral movement?
Data Sets


- A recent, inadvertent "field test“ from an Antero operation in West Virginia that affected groundwater
Duke University study released summer 2011:

- Assessed methane content in groundwater in 68 wells.
- Found higher concentrations near gas wells in NE PA.
- Up to 17 times higher than background levels away from gas wells.
- The methane was determined to be thermogenic in origin.
- Researchers conclude that it is related to the shale gas wells.
- No evidence of frac chemicals or formation brine associated with the high CH₄ in aquifers.
Cabot Oil and Gas Study

- Released December 2011:

- Assessed methane baseline data from 1700 water wells sampled prior to gas drilling.

- Concluded that methane is common in NE PA groundwater, and varies with topography (highest in stream valleys).

- Interpretation is that CH$_4$ is migrating along fracture systems that control stream locations.
How to Reconcile the Two Data Sets?

• Cabot study concludes that methane is ubiquitous throughout the aquifers in NE PA, occurring at higher concentrations in stream valleys.

• Duke study concludes that methane is present at higher concentrations near recent gas wells (active extraction areas) than away from such wells.

• Remember: source versus transport

• If the methane source is natural upward migration of thermogenic gas, and the gas is more concentrated near wells, the well drilling process itself must be affecting gas accumulation.

• Q: So how does shale drilling affect domestic water wells when methane is present in the aquifer?
Old: vertical drilling with a single frac

New: lateral drilling with multiple, (10-15) staged fracs

Cost: 2-3X higher; production: 3-4X greater (Engelder, Penn State)
How are the Wells Drilled?

- Vertical part often drilled using air instead of mud, although many operators have switched to water.
- Well is drilled open hole or through a short conductor casing to the base of the deepest fresh water aquifer (as defined by state regs)
- Surface or coal casing is set, cemented, and then drilling continues downward to the kick-off point, still using air, water or sometimes mud.
- Intermediate casing is set and cemented, then downhole mud motor is deployed to build curve.
- Mud motor uses hydraulic pressure of mud to operate bit, builds curve and drills lateral.
- Production casing is set and cemented, perforated and hydraulically fractured, and well produces gas.
DIMENSIONS OF A HORIZONTAL WELL: Central Park, New York
Land surface 110th St; Base freshwater 106th St; Bottom of vertical 85th St; 500 ft curve through softball fields; Lateral: out E 83rd St, Top of fracs; E 86th St. To scale except for thickness of line depicting wellbore
Conceptual Model Assumptions

• Duke and Cabot data are of good quality.
• Gas from the Marcellus Shale is generally not migrating upward to shallow aquifers.
• Gas in shallow aquifers is ubiquitous and sourced from higher in the geologic column.
• Some gas migration may be via the annulus from open hole completions, bad cement or defective casing, but not all wells are bad completions.
• A gradient is needed to get the methane to migrate laterally – otherwise gas leaking from a bad wellbore would tend to rise through buoyancy along the outside of the casing.
• Something unique about NE PA geology and Marcellus Shale gas drilling largely limits the problem to NE PA
A Conceptual Model for Gas Mobilization

1. CO₂ in beer and CH₄ in fractured aquifers are both dissolved. At saturation, small bubbles cling to the side of the glass (or the fractures) and gradually move upward through buoyancy.

2. When high pressure drilling air gets trapped in the fracture system, it pushes groundwater in a radial surge away from the well.

3. Like stirring the beer in a beer glass, the surging groundwater entrains the gas and transports it.

Ubiquitous methane gas in an aquifer will be more highly concentrated in the radial surge of groundwater moving away from air-drilled wells.

This honors both the Duke and Cabot data sets.

It also explains other observations, such as cloudiness, sediment, bad taste and minerals in the water.

Why air? Compressibility.
Trapped, high pressure drilling air in fractured aquifer causes groundwater surge, entraining and mobilizing pre-existing methane.

Surge is stronger closer to well, entraining more gas. Surge also entrains minerals and sediment.

NETL is collaborating with industry and other researchers to obtain field data for this conceptual model, and numerically model GW flow near drill sites.
How to Test?

• Simplest method is to install one or two groundwater monitoring wells a fixed distance from gas well location prior to spud-in, and measure groundwater levels as a surrogate for pressure heads.

• Water level can be measured with automated recording transducers. Need to know drilling schedule and activities to interpret data. Monitor while drilling through aquifer, setting surface casing, and again during hydraulic fracturing.

• Soil gas analysis, etc. can also be done with time and $

• Analysis of gas in water samples from monitoring wells before and after drilling would show if there was an increase in groundwater methane from the drilling process.
Potential Collaborators

NETL Office of Research and Development, Earth and Mineral Science Division:
Dan Soeder, PI; Rebecca Rodriguez and Kimberly Ayers, interns.

URS Corporation (NETL site support):
Bill Schuller, geologist, David Reese, technician

Shell: Bryce McKee
Cabot Oil & Gas: Emily Mercurio
Other industry (?) Talisman, Range Resources, ECA

New Jersey Institute of Technology (NJIT): Michel Boufadel (groundwater flow modeling)
Duke University: Avner Vengosh (methane analyses)
So.....

CAN GAS REALLY PUSH WATER?
Antero incident in WV

At the Antero drill pad:
- Occurred June 6, 2012, Sardis, WV (near Clarksburg)
- Drilled to 290 ft using water and air; bit got stuck around 150-170 ft
- The air compressor was left on as crews attempted to dislodge bit
- Surface casing had not yet been set, so compressed air "charged up the aquifer," per Antero VP Al Schopp (AP interview)

At local homes:
- Pressurized groundwater surged out of several old wells
- Homes are on city water, and all the affected wells were unused.
- The old groundwater wells began flowing water – one shot a stream 10-12 ft in the air, several others just overflowed
- Some homes flooded
Antero incident in WV

Data collected:
- Location of drill pad
- Location of at least one flowing well (~1000 yards from gas well being drilled, according to AP story; this needs confirmation.)
- Affected groundwater aquifer – most likely Conemaugh Group or Monongahela Group sandstones

Data needed for hydrologic model:
- Precise distances of affected groundwater wells
- Water elevations at all groundwater wells within 1 mile of drill pad
- Air pressure used at gas well (we were informally told ~ 300 psi)
- Estimate for hydraulic conductivity of the aquifer
- Any data on methane concentrations before and after flow

Status:
- Antero told us to contact a VP in Colorado for information
- WV State DEP is mulling over our information request
What next?

- Try to collect available data from the Antero incident.
- Try to arrange field tests to collect data for models.
- Ideally, assess and compare wells drilled with air, and wells drilled with water or mud at several locations in NE PA and SW PA or WV.
- Use model outputs to assess risks from different drilling techniques in different geology.
- Develop recommendations for drilling methods that apply nationally to various types of aquifer systems.
- Publish data and conclusions in a publically-available DOE report, and in a peer-reviewed scientific journal.