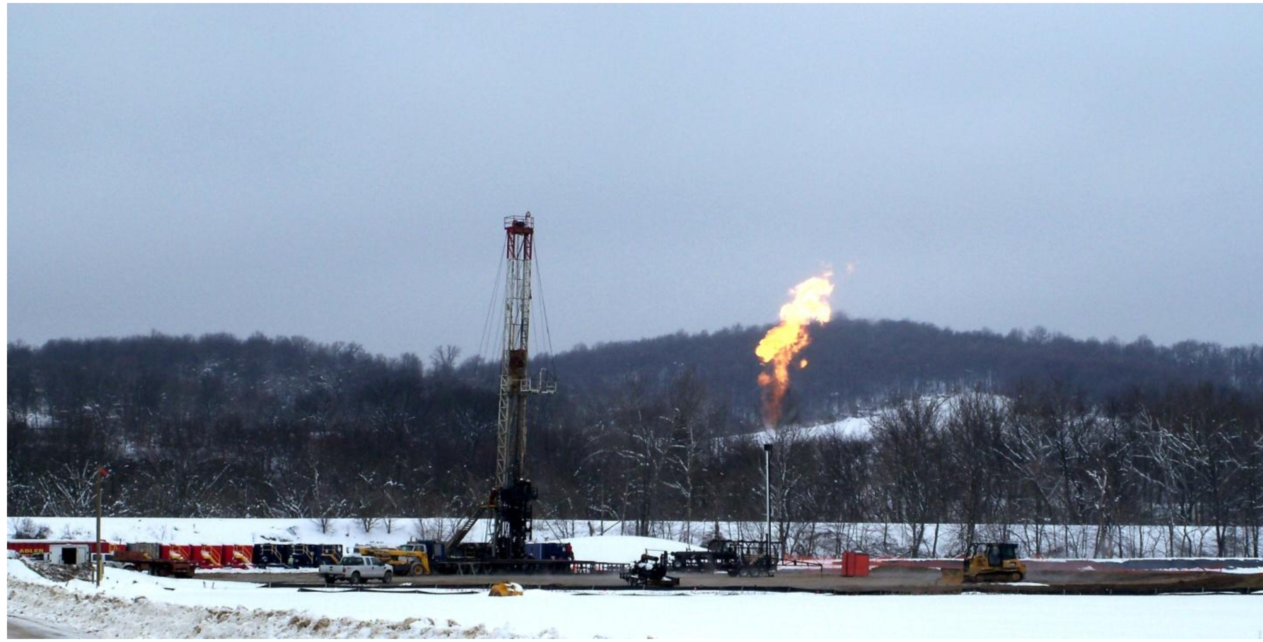
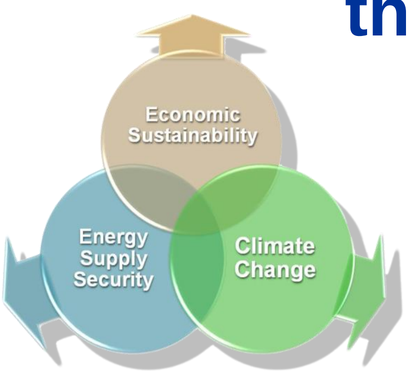


Resource and Environmental Studies on the Marcellus Shale



Daniel J. Soeder, NETL
Geology and Environmental Science
Morgantown, WV

U.S. DEPARTMENT OF ENERGY

National Energy Technology Lab

- Functions within USDOE Office of Fossil Energy
- Only federally owned and operated National Laboratory
- Locations in
  - Morgantown, WV
  - Pittsburgh, PA
  - Albany, OR
  - Houston, TX
  - Fairbanks, AK
- Expertise includes coal, natural gas, oil and related environmental technology
- Organized into 7 units:
  - Strategic Center for Natural Gas and Oil (SCNGO)
  - Strategic Center for Coal (SCC)
  - Office of Research and Development (ORD)
  - Office of Systems, Analyses and Planning (OSAP) (*econ*)
  - Project Management Center (PMC) (*utilization*)
  - Plus 2 internal business units

ORD Shale Gas Project Areas

Resource Characterization

- Improve the predictability of recoverable gas from the Marcellus Shale and other gas shales.
- Constrain estimates of gas-in-place.

Environmental Assessment

- Measure the environmental impacts from shale gas drilling and production.
- Perform a rigorous environmental assessment at a “typical” well site.

This seminar:

- Brief history of shale geology and gas development
- Summary of NETL resource characterization program
- Discussion about environmental impacts and assessment
- Questions and conversation

What is Shale?

- Sedimentary rock formed from mud
- Composed of fine-grained material: clay, quartz, organic matter, and other minerals.
- Clay-rich shales are fissile: split into thin sheets
- Shale types: organic-rich (black) and organic lean (gray or red)
- Shale porosity ~ 10%, permeability is very low. Pore spaces between grains are small.
- Gas occurs in fractures, in pores and adsorbed onto organic materials and clays.
- High permeability pathways are needed for economical rates of gas production.

Why “Marcellus” Shale?

Geologists name rocks after a location where the exposures are representative of the formation.

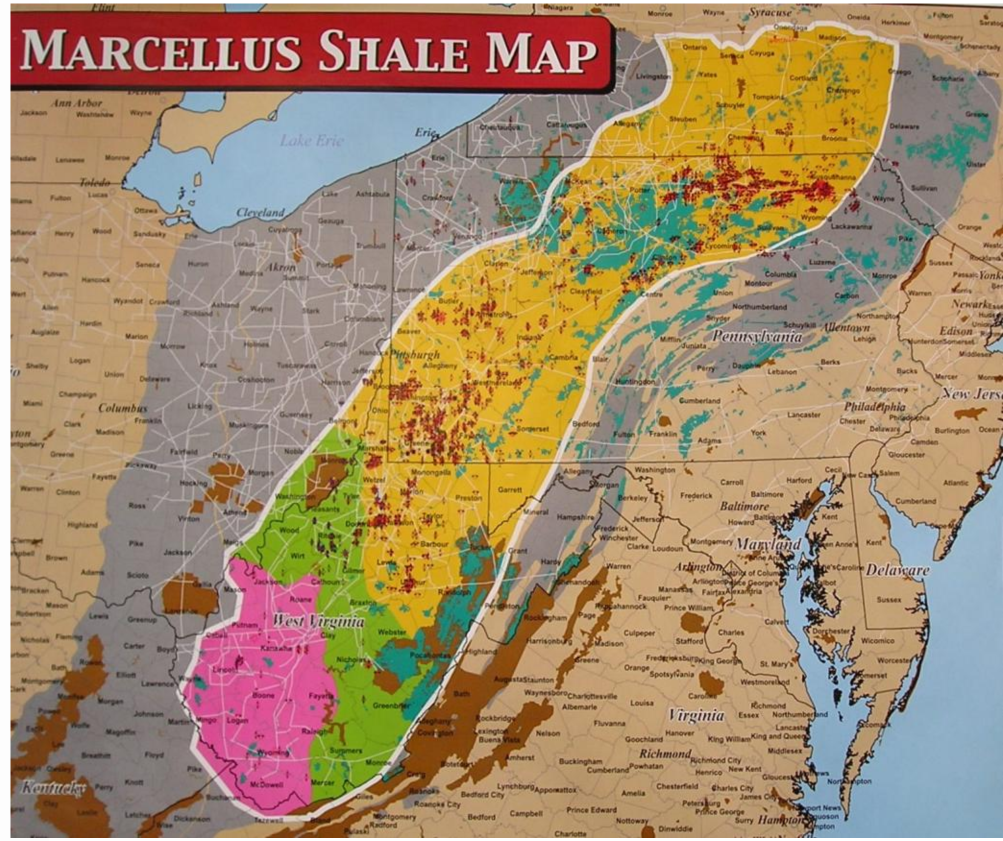
This is known as the “type locality.”

Descriptions are published in the scientific literature (Cooper,1936)

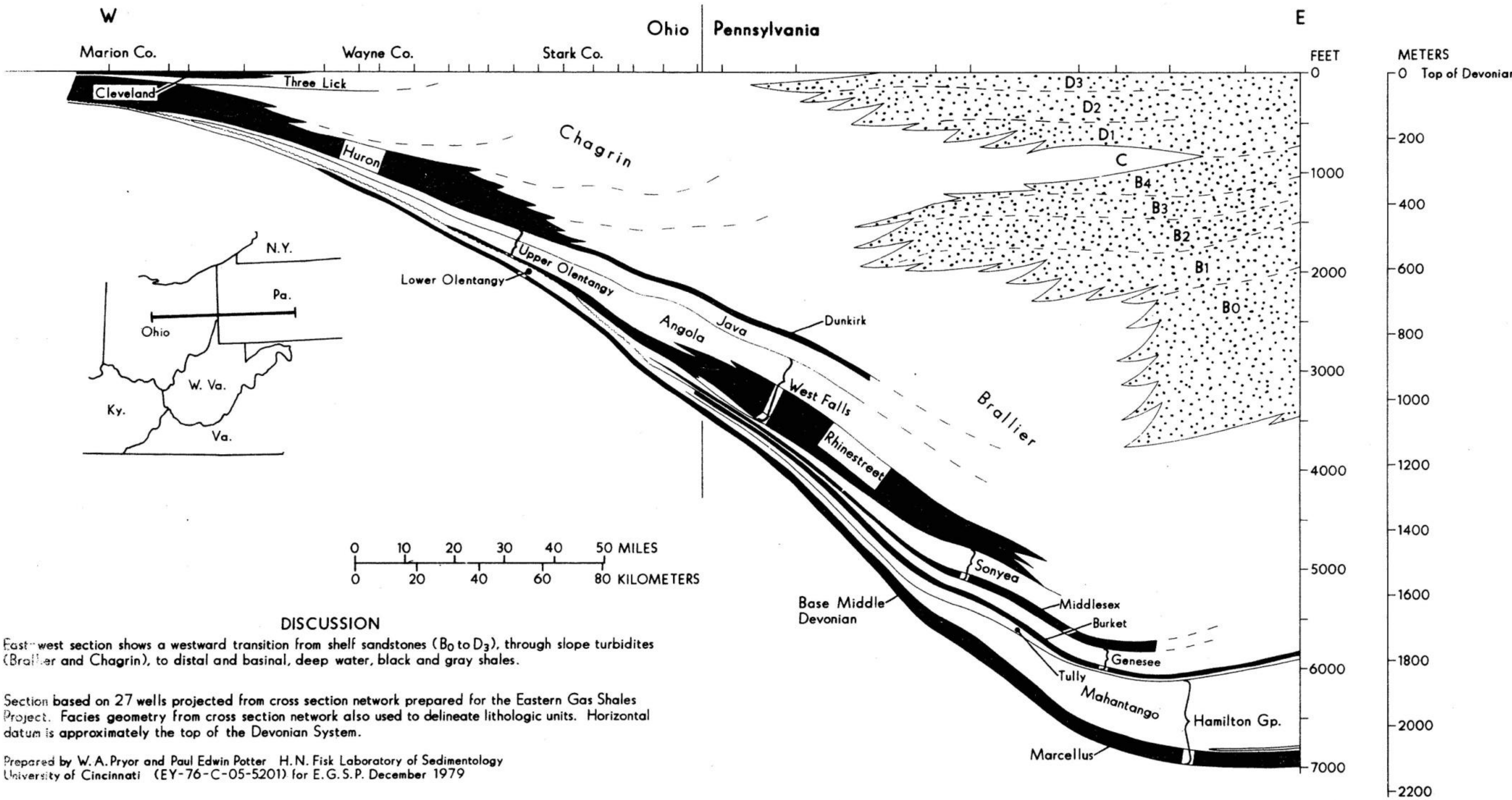
The type locality for the Marcellus Shale is an outcrop on Slate Hill, a mile south of the town of Marcellus, New York, in Onondaga County.

