# THE MARCELLUS SHALE GAS PLAY
# Geology, Development, and Water-Resource Impact Mitigation

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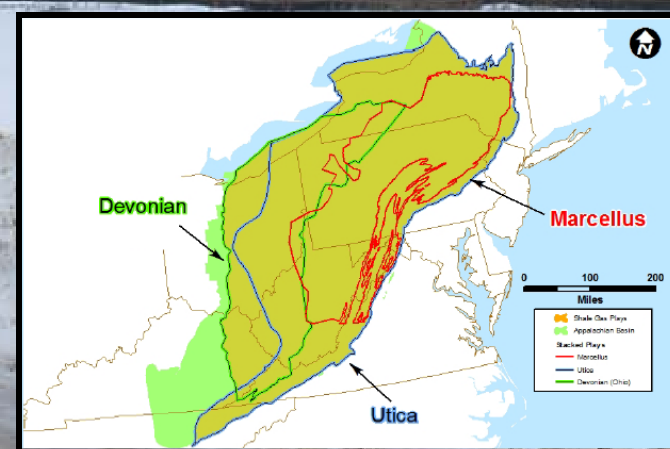
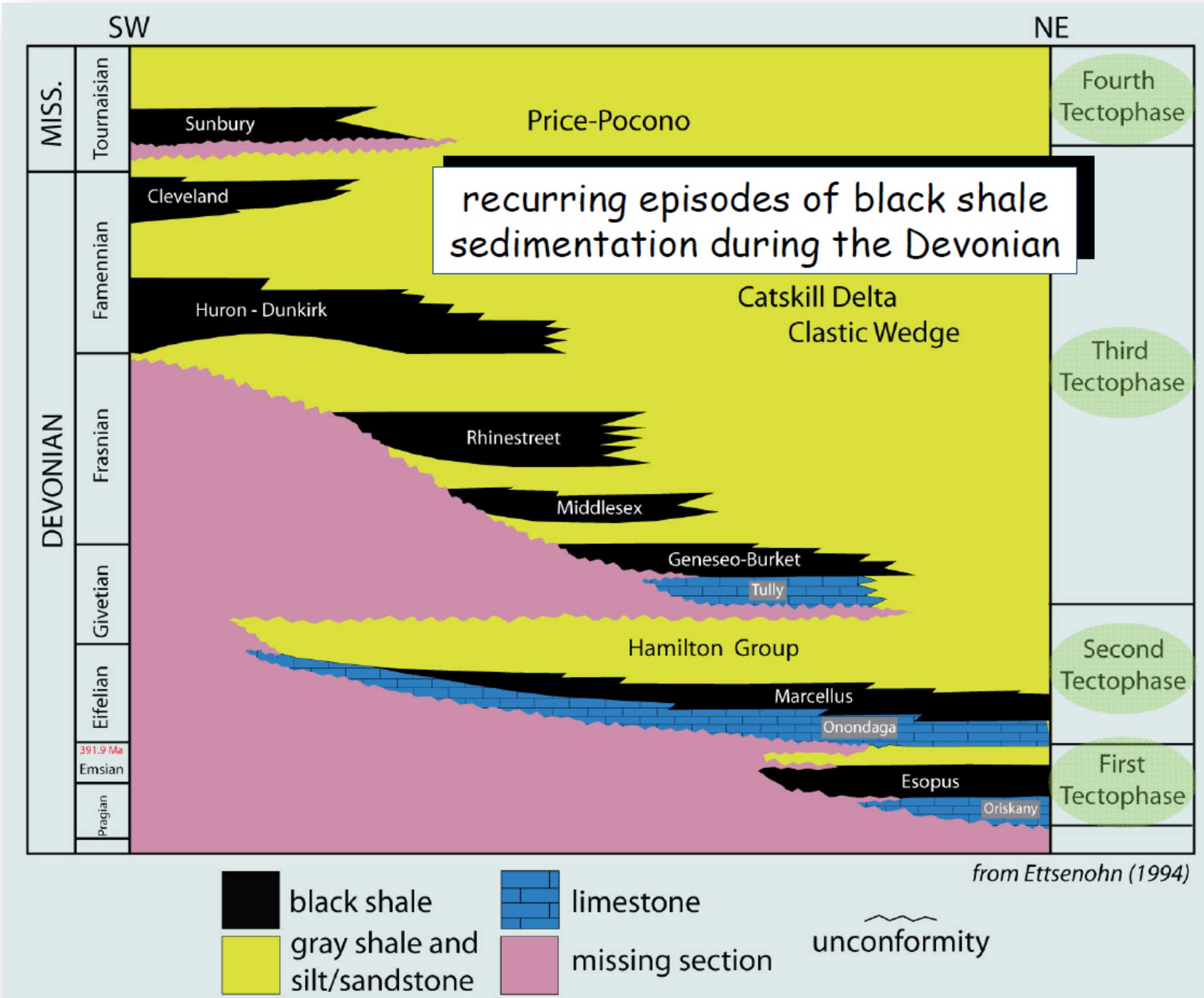
Marcellus shale play is located in the Appalachian basin and covers parts of New York, Pennsylvania, Maryland, and West Virginia


Marcellus shale play is the one of three overlapping shale plays that includes the older Utica shale and the younger Devonian shales