Town named for Marcus Claudius Marcellus (268–208 BC), a famous Roman general and consul.


Superior
Great Lakes
Huron
Michigan
Ontario
Erie
ME
VT
NH
NY
MA
CT
RI
WI
MI
A
A'
PA
NJ
IL
IN
OH
MD
DE
WV
VA
KY
TN
NC
SC
MS
AL
GA
FL
ATLANTIC OCEAN
N
0
300 MILES
0
300 KILOMETERS
EXPLANATION
EXTENT OF DEVONIAN SHALE
MARCELLUS SHALE


MARCELLUS SHALE MAP
Lake Erie
Cleveland
Akron
Columbus
Pittsburgh
Pennsylvania
Allentown
Philadelphia
New Jersey
West Virginia
Maryland
Baltimore
Delaware
Virginia
Richmond
Kentucky

Appalachian Basin Stratigraphy

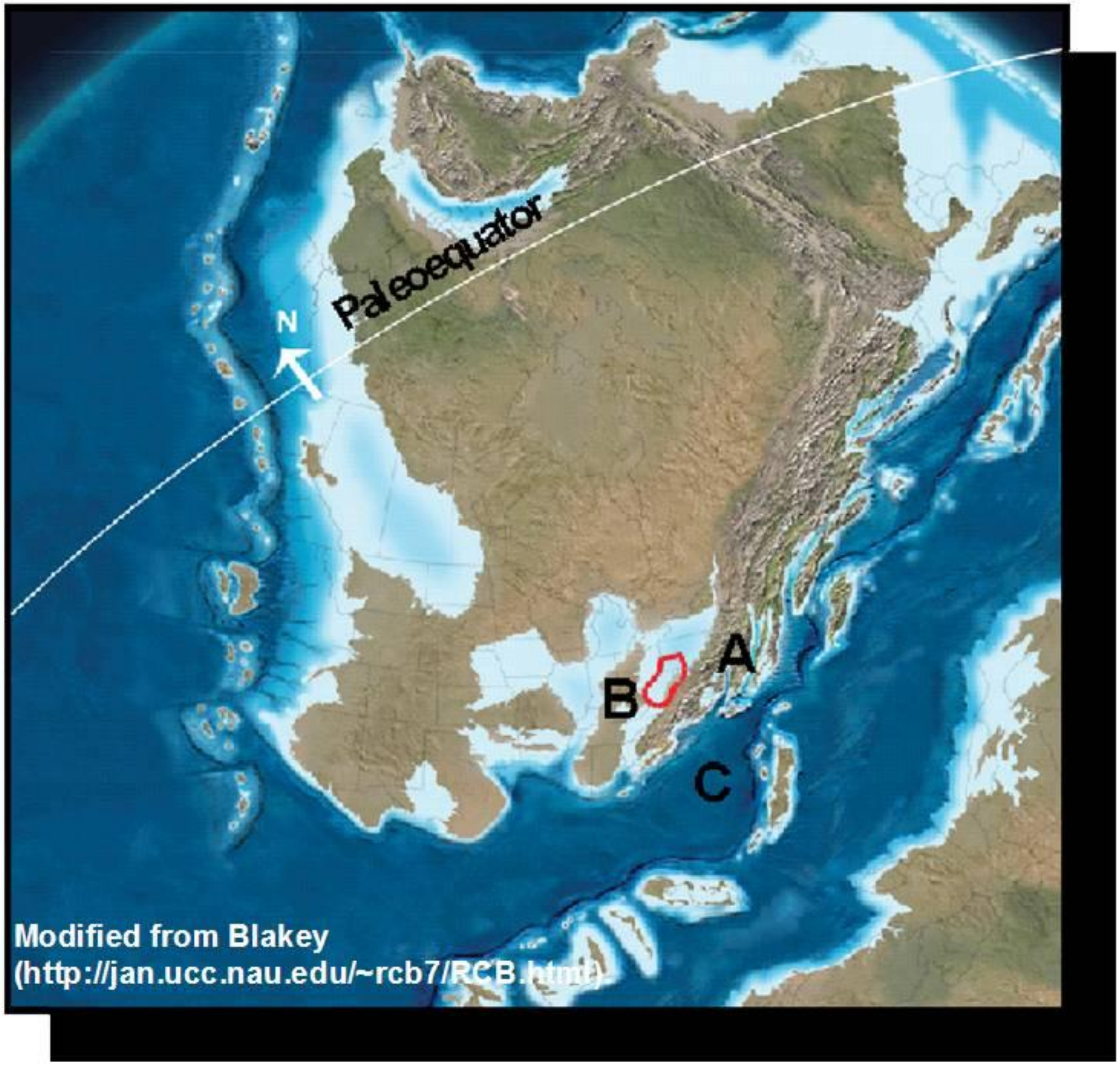


DISCUSSION

East-west section shows a westward transition from shelf sandstones (B_0 to D_3), through slope turbidites (Brallier and Chagrin), to distal and basinal, deep 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. P. December 1979



From Boyce, 2010: Middle Devonian (390 MA)

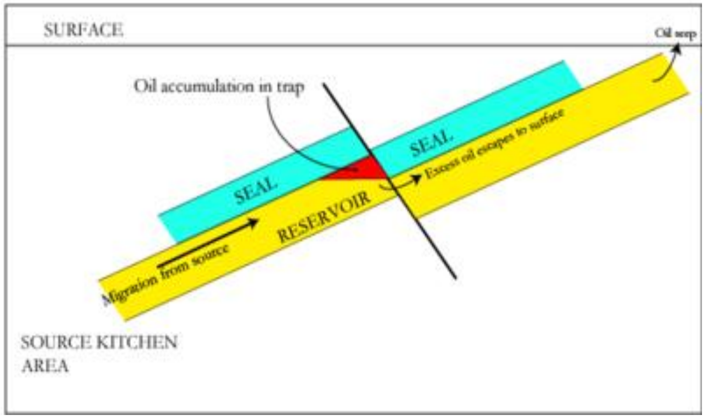

Marcellus Shale in Hanson Quarry, NY
Oatka Creek Member
Cherry Valley LS
Union Springs Member

Basic Petroleum Geology

Conventional Reservoir: concentrated deposit of recoverable oil and/or gas.

NEED:

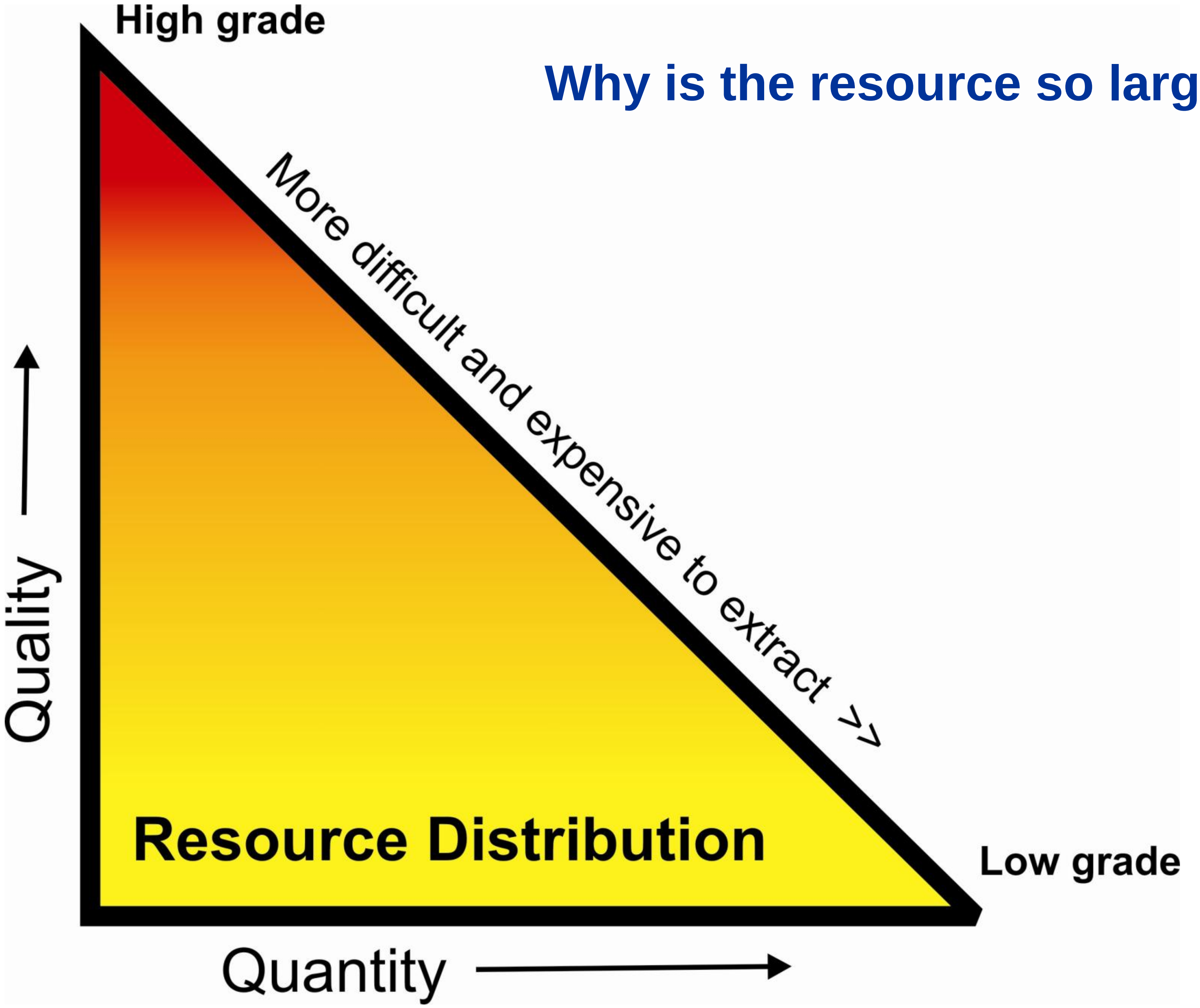
1. Source rock: 1-2% organics (kerogen)
   a. Types I and II kerogen (petroleum + gas)
   b. Type III kerogen (coal + gas)
2. Thermal maturity
3. Reservoir rock
4. Seal and Trap
5. Migration pathway



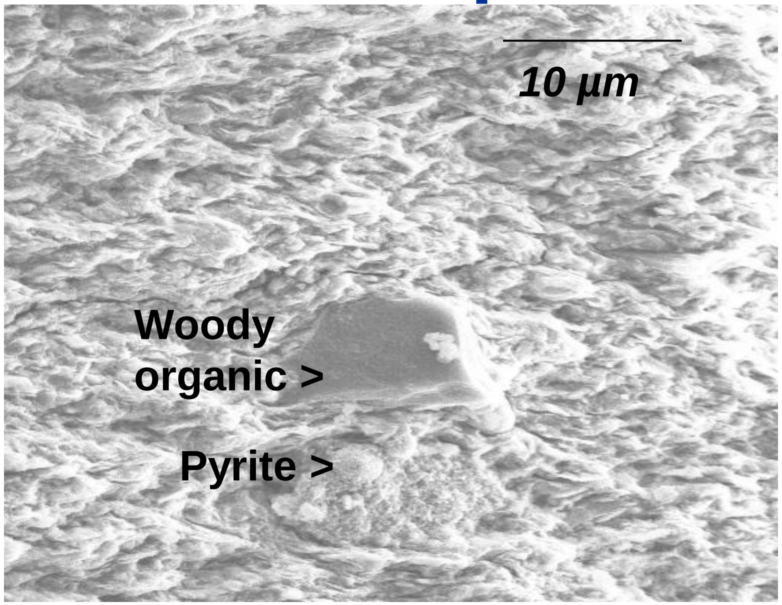
If any one of these is missing, no production.

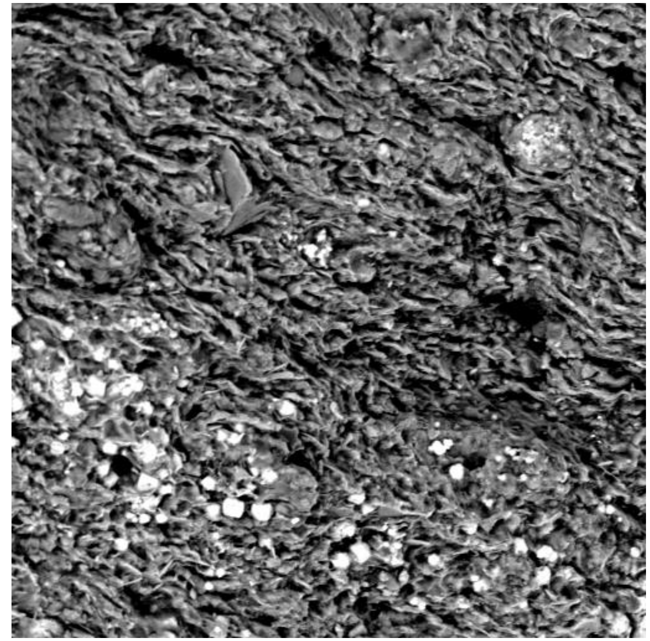
Shale gas: Need only 1 and 2

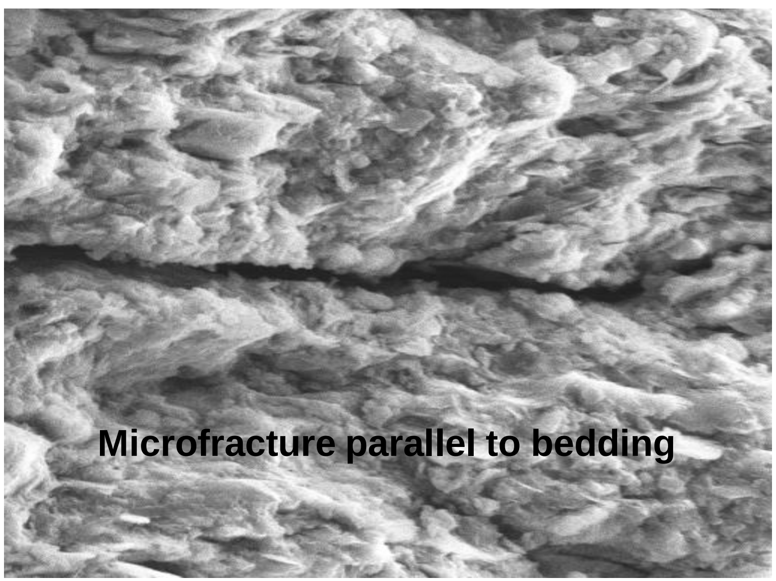
Why is the resource so large?



Microscopic Features in Black Shale

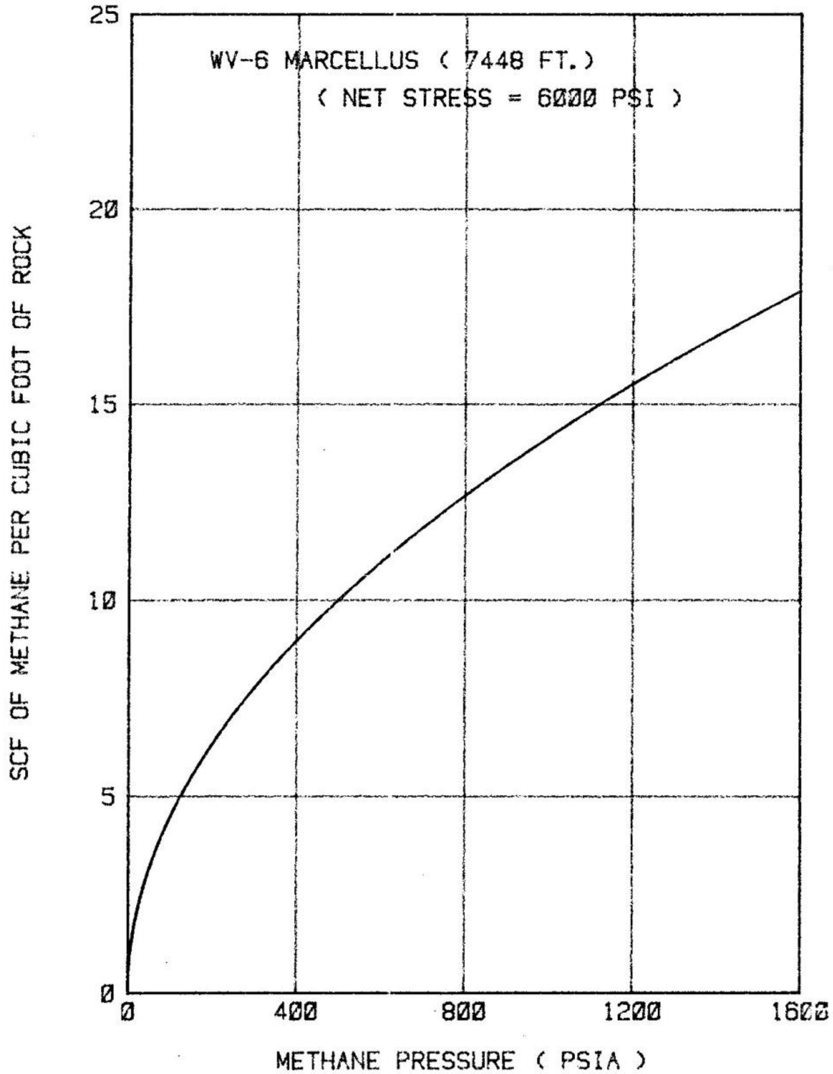


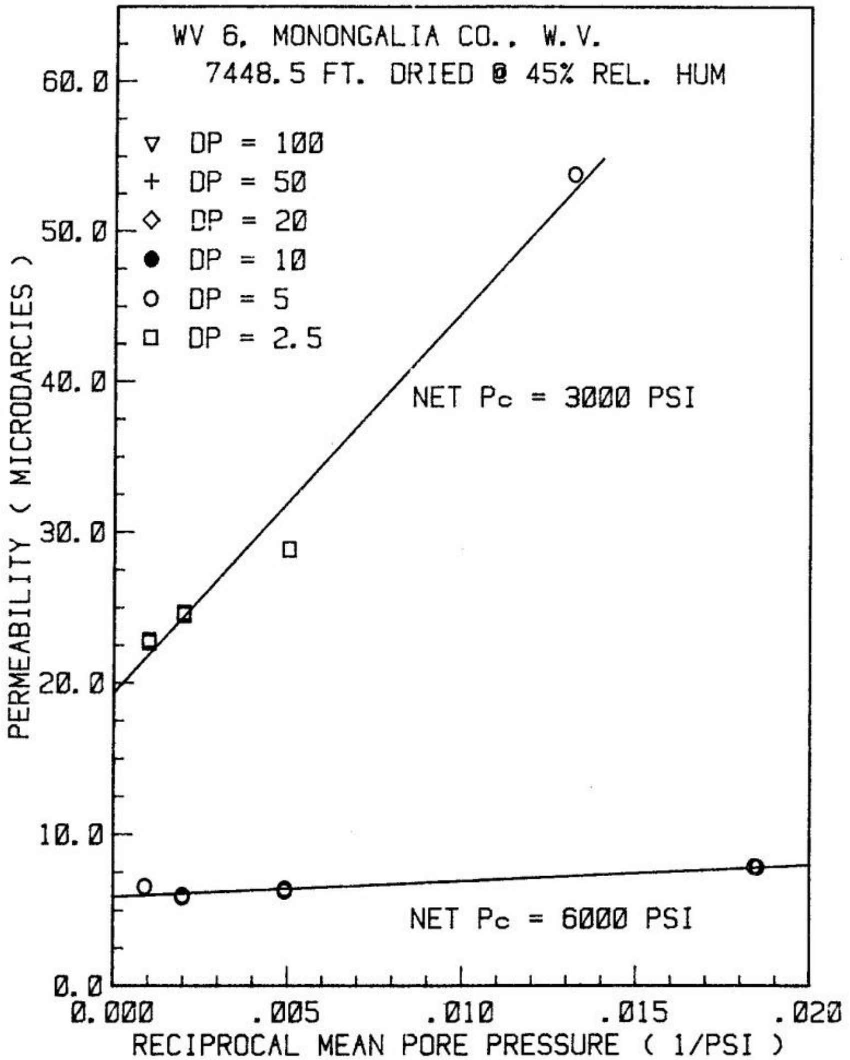




Nanoporosity inside kerogen

Marcellus φ & K Remarkably High





Porosity and Permeability of Eastern Devonian Gas Shale

Daniel J. Soeder, SPE, Inst. of Gas Technology

Summary. High-precision core analysis has been performed on eight Devonian gas shale samples from the Appalachian basin. Seven of the core samples consist of the Upper Devonian Age Huron member of the Ohio shale, six of which came from wells in the Ohio River valley, and the seventh from a well in east-central Kentucky. The eighth core sample consists of Middle Devonian Age Marcellus shale obtained from a well in Morgantown, WV.

The core analysis was originally intended to supply accurate input data for Devonian shale numerical reservoir simulation. Unexpectedly, the work has identified a number of geological factors that influence gas production from organic-rich shales. The presence of petroleum as a mobile liquid phase in the pores of all seven Huron shale samples effectively limits the gas porosity of this formation to less than 0.2%, and gas permeability of the rock matrix is commonly less than 0.1 μd at reservoir stress. The Marcellus shale core, on the other hand, was free of a mobile liquid phase and had a measured gas porosity of approximately 10%, and a surprisingly high permeability of 20 μd. Gas permeability of the Marcellus was highly stress-dependent, however; doubling the net confining stress reduced the permeability by nearly 70%.