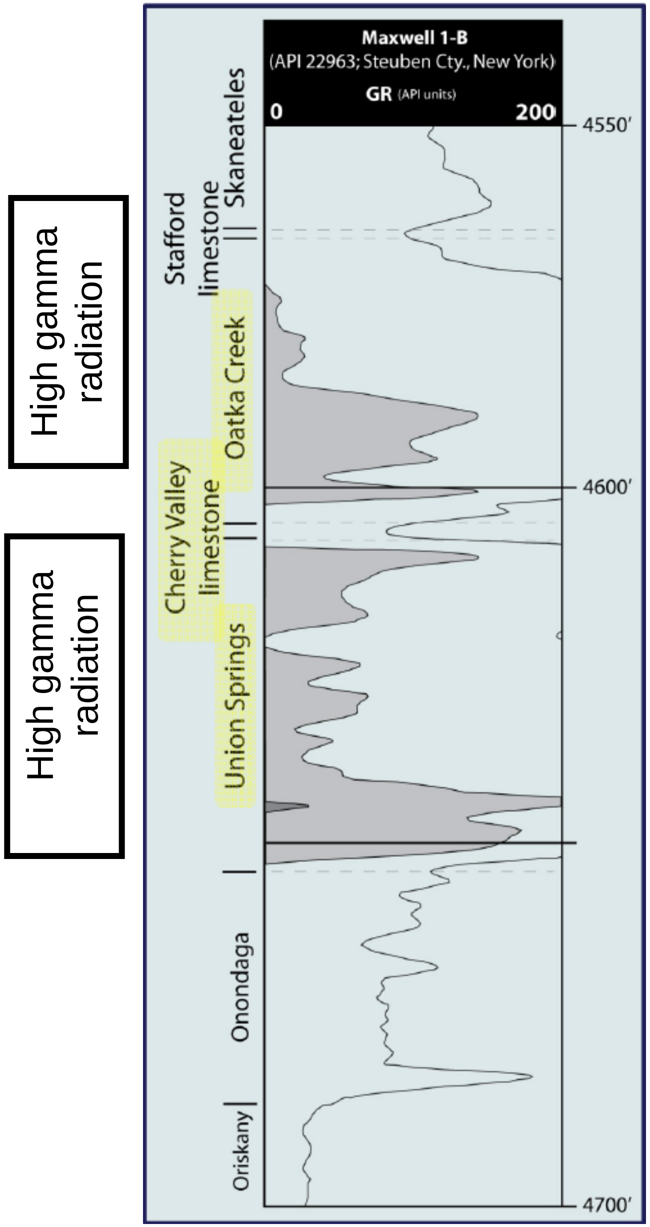




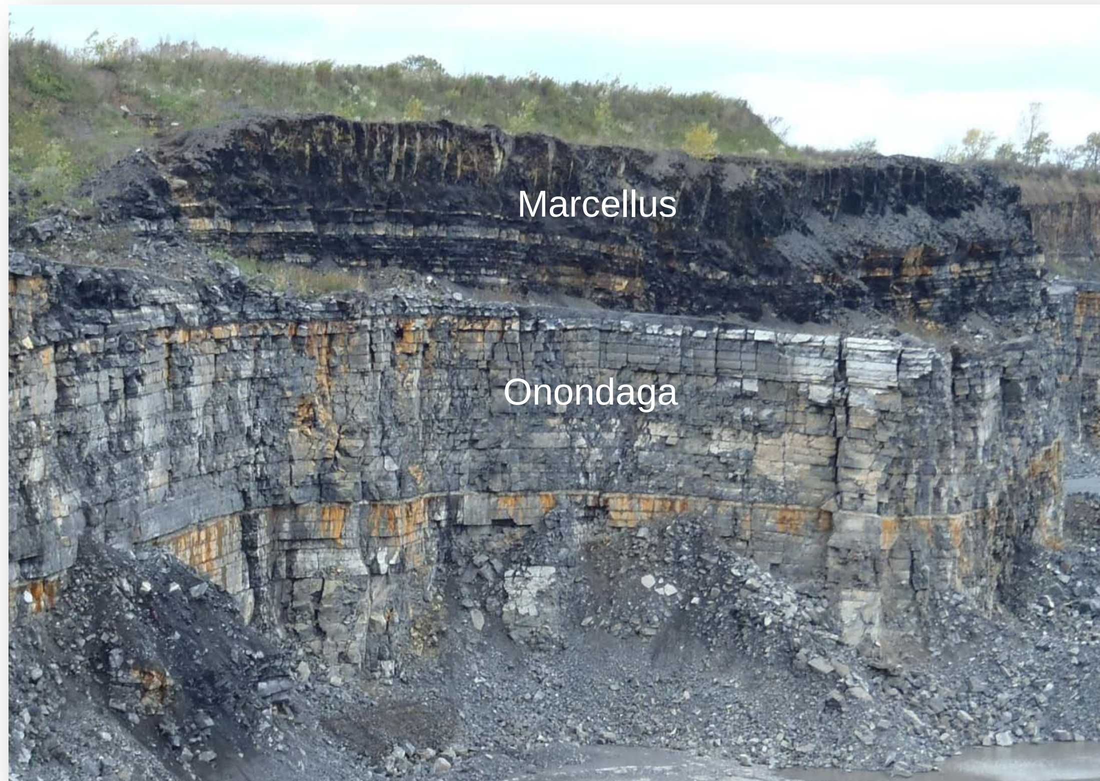
SW
NE
MISS.
Tournaisian
DEVONIAN
Famennian
Frasnian
Givetian
Eifelian
391.9 Ma
Emsian
Pragian
Price-Pocono
Sunbury
Cleveland
recurring episodes of black shale sedimentation during the Devonian
Huron - Dunkirk
Catskill Delta
Clastic Wedge
Rhinestreet
Middlesex
Geneseo-Burket
Tully
Hamilton Group
Marcellus
Onondaga
Esopus
Oriskany
Fourth Tectophase
Third Tectophase
Second Tectophase
First Tectophase
from Ettsenohn (1994)
black shale
gray shale and silt/sandstone
limestone
missing section
unconformity