The conclusion reached from this study is that the gas productivity potential of Devonian shale in the Appalachian basin is influenced by a wide range of geologic factors. Organic content, thermal maturity, natural fracture spacing, and stratigraphic relationships between gray and black shales all affect gas content and mobility. Understanding these factors can improve the exploration and development of Devonian shale gas.

Introduction

Organic-rich, Devonian-Age shales in the Illinois, Michigan, and Appalachian basins are considered a major potential source of future domestic natural gas by the U.S. government and the gas industry.[1] As such, both the U.S. Department of Energy (DOE) and the Gas Research Inst. (GRI) have been funding research aimed at encouraging better gas recovery from this resource through improvements in recovery technology and increased understanding of where gas is trapped and how gas is transported within the shale formations.

Most of the difficulties with Devonian shale gas production are related to the fact that the matrix permeability of these rocks is very low, and an extensive natural and/or manmade fracture system is required in the reservoir to move economical quantities of gas to a wellbore. Shale wells generally exhibit a fairly rapid initial decline curve as gas is drained from the fracture system, followed by a slow, gradual decline as gas from the matrix moves into the fractures. This type of reservoir results in a well that produces slowly and steadily over long periods. The typical productive life of a shale gas well is about 40 years, although a few wells in the Appalachian basin have been producing for more than 100 years.[1]

The DOE was trying to model gas production from the Devonian shales using complex numerical simulations. The modelers were encountering difficulties in their simulation attempts because of a number of uncertain or unknown shale gas reservoir properties that resulted in inaccurate input parameters for the computer model. The parameters that caused the modelers the greater problems included measurements of shale gas content that varied with stratigraphy and geographic location (for poorly understood reasons), total gas content determinations that contained an unknown component of adsorbed gas, and matrix porosity and permeability values that were very close to the resolution limits of the equipment used to make the measurements. Other properties, such as the nature of shale pore structure and the effect of confining pressure on shale permeability, were unknown.

To address some of these data uncertainties and provide accurate input parameters for the reservoir modelers, the Inst. of Gas Technology (IGT) measured the porosity, permeability, and other properties of a limited number of Devonian shale samples with recently developed, high-precision core-analysis apparatus. It should be emphasized that porosity and permeability are *not* single numbers to be measured and reported for each sample analyzed in the laboratory. Rather, these are coefficients that appear in the differential equations used to calculate fluid content and movement in porous media. For most high-porosity, high-permeability formations, adequate descriptions of well and reservoir performance can be achieved by assuming that these coefficients are constants. This is not a valid assumption for such tight formations as Devonian shale, however, where the small pore sizes affect fluid flow through the rock matrix on a molecular scale.

Core-Analysis Procedure

Between 1976 and 1981, the U.S. government cut and retrieved nearly 17,000 ft [5180 m] of Devonian shale drill core under the Eastern Gas Shale Project (EGSP).[2] This large supply of oriented core provided the raw material for the selection of a limited number of samples to be analyzed in our laboratory.

High-precision core analysis at IGT is performed in a device known as the computer-operated rock analysis laboratory (CORAL). CORAL is capable of measuring actual gas flow rates through rock as low as 10^{-6} std cm^3/s to an accuracy of a few percent, and can measure steady-state gas permeabilities with a resolution of ± 0.2 nd. Other rock properties measured by CORAL include gas porosity under stress with a resolution of about $\pm 2\%$ of the measured value, and PV compressibility. A description of the engineering and operational design of CORAL has been presented by Randolph.[3]

Although CORAL was originally designed to perform high-precision core-analysis measurements on western tight gas sandstones, it soon became apparent that the accuracy and high resolution of this equipment would also have applications to other tight gas formations, such as Devonian shale. In the past, there have been several situations where Devonian shale permeabilities were reported from runs in equipment designed for tight sands.[4,5] In both cases reported, the porosity and permeability values measured were near the resolution limits of the equipment, resulting in a significant degree of uncertainty concerning the accuracy of the data. The approach taken toward the Devonian shale core measurements at IGT was to try to understand how the composition and internal pore structure of the rock control gas flow through the matrix into the fracture system, and thereby define the long-term gas production rates in a wellbore.

Twenty-eight zones of interest were sampled from 13 EGSP cores selected from a list supplied by DOE. Portions of the shale section

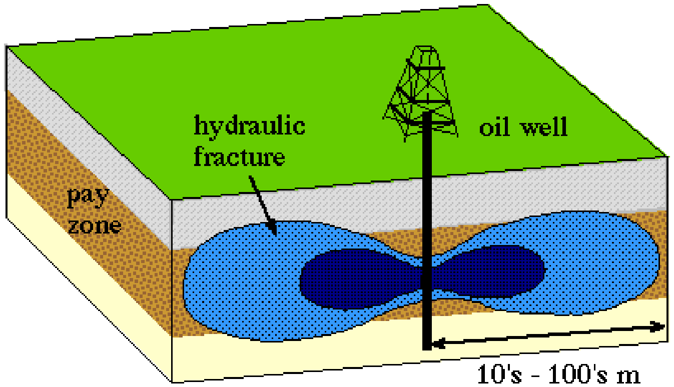
Findings published in March, 1988:

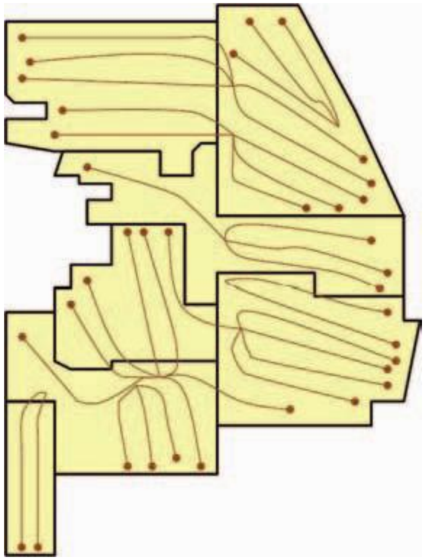
National Petroleum Council had assessed the gas potential of Appalachian Basin shales at 0.1 to 0.6 scf/ft^3 in 1980.

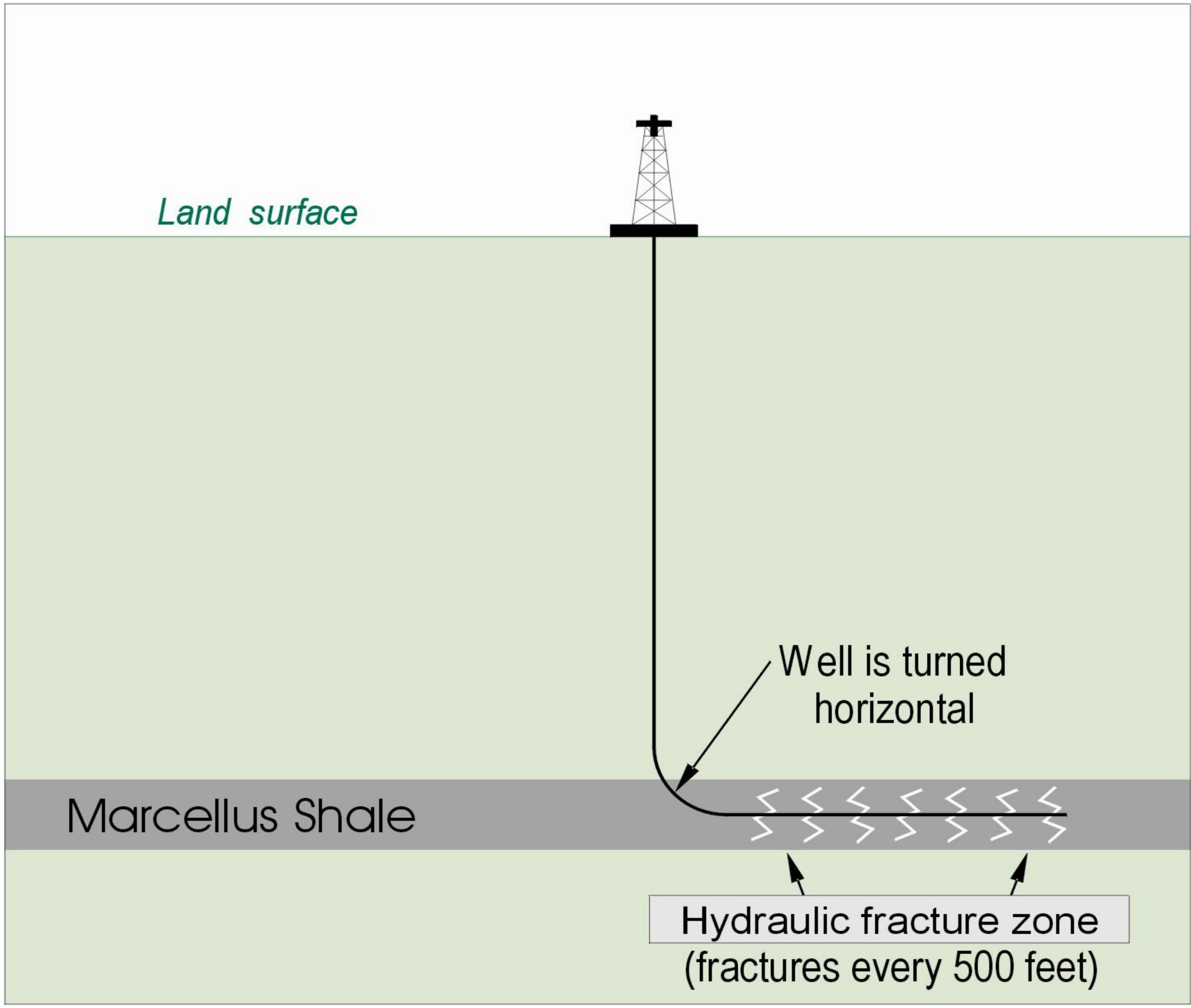
"…the measured initial reservoir pressure of the Marcellus Shale in EGSP Well WV-6 was 3500 psi …(which) results in a potential in-situ gas content of 26.5 scf/ft^3…"

Data showed 44 to 265 times as much gas in shale as NPC estimate.

Vertical versus Horizontal Wells







Mitchell Energy – offshore directional drilling technology applied to Barnett Shale, 1990's
Range Resources – applied "Barnett" completion to Marcellus Shale in 2005

Hydraulic Fracturing

- Hydraulic fracturing for gas and oil has been used since 1949.
- A hydrofrac creates high-permeability pathways into a formation.
- Hydraulic fractures are made by filling the well with fluid and then increasing the pressure until the rock strength is exceeded.
- Fluid and proppant are pumped out into the fractures; the proppant stays behind and keeps the fractures open after pressure is released.

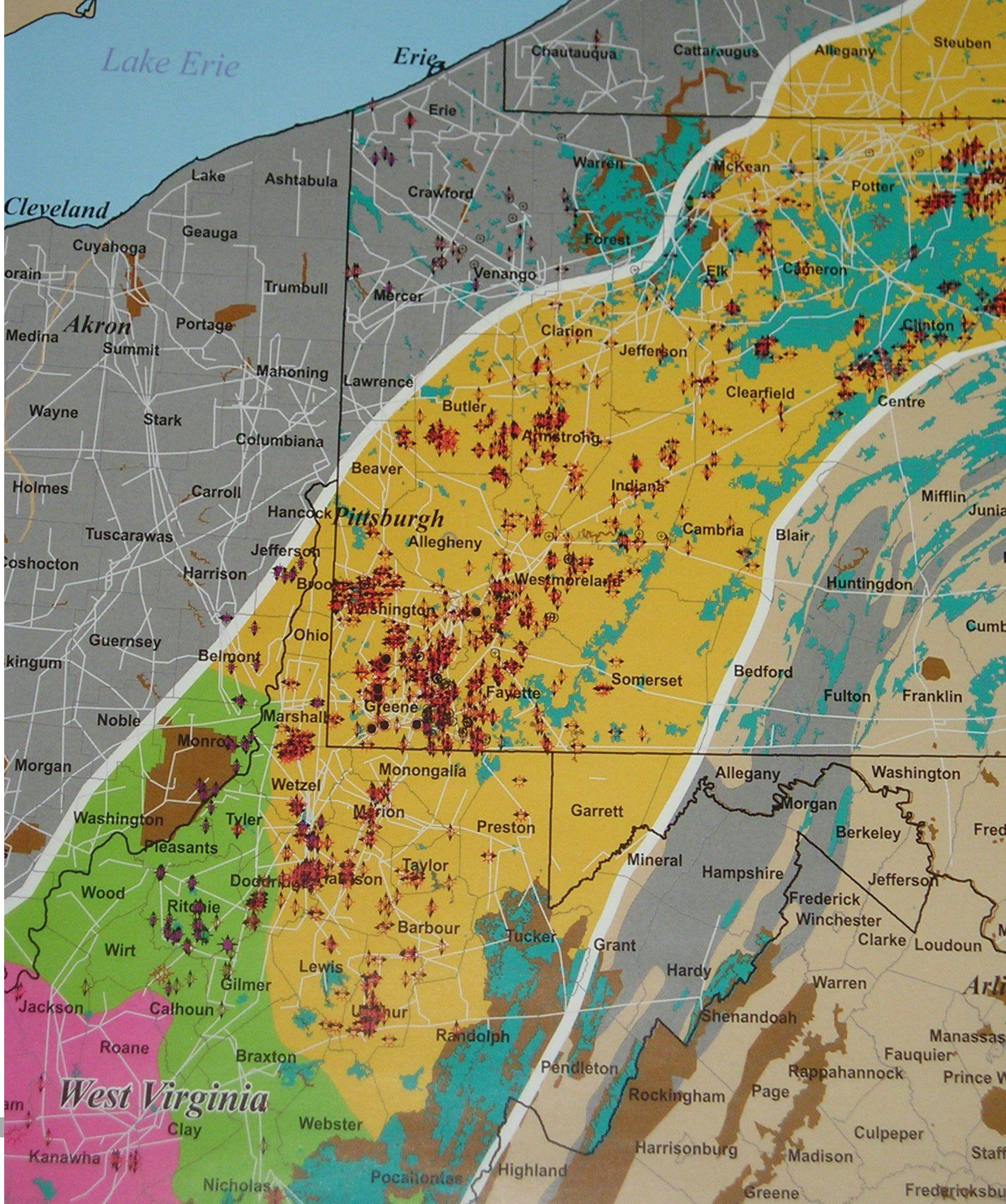
Marcellus Gas Production

- Range Resources, Renz #1 well, October 2004, Washington County, PA; vertical, poor return from Trenton – Black River Limestone, tested Marcellus Shale; IP 300 MCFD
- Range Resources, Gulla #9 well, 2005; “Barnett completion” drilled horizontally, IP 4 MMCFD
- November, 2008: Engelder estimated recoverable gas from the Marcellus at 363 TCF; since revised upward.
- With the addition of shale gas, some industry executives claim the total energy value of domestic natural gas is twice the amount of oil in Saudi Arabia.

Hot spots in the southern Marcellus Play: SW corner of Pennsylvania, north-central WV and the northern panhandle, small piece of southeastern Ohio

A “play” in oil and gas is defined as geologically similar prospects with a similar source, reservoir, and trap controls on hydrocarbon migration, accumulation, and storage. (Patchen, 1996)

In plain English: Find out where other people are successfully drilling, and go drill there.



NETL Characterization Research

- Which properties control the amount of gas in shale?
- How do these properties vary with geology, and are they predictable?
- Can the resource estimates of recoverable shale gas be better constrained?

Tools:

Rock Petrography Lab (NETL-MGN)

- Standard petrographic microscopes
- Source Rock Analyzer (RockEval)
- Scanning electron microscopy with ion polisher (NETL and LBNL)

Precision Petrophysical Analysis Lab (WVU)

- Porosity and permeability of shale
- Behavior under in situ pressures

Rock and brine chemical analyses

- Separation Design Group, Waynesburg PA
- Geochemical expertise at WVU Department of Geography & Geology

X-ray Computerized Axial Tomography (CAT Scan)

- Current Medical C-T scanner: 250 micron resolution
- New Industrial C-T scanner in Morgantown: 5 micron resolution
- New Micro-CT scanner in Pittsburgh: 1 micron resolution; testing on shale

Geologic Framework Model (EarthVision)

Carbon Sequestration Lab (NETL-PGH)

- Pore size distribution
- Behavior of different gases in pore system

Resource Characterization Summary

- Goal: better understand links between Marcellus Shale geology and gas productivity.
- Outcome: improve gas shale resource predictability.
- Applications: gas resources in other shales; behavior of shale with other gases.
- Benefits: policymakers, small drillers, regulators and the general public.

Environmental Issues - Marcellus Shale

DOE goal: Encourage the production of domestic energy resources in an environmentally-responsible manner.

Three problems with shale gas:

Not all of the potential environmental impacts are known

- What are the long-term and cumulative effects on the landscape, terrestrial and aquatic ecosystems, water resources, and air quality?
- Which environmental impacts are more important than others?

Some known environmental impacts are not regulated

- Surface water withdrawals are not regulated in West Virginia
- Brine discharge regulations in Pennsylvania were lax until recently

Existing regulations are not fully enforced.

- West Virginia has 17 inspectors for hundreds of oil and gas wells
- Pennsylvania has lost many personnel from DEP and DCNR to industry

Models for approaches to regulation of gas production:

- Drug company model: prove the product is safe before proceeding
- Automobile company model: proceed with best design; fix any problems

NETL Environmental Objectives

Programmatic Goals

- Investigate the short and long term environmental impacts of drilling for gas in the Marcellus Shale.
- Obtain data to help regulators assess environmental indicators.

Project Objectives

- Measure baseline environmental parameters prior to drilling.
- Monitor air, water, habitat, soil, landscape and ecological impacts during drilling and production phases, and for some time afterward.
- Investigate landscape effects, resettlement, succession and edge effects.
- Anticipated outcomes:
  - Improve BMPs for shale gas production to reduce environmental impacts.
  - Define environmental indicators for focused regulatory monitoring.
  - Publish data to create a more informed environmental debate.

Short and Long Term Issues

Short Term (construction)

- Water withdrawals
- Flowback disposal
- Light and noise
- Drilling ponds – wildlife
- Air quality
- Seismic activity

Long Term (occupancy)

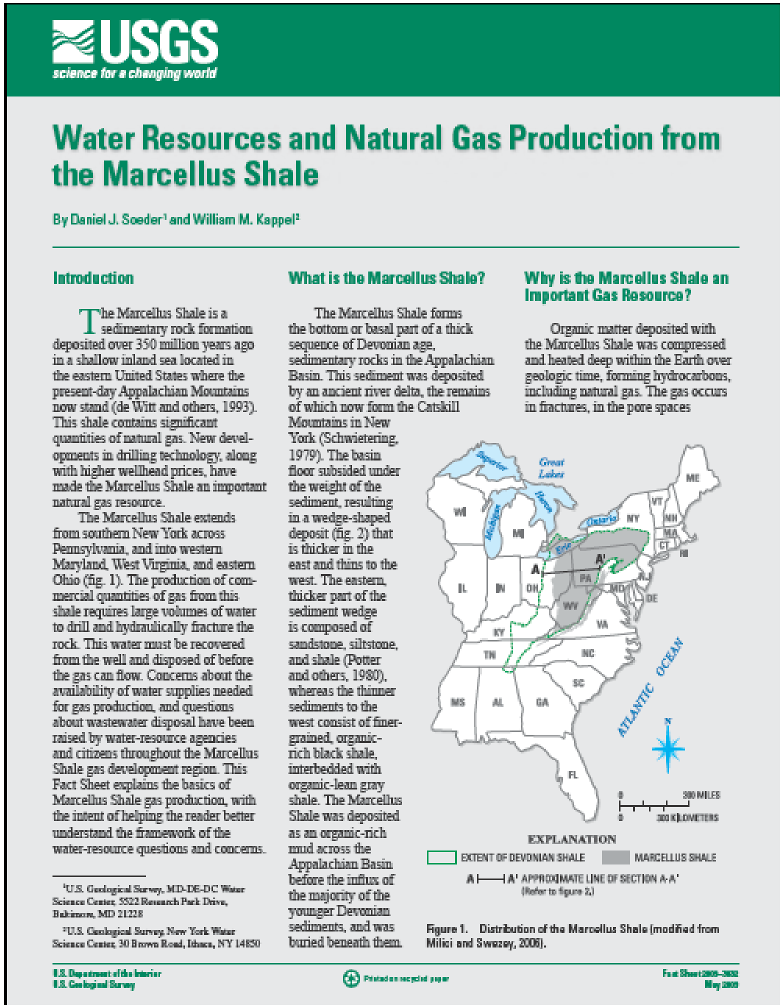
- Pad on landscape
- GW contamination
- Habitat fragmentation
- Solids disposal on site
- Invasive species
- Edge effects; succession

Impacts to Landscapes

- The 3 to 4 million gallons of water needed to fracture a well must be transported to the drill site.
- Proppant (sand) and chemical additives must also be brought in.
- Many drill pads are only accessible by unimproved rural roads.
- Small watersheds and headwater streams may be at risk from erosion, sedimentation and spills.
- Invasive species might hitchhike with the water and equipment.
- Impoundments can leak into streams and groundwater.

145 pieces of equipment on 5-acre drill pad for Marcellus Shale hydrofrac

Drilling and Water Resources



USGS
science for a changing world

Water Resources and Natural Gas Production from the Marcellus Shale

By Daniel J. Soeder[1] and William M. Kappel[2]

Introduction

The Marcellus Shale is a sedimentary rock formation deposited over 350 million years ago in a shallow inland sea located in the eastern United States where the present-day Appalachian Mountains now stand (de Witt and others, 1993). This shale contains significant quantities of natural gas. New developments in drilling technology, along with higher wellhead prices, have made the Marcellus Shale an important natural gas resource.

The Marcellus Shale extends from southern New York across Pennsylvania, and into western Maryland, West Virginia, and eastern Ohio (fig. 1). The production of commercial quantities of gas from this shale requires large volumes of water to drill and hydraulically fracture the rock. This water must be recovered from the well and disposed of before the gas can flow. Concerns about the availability of water supplies needed for gas production, and questions about wastewater disposal have been raised by water-resource agencies and citizens throughout the Marcellus Shale gas development region. This Fact Sheet explains the basics of Marcellus Shale gas production, with the intent of helping the reader better understand the framework of the water-resource questions and concerns.