# Marcellus Stratigraphy

## Geophysical Log




Lash and Engelder (2009)

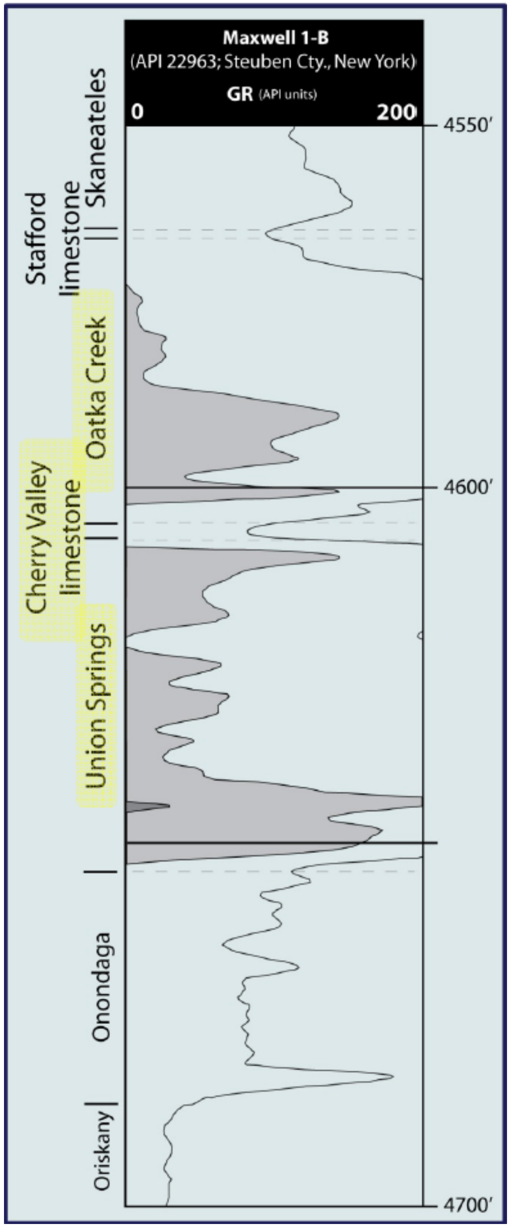


# Marcellus Stratigraphy

Geophysical Log

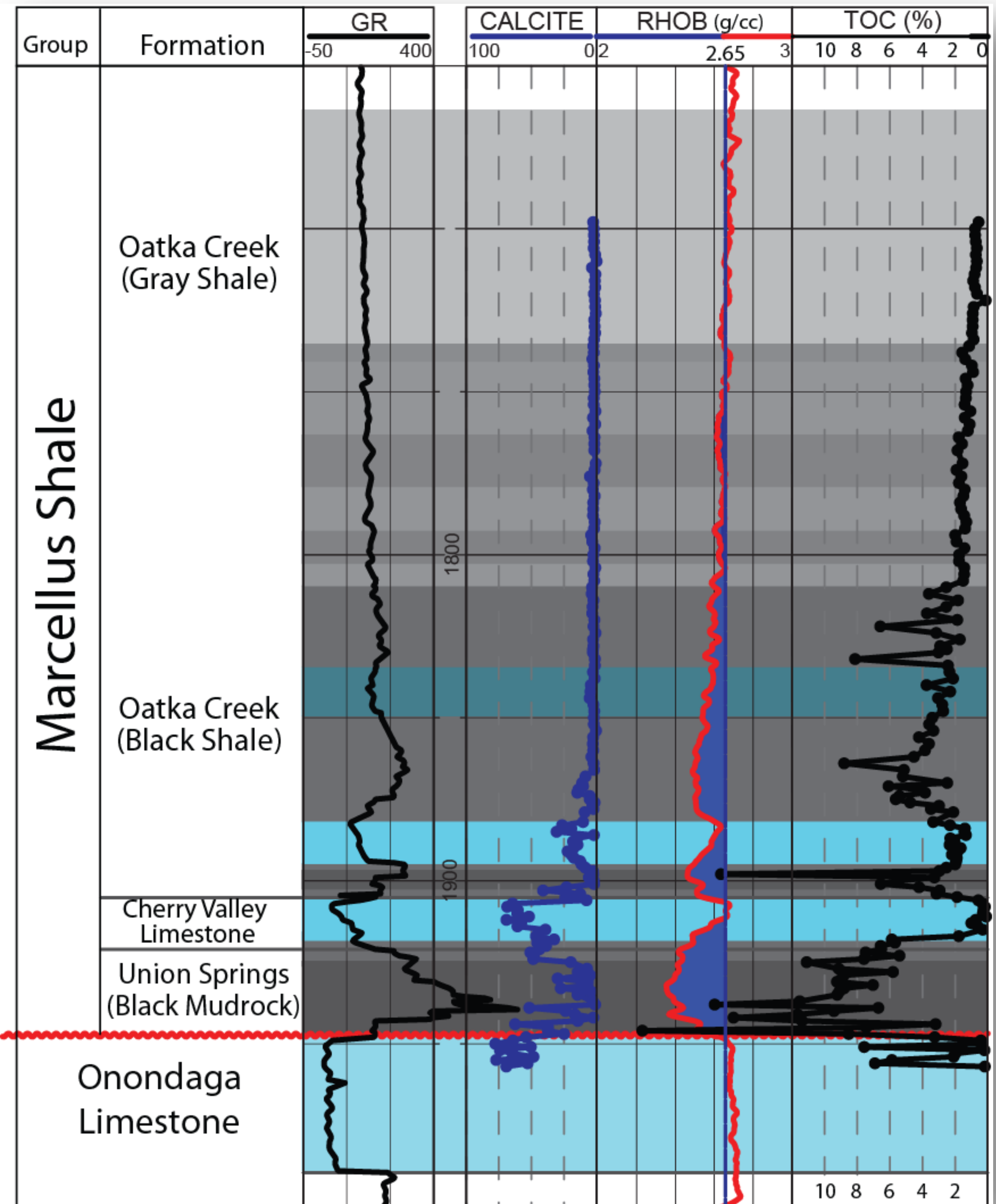
High gamma radiation

High gamma radiation

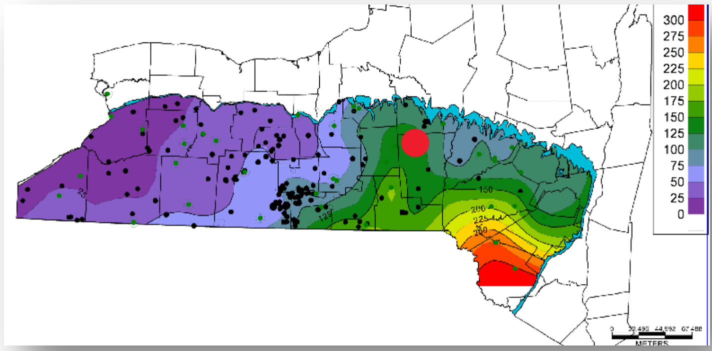



Lash and Engelder (2009)

# Beaver Meadows #1 Core



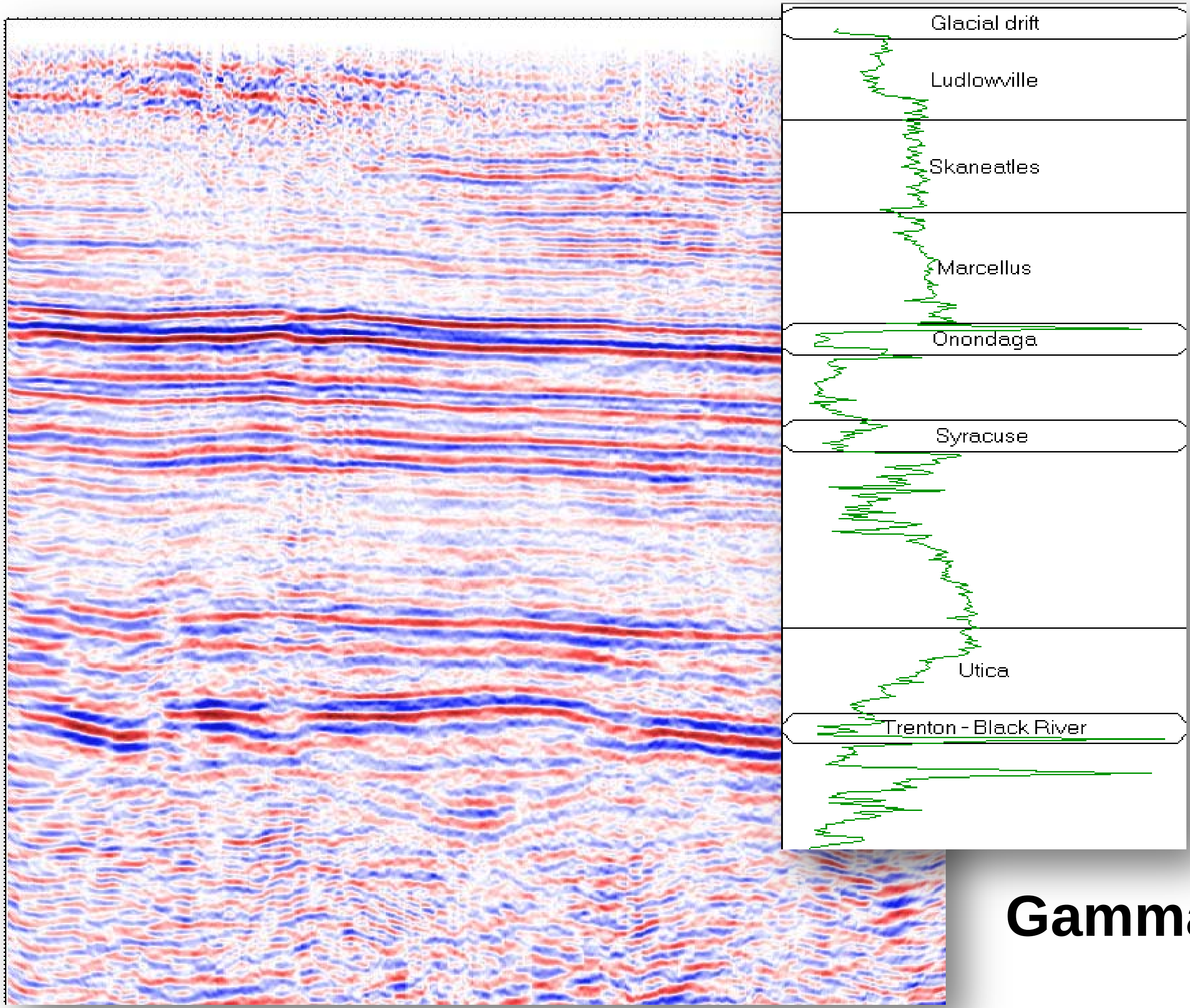

Darker gray = more organic rich




Smith (2010)