[1] U.S. Geological Survey, MD-DE-DC Water Science Center, 5522 Research Park Drive, Baltimore, MD 21228

[2] U.S. Geological Survey, New York Water Science Center, 30 Brown Road, Ithaca, NY 14850

What is the Marcellus Shale?

The Marcellus Shale forms the bottom or basal part of a thick sequence of Devonian age, sedimentary rocks in the Appalachian Basin. This sediment was deposited by an ancient river delta, the remains of which now form the Catskill Mountains in New York (Schwietering, 1979). The basin floor subsided under the weight of the sediment, resulting in a wedge-shaped deposit (fig. 2) that is thicker in the east and thins to the west. The eastern, thicker part of the sediment wedge is composed of sandstone, siltstone, and shale (Potter and others, 1980), whereas the thinner sediments to the west consist of finer-grained, organic-rich black shale, interbedded with organic-lean gray shale. The Marcellus Shale was deposited as an organic-rich mud across the Appalachian Basin before the influx of the majority of the younger Devonian sediments, and was buried beneath them.

Why is the Marcellus Shale an Important Gas Resource?

Organic matter deposited with the Marcellus Shale was compressed and heated deep within the Earth over geologic time, forming hydrocarbons, including natural gas. The gas occurs in fractures, in the pore spaces

Figure 1. Distribution of the Marcellus Shale (modified from Milici and Swezey, 2006).

U.S. Department of the Interior
U.S. Geological Survey

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Fact Sheet 2009–3032
May 2009

- Each stage of a hydrofrac uses 300,000 to 500,000 gallons of water, up to 3 to 4 million gallons per well.
- Water resource agencies (SRBC) allow frac water withdrawals at high flows under an industrial water use permit. Not all locations require permits (WV).
- Non-permit withdrawals: streamflow? Flow bypass requirements? Other withdrawals from same stream?
- Proper disposal of flowback fluids
  - Wastewater treatment - TDS
  - Reinjection
  - Recycling

Flowback Fluid

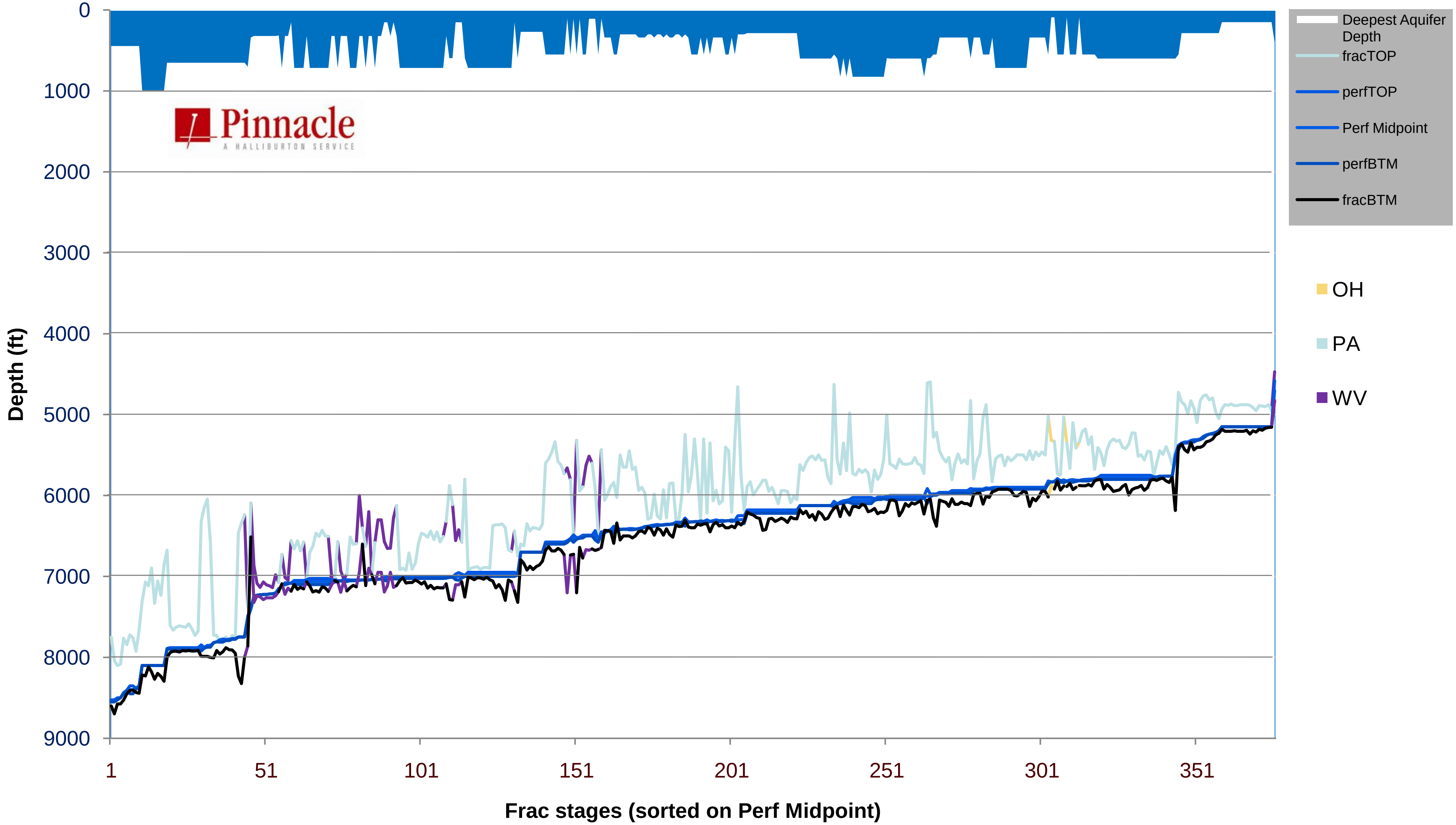
- Hydrofrac fluid is in contact with the rock; about 25% is recovered after the frac and pumped back out.
- Porewater in the Marcellus Shale is very salty with high TDS.
  - Concentrated brine, not dissolved solids from pore minerals.
  - Flowback starts out fresh, and increases in TDS during recovery.
- Source of the brine, and relationship between brine chemistry and bulk rock geochemistry of shale are not well understood.
- Marcellus Shale coalition funded water-quality analysis of fluids recovered in time series from 19 shale wells:
  - chloride at more than 100 g/L (NaCl, MgCl)
  - TDS of almost 200 g/L - about 6X seawater
  - Barium and strontium are unusually high – source unknown
  - Metals present at hundreds of mg/L
  - Composition "similar" to other Appalachian brines, but concentrations higher.
  - No data on radioactivity or "NORM" because of high TDS

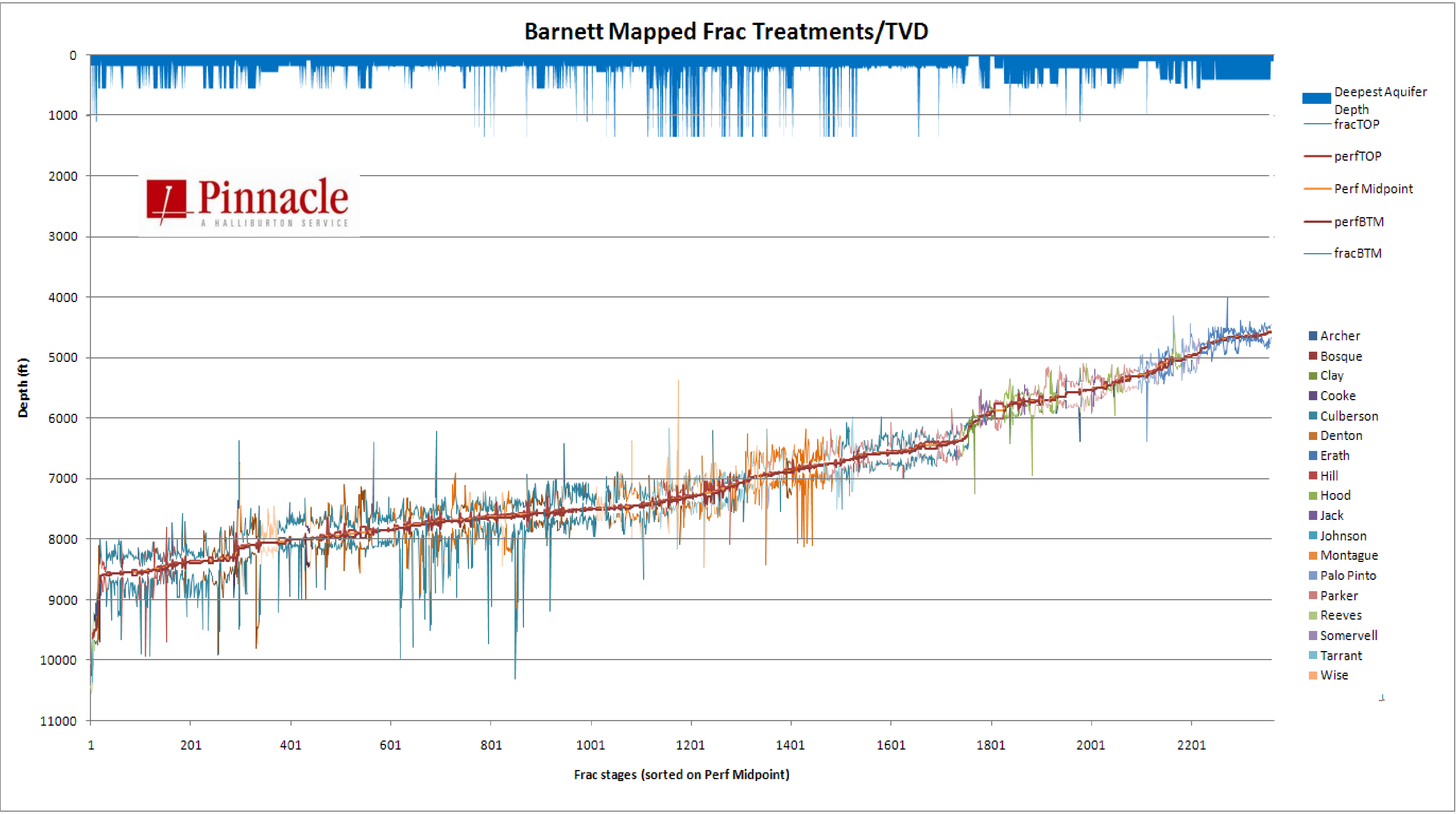
Groundwater Contamination

- Can hydraulic fracturing directly contaminate aquifers?
- Hydraulic conductivity, flow gradients, the depth of the target formation, and GWTT suggest that such contamination is unlikely.
- No definitive evidence of direct water contamination from deep hydraulic fracturing has been documented.
- GW contamination from surface spills and leaky impoundments is a far greater risk.
- A hydraulic fracturing tracer test with a drillback experiment to sample aquifers would provide a definitive answer.