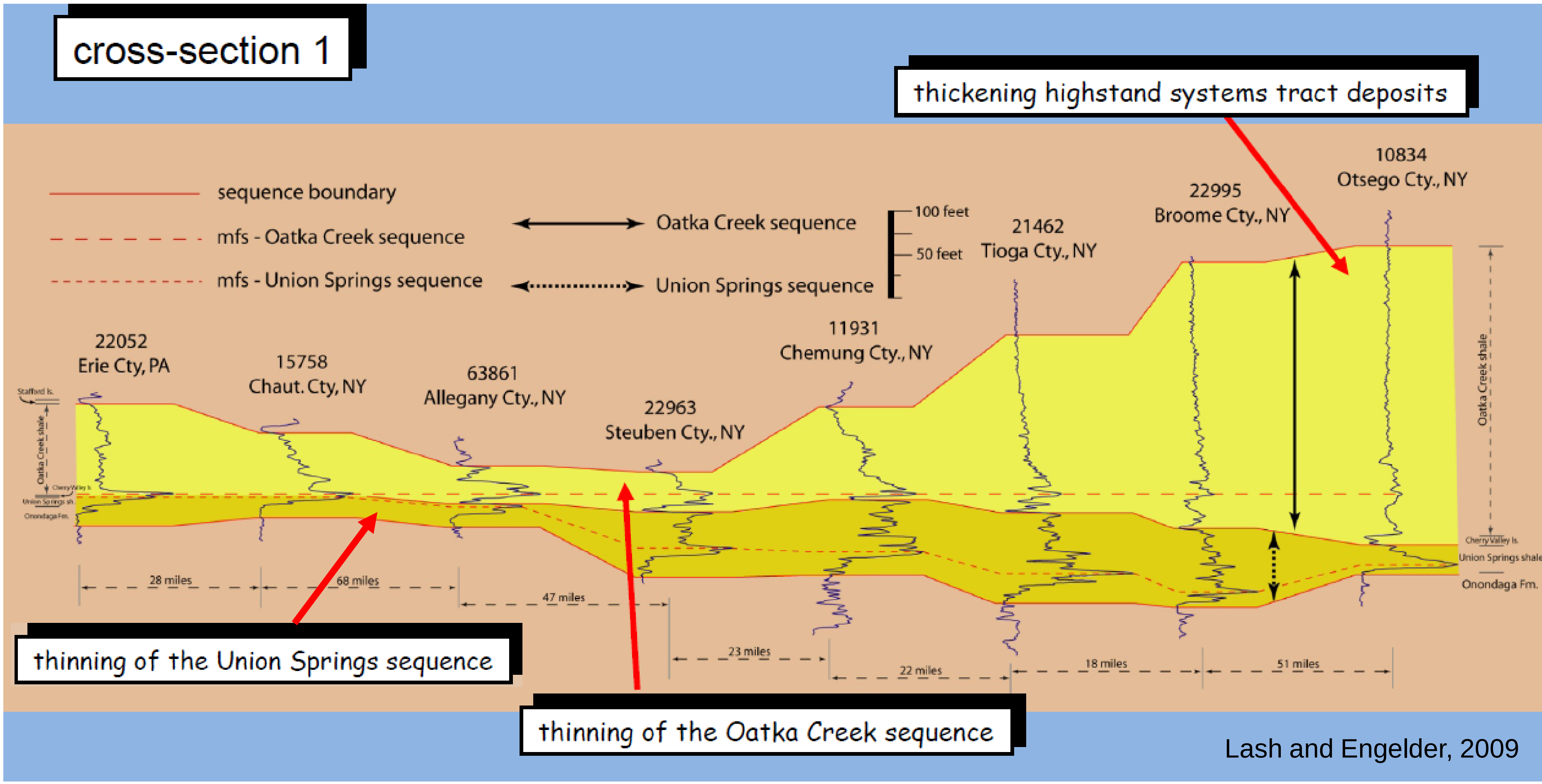
Highest TOC (up to 20%)

# Seismic survey from Otsego County




**Gamma log**

Seismic image courtesy of Gastem


cross-section 1
thickening highstand systems tract deposits
sequence boundary
mfs - Oatka Creek sequence
mfs - Union Springs sequence
Oatka Creek sequence
Union Springs sequence
100 feet
50 feet
22052
Erie Cty, PA
15758
Chaut. Cty, NY
63861
Allegany Cty., NY
22963
Steuben Cty., NY
11931
Chemung Cty., NY
21462
Tioga Cty., NY
22995
Broome Cty., NY
10834
Otsego Cty., NY
Oatka Creek shale
Cherry Valley ls.
Union Springs shale
Onondaga Fm.
28 miles
68 miles
47 miles
23 miles
22 miles
18 miles
51 miles
thinning of the Union Springs sequence
thinning of the Oatka Creek sequence
Lash and Engelder, 2009

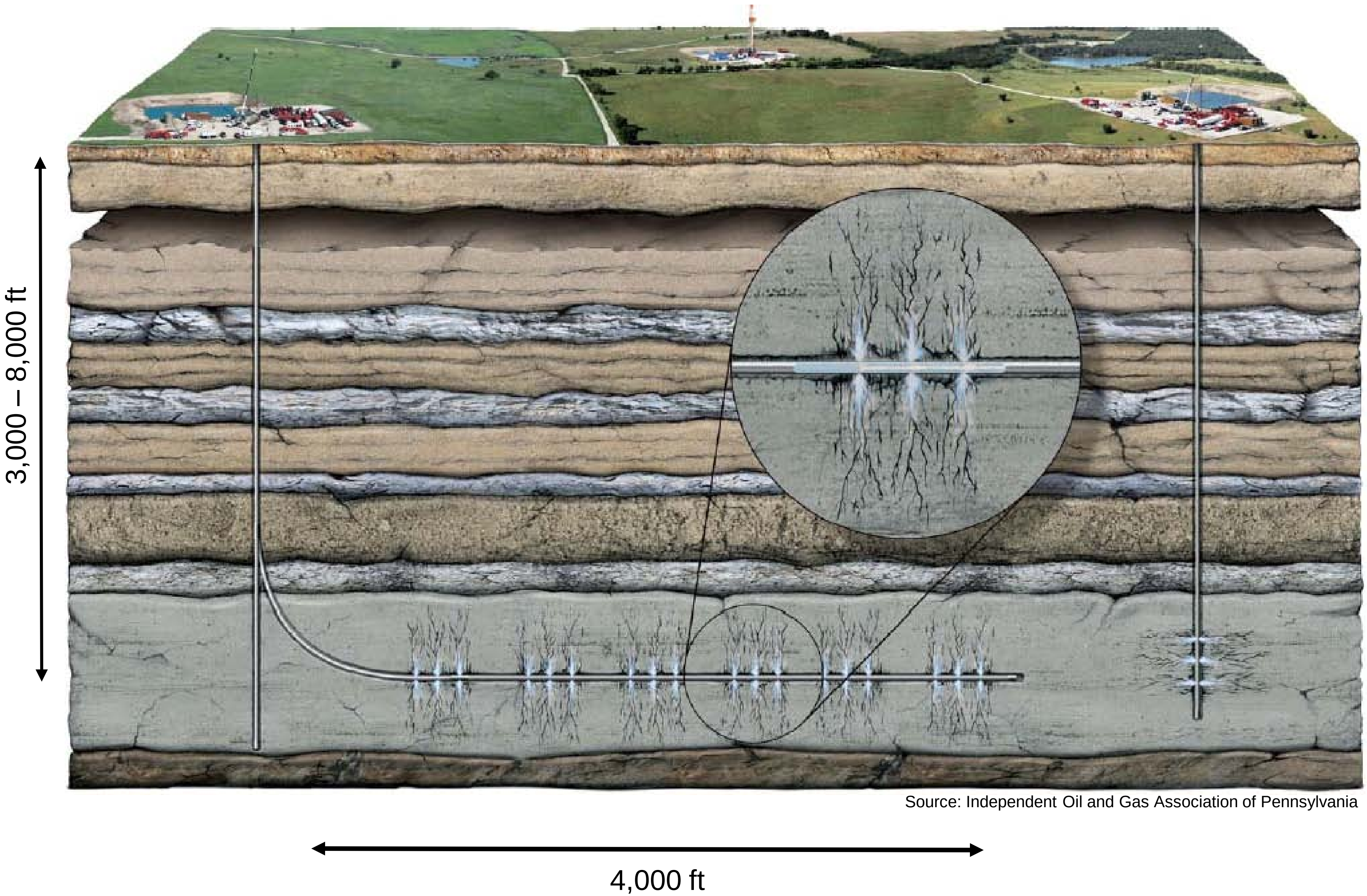
# Shale Gas Development

- **First commercial gas well in the United States was a Devonian shale gas well drilled in 1821 near Fredonia, NY**