Hydraulic Fracture Heights and Aquifers

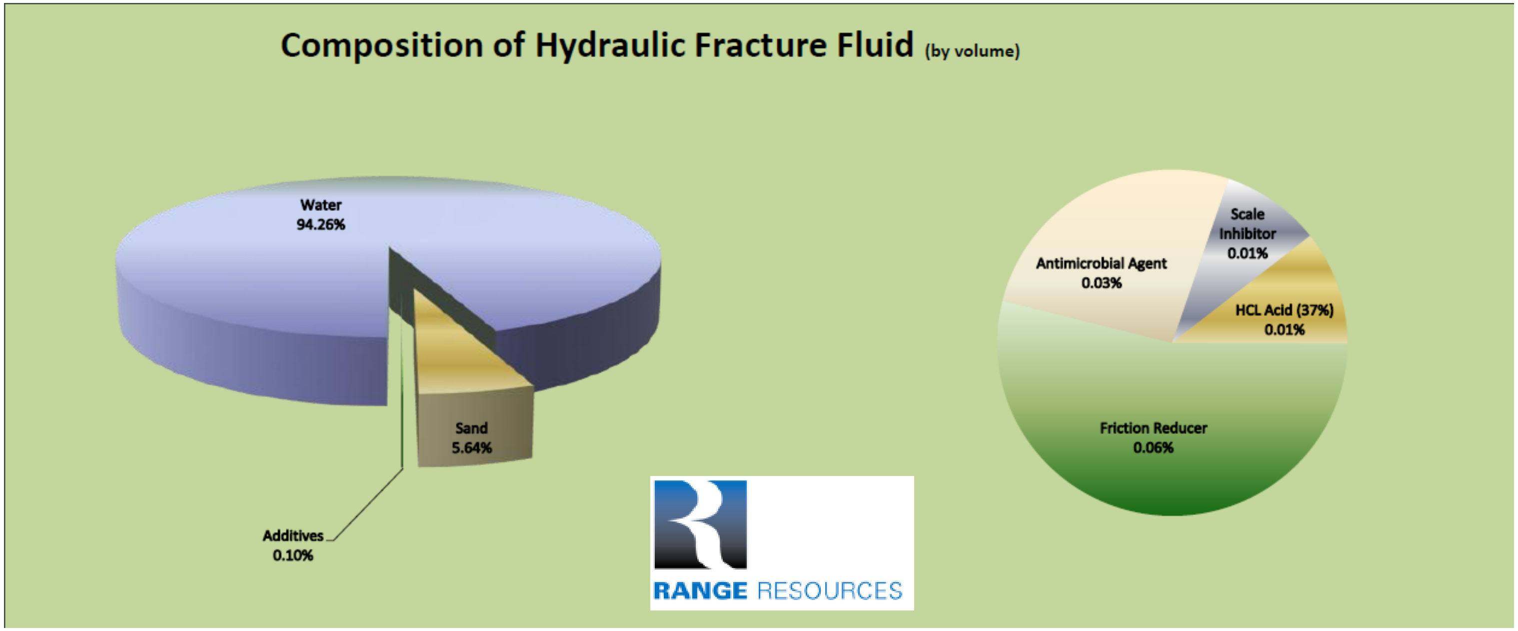
Marcellus Mapped Frac Treatments





Reference: Fisher, Kevin, 2010, Data confirm safety of well fracturing, The American Oil and Gas Reporter, July 2010, www.aogr.com

Range Resources Completion Report



Sierzega Unit #8H | **Completion Date: October 19 -23, 2010**
Well API: 37-125-23937 | **Township: Amwell**

% Composition of Hydraulic Fracture Fluid (by volume)						
Product Name	**Additive**	**Purpose**	**Use and Dillution**	**Volume**	**Overall %**	**Common Uses**
Water	Carrier Fluid	Creates fracture network in shale and carry proppant to the formation	Primary constituent	3,442,079 gal	94.26%	Water is the most abundant molecule on the Earth's surface
Sand	Sand	Allows fractures to remain open so gas can escape	Second most common constituent, making up almost 6% of the fluid	205,929 gal	5.64%	Drinking water filtration, play sand
FRW-200 and FRW-300	Friction Reducer	Reduces friction between fluid and pipe	Diluted at one-half gallon per 1,000 gallons of water	2,033 gal	0.056%	Water treatment; soil conditioner; some children's toys
MC B-8642/Bioban	Antimicrobial Agent	Eliminates bacteria in the water that produce corrosive byproducts	Diluted at one-half gallon per 1,000 gallons of water	993 gal	0.027%	Water treatment, disinfectant; sterilize medical and dental equipment and surfaces
MX 588-2	Scale Inhibitor	Prevents scaling in pipe	Diluted at one-tenth gallon per 1,000 gallons of water	346 gal	0.009%	Water treatment, household cleaners, de-icing agent
HCL Acid	Perf Clean-Up	Dissolves cement and minerals to help initiate fractures	139 gallons per stage (non-diluted chemicals)	402 gal	0.011%	Swimming pool and household cleaner

Surface Leaks and Spills

- Much greater threat to groundwater and surface water contamination: concentration and gravity.
- Spilled hydraulic fracture chemicals may be consumed by animals with fatal results.
- Monitoring of groundwater downgradient of pad, and stream monitoring at the mouth of small watersheds could detect chemicals.

DATA NEEDS:

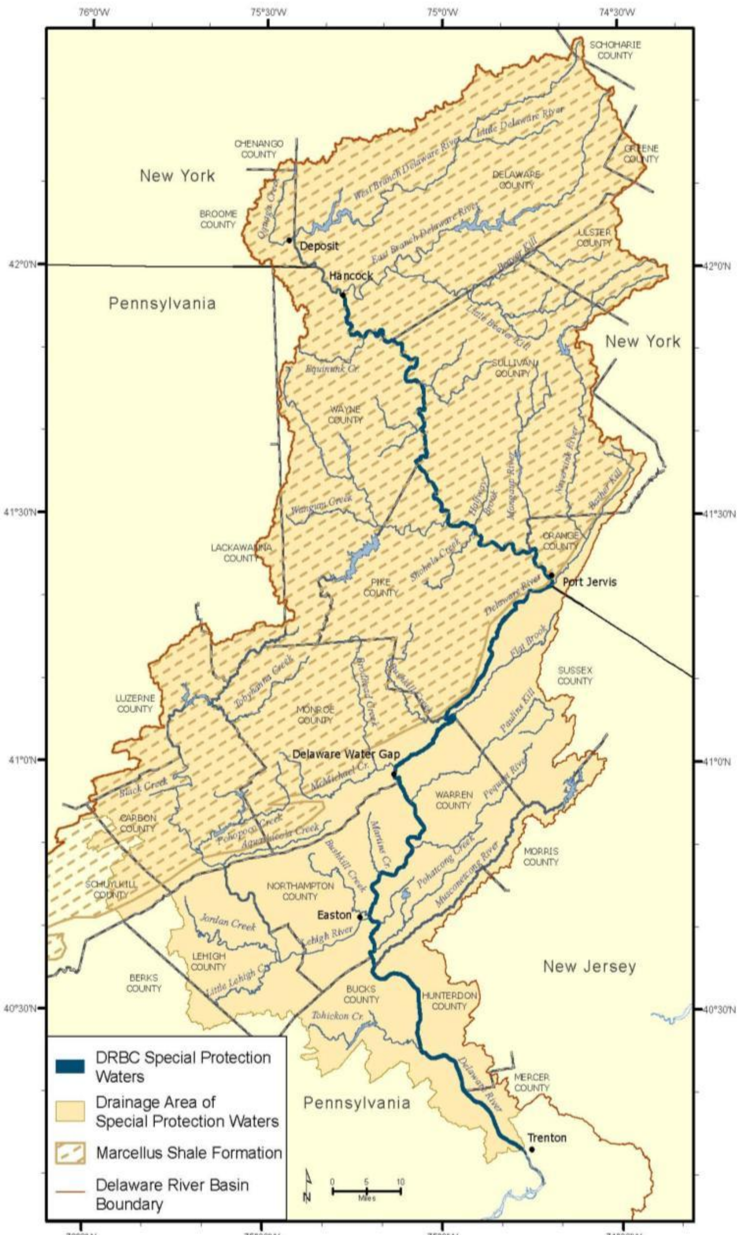
What steps can be taken to protect the environment from chemicals? (closed loop, dikes, berms, trenches, fences, etc.)

Foolproof leak detection and warning?

Less toxic substitutes: ozone for biocide

Can volume of chemicals on the pad be reduced? (premixing, JIT delivery, etc.)

Drinking Water Contamination



- Many people are concerned that Marcellus Shale drilling is a threat to their drinking water supply (not just New York City).
- Cumulative effects of drilling might degrade a water supply watershed.
- USEPA (Ada, OK lab) is investigating possible links between hydrofracs and drinking water contamination.
  - Public input gathered in 2010
  - Technical expert workshops scheduled for spring 2011
- Could a monitoring program on tributaries and groundwater provide an early warning for spills?

Stray Gas

- Media reports suggest methane in water wells is sourced from nearby Marcellus Shale production.
- Other possible sources for methane are biogenic gas in aquifer, shallow coal, or from other shales above Marcellus in an uncased borehole. Difficult to trace.

DATA NEEDS:

Documentation of possible methane in the well before the arrival of the drill rig.

Potential for mobilization of pre-existing gas in the aquifer by vibrations from the drilling activity.

Define the migration path for gas behind a casing to get into an aquifer and then to a water well.

Investigate the configuration of wells and aquifers from these incidents

A precise isotopic method or tracer is needed to determine the origin of the gas.

Radioactivity and Metals

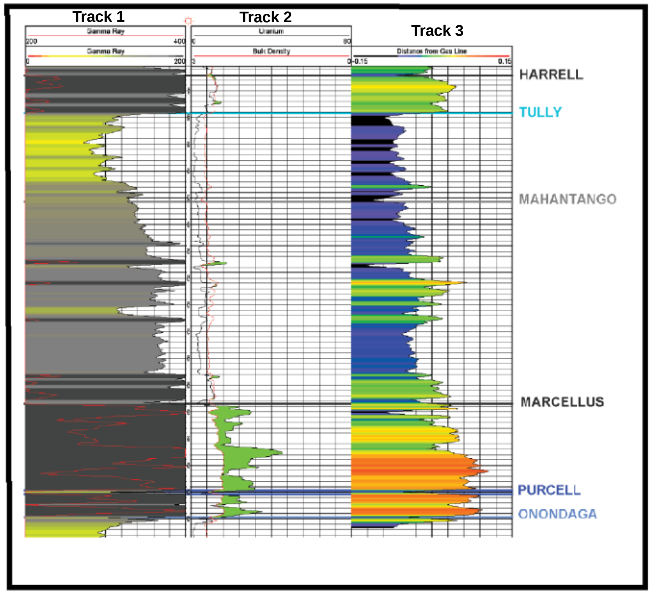
- Organic matter in black shale has an affinity for radionuclides.
- Target horizons in the shales have high gamma log counts – typically above 290 API units.
- Other metals are also a concern: As, Ba, Cd, Co, Cr, Cu, Li, Mn, Mo, Ni, Pb, Sn, Sr, V, Zn, and Zr measured in Marcellus above MRL
- A leaching study of drill cuttings seeks to define the potential scope of this issue.
- Funding is uncertain.

Black shale was deposited in anoxic conditions.

Heavy metals in the shale have been in a reduced state for hundreds of millions of years.

Hundreds of tons of drill cuttings from the black shale are exposed to oxygen and rain water.

Oxidized forms of metals are usually much more soluble in water.



From Boyce, 2010

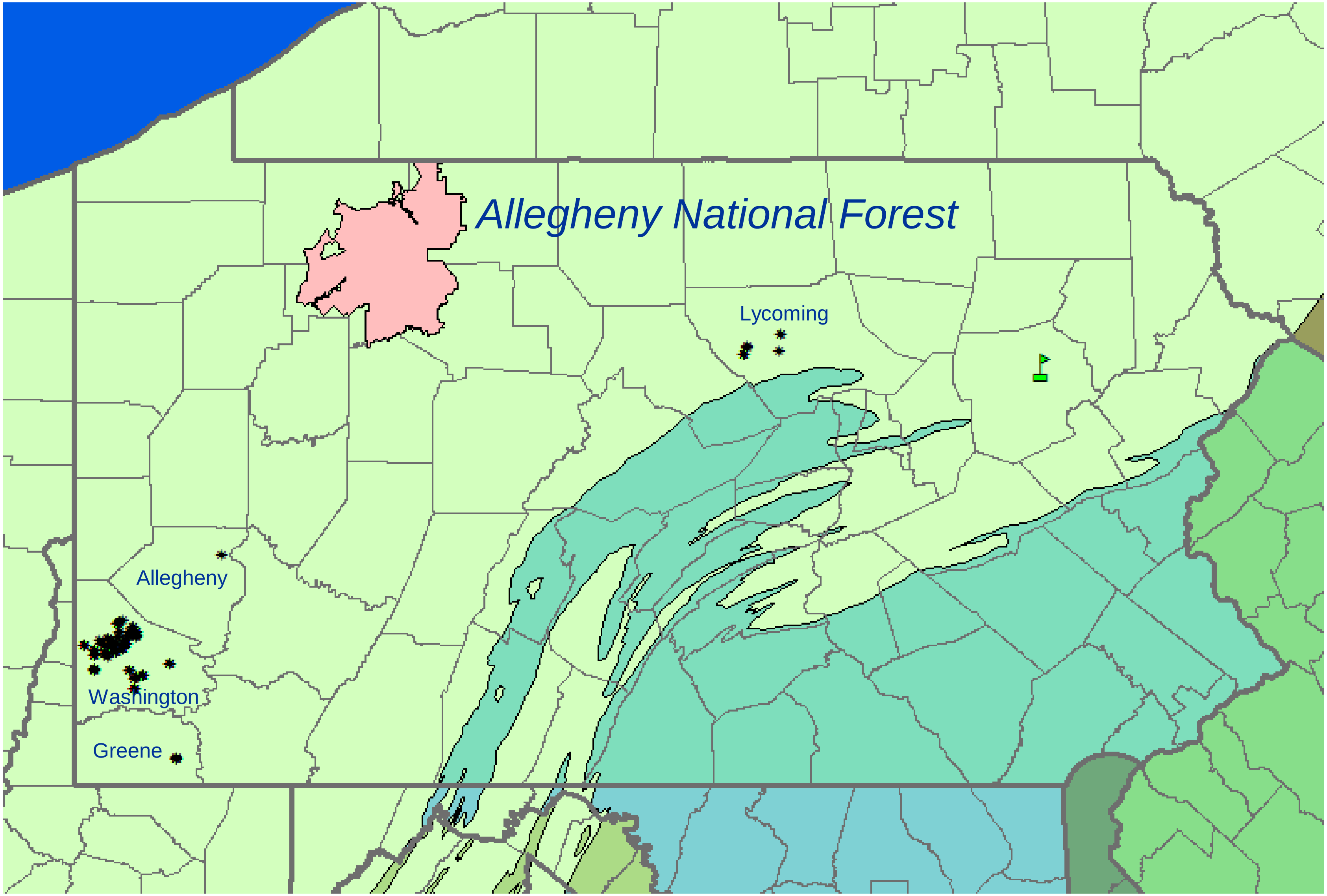
Existing Stream & Groundwater Contaminants

- BTEX: Benzene, toluene, ethylbenzene, xylenes: the water soluble components of gasoline, commonly sourced from leaking underground storage tanks or surface spills.
- DNAPL & LNAPL: non-aqueous phase liquids (jet fuel, diesel)
- Endocrine Disruptors: external compounds that interfere with or mimic natural hormones in the body (EPA, 1997)
  - Sources: pesticides (atrazine, carbaryl), industrial chemicals (phenols, PCBs), plastics (phthalates), fire-resistant fabrics, detergents, household chemicals, pharmaceuticals, and synthetic hormones
  - Common transmission route: Municipal sewage via wastewater treatment plant effluent (USGS). Please don't flush old medicines!
  - Effects: intersex fish: Potomac River, Minnesota lakes
- Nitrates: plant fertilizers, sourced from agricultural operations
- Pesticides: herbicides and insecticides from agriculture operations
- Heavy metals: commonly sourced from mining operations
- Chlorinated solvents: engine degreasers, coolant fluids
- Methane and CO_2 gas: from natural attenuation of organics

Environmental Site Assessment

- Interagency meeting in Harrisburg in June 2010, followed by a meeting with Range Resources.
- Range offered DOE several future site locations for monitoring.
- NETL asked the other agencies from the Harrisburg meeting for suggestions on what to monitor.
  - Six federal agencies: USGS, USFWS, USACE, USFS, NPS, DOE
  - Three river basin commissions: Delaware, Susquehanna, Ohio
  - Four state governments: NY, PA, WV, MD
- About 150 individual suggestions in total were received.
- Suggestions were compiled into a large spreadsheet, duplicates combined, suggestions categorized and passed back to Range.
- Range offered Pennsylvania locations in Washington and Lycoming Counties.
- USEPA is interested in collecting data from these sites and collaborating on their drinking water study.
- DOE program funding is uncertain – some monitoring will be done.

Baseline Monitoring Sites



Category	Parameters to Monitor	before	during	after
Air	Measure methane, CO2, dust, fumes, ozone	x	x	x
Drilling	Impacts of noise and lights on wildlife		x	
Drilling	Monitor wildlife use of drilling ponds as a water source		x	x
Drilling	Collect fluid and gas samples during drilling		x	
Drilling	Seismic monitoring of hydrofrac		x	
Drilling	Assess integrity of well and casing		x	x
Ecology	Assessment of land and aquatic species assemblage	x		x
Ecology	Invasive species assessment	x		x
Ecology	Rare, threatened or endangered (RTE) species	x		x
Habitat	Effects of cleared pad on habitat/edge effects	x	x	x
Habitat	Resettlement of area afterward; succession		x	x
Landscape	Monitor sediment, erosion and topography changes	x	x	x
Site char	Land use, geology, topography, hydrogeologic setting, etc.	x		
Social	Property values, land access, timber, farming, etc	x		x
Soil	Road/pad impacts on soil compaction, infiltration, etc.	x		x
Water	Establish surface water flow monitoring network	x	x	x
Water	Establish groundwater monitoring network: existing/new wells	x	x	x
Water	Establish water quality monitoring sites	x	x	x

NETL SCNGO Environmental Programs

Water Management

- Comprehensive Lifecycle Planning and Management System for Addressing Water Issues Associated With Shale Gas Development in New York, Pennsylvania and West Virginia-*Arthur Langhus Layne LLC*
- Integration of Water Resource Models with Fayetteville Shale Decision and Support Systems-*University of Arkansas*
- Sustainable Management of Flowback Water during Hydraulic Fracturing of Marcellus Shale for Natural Gas Production-*University of Pittsburgh*
- Zero Discharge Water Management for Horizontal Shale Gas Well Development-*West Virginia University*
- Produced Water Treatment Catalog and Decision Tool-*Arthur Langhus Layne LLC*

Frac Flowback and Produced Water

- Cost Effective Recovery of Low-TDS Frac Flowback Water for Re-Use-*GE Global Research*
- Pilot Testing: Pretreatment Options to Allow Re-Use of Frac Flowback and Produced Brine for Gas Shale Resource Development-*Texas A&M University*
- An Integrated Water Treatment Technology Solution for Sustainable Water Resource Management in the Marcellus Shale-*Altela, Inc.*

EPAct Program - External

- Barnett and Appalachian Shale Water Management and Reuse Technologies - *Gas Technology Institute*
- Pretreatment Processing for Salt By-Product Recovery- *GE Global Research*
- An Integrated Framework for the Treatment and Management of Produced Water - *Colorado School of Mines*

NETL-ORD Environmental Research

Characterization of Marcellus Flowback/Produced Waters

- Inorganics
- Organic Components
- Isotopic Characterization
  - Pitt: Source brines
  - WVU: Stray gas

Microbial Ecology of Flowback/PW pits

- Genome Classification
- Microbiological Transformations during On-Site Storage

Simulated Weathering of Drill Cuttings

- Inorganics, including sulfides
- NORM
- Funding for lab uncertain
- Bulk Rock Geochemistry
  - Pitt
  - WVU

Monitoring of Air Emissions

- Mobile Air Monitoring Laboratory
  - Allegheny National Forest
  - Washington County, PA (Range Resources)

Ecological Impacts of Access Roads and Drill Pads

- Better Road Design Criteria (PSU-Dirt and Gravel Roads Program)
- Impact on Sensitive Bird Species (WVU)
- Impact on Streams and Aquatic Life (Clarion University-macroinvertebrate surveys; USGS- stream sedimentation)

Hydraulic Fracture Tracer Test and Drillback Field Experiment

- Planning stage only - in cooperation with USEPA and USGS
- Funding is uncertain

Marcellus Environmental Summary

Goals

Assess short/long term environmental impacts.

Address scientific concerns

Outcomes

Rigorous study with well-documented data

Applications

Public information to create a more informed environmental debate.

Benefits

Improved practices for shale gas production.

Environmental indicators for focused regulatory monitoring.

Positive Things about Natural Gas

- ***Energy Independence:***
  - Natural gas is an abundant domestic resource.
  - Expensive and difficult to import as a cryogenic liquid
  - Efficiently transmitted over land through a pipeline.
- ***Infrastructure*: A nationwide infrastructure for natural gas already exists, unlike other resources such as wind, solar or ethanol.
- ***Greenhouse Gas Reduction and Environmental Benefits*:**
  - Gas is the cleanest fossil fuel in terms of air emissions:
    - No sulfur; no ash as combustion products
    - No cracking or refining – essentially pure methane
    - Low NOx and ozone, no photochemical smog
    - Lowest carbon dioxide emission per BTU of any fossil fuel.
  - Can directly substitute for coal and petroleum combustion
  - No mountaintop removal mining or offshore drilling is required
  - Can be used as a transportation fuel to replace imported oil
  - Small gas turbines can economically generate electricity

Questions?

Daniel J. Soeder
USDOE/NETL
3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507
(304) 285-5258
Daniel.Soeder@netl.doe.gov

http://www/netl.doe.gov

< Eastern Alberta badlands, Canada