Site of first gas well in the United States

# Marcellus Shale Gas Development

## Hydraulic Fracturing and Horizontal Drilling



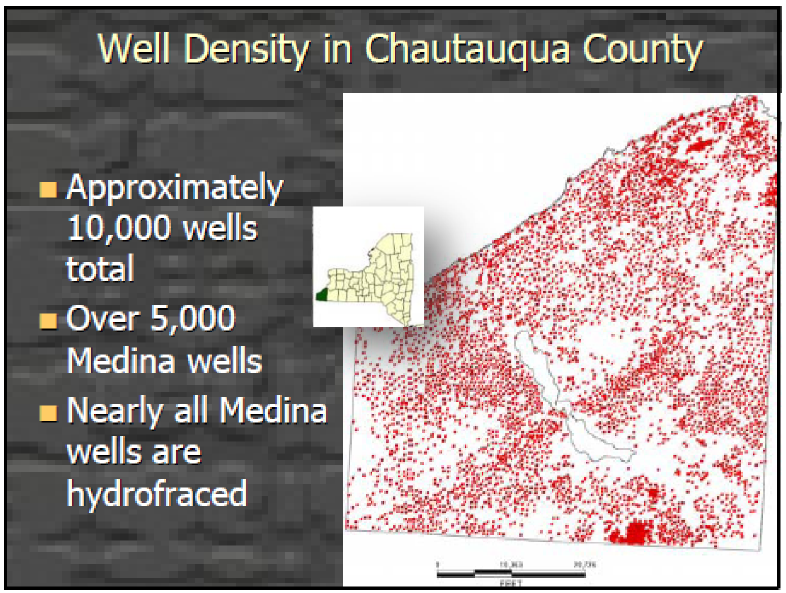

Source: Independent Oil and Gas Association of Pennsylvania

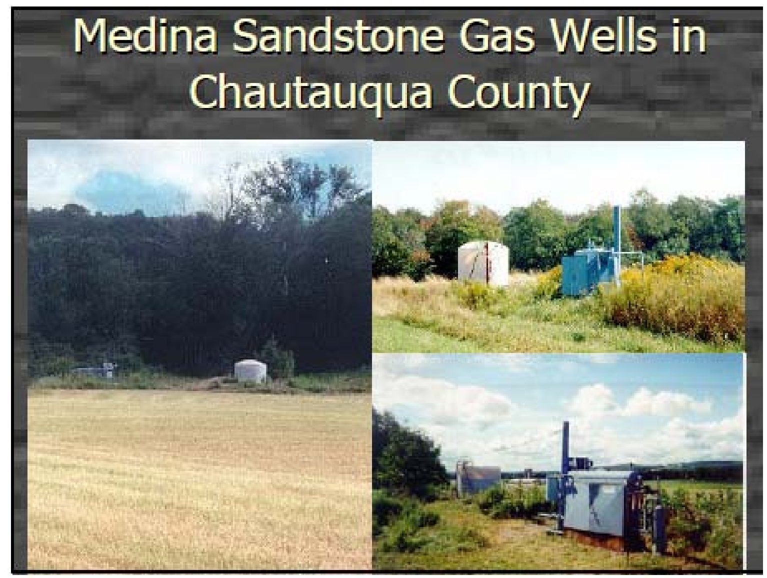
# Hydraulic Fracturing

- First hydraulic fracturing of oil & gas well was in 1948

- Medina Sandstone, a tight gas reservoir, was extensively fraced in western New York and Pennsylvania during the 1970s

- 100,000 oil & gas wells are fraced per year

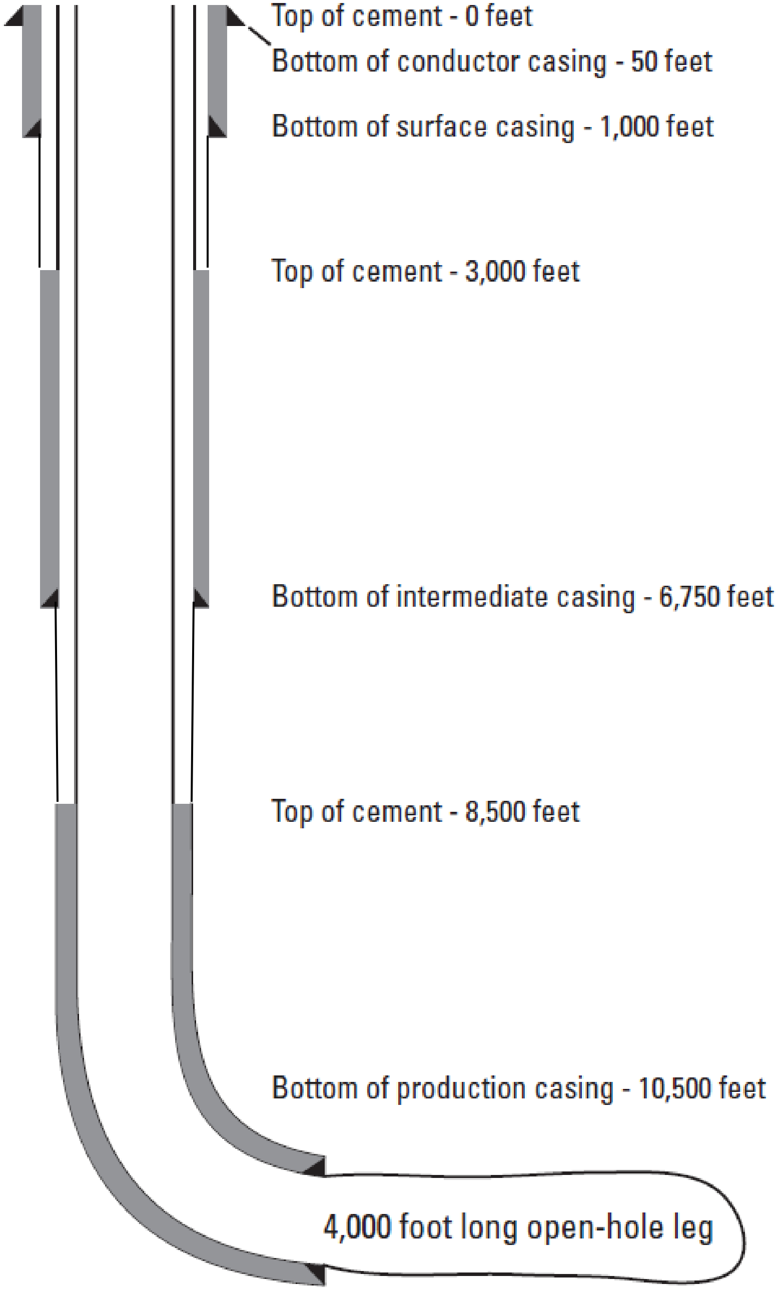


# Horizontal Drilling

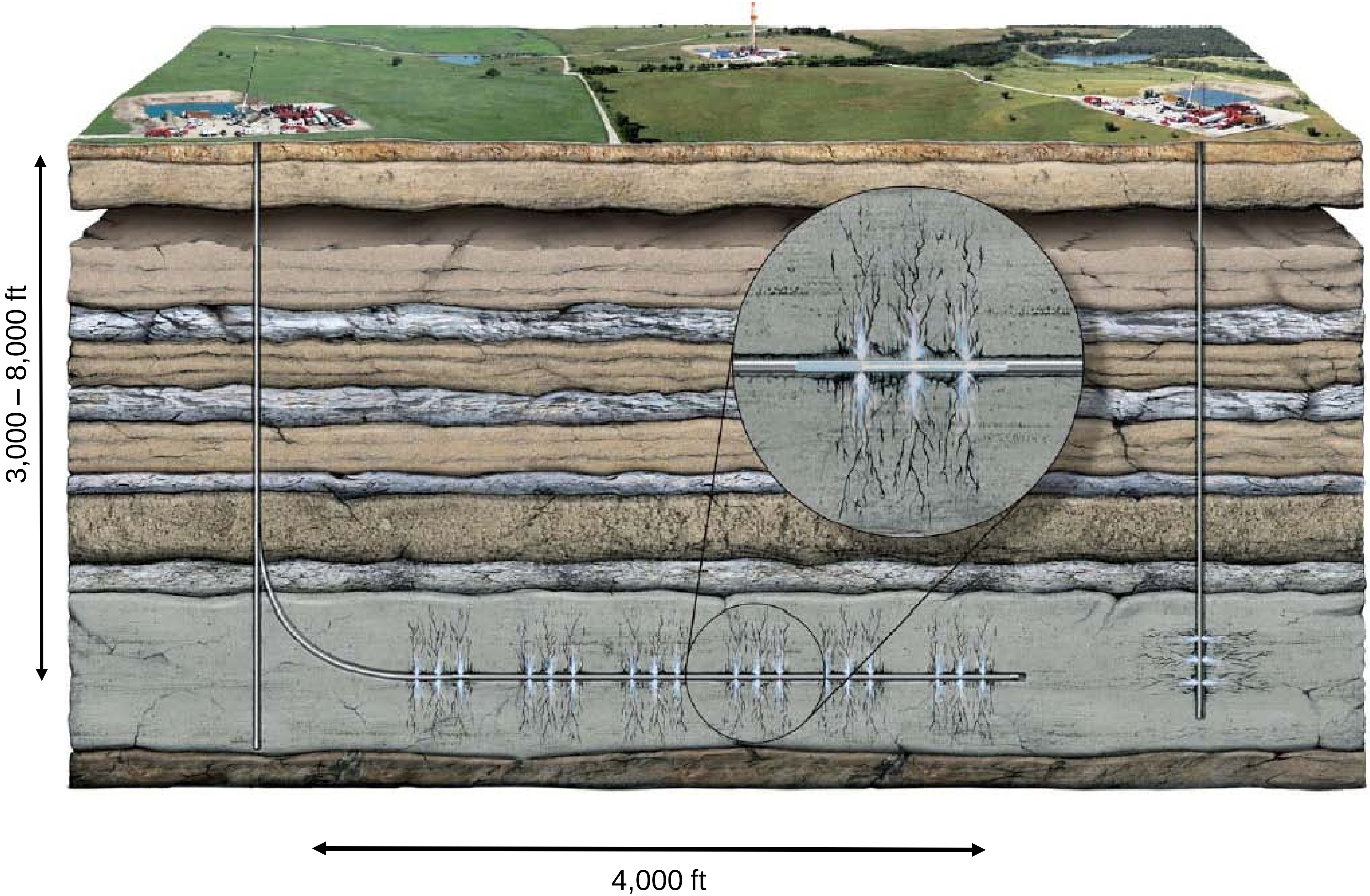
- **First horizontal well was drilled in 1948**
- **First horizontal shale gas well was drilled in 1988 in the Antrim Shale, Michigan**
- **First horizontal gas well in New York was drilled in 1989**

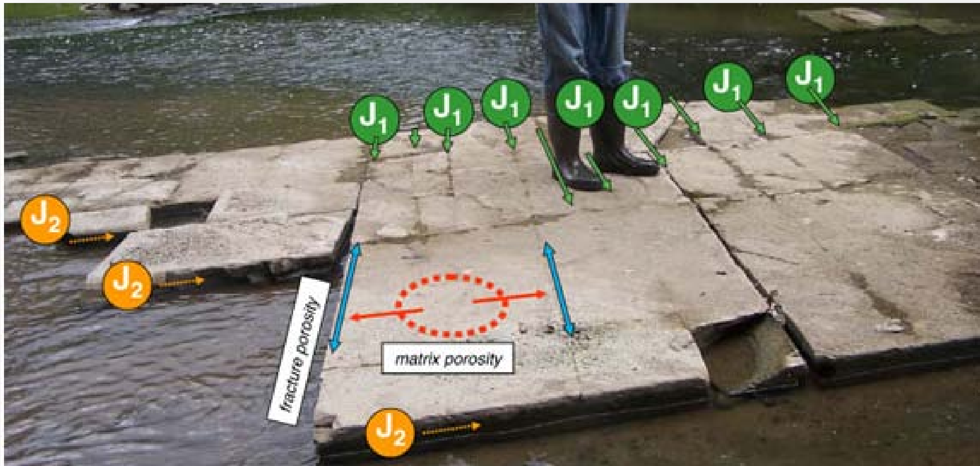

## Trenton/Black River well



# Marcellus Shale Gas Development

## Horizontal Drilling
## at Multi-Well Pad Sites in Black Shale






Orthogonal joint sets
East-northeast trending J1 fractures and northwest-trending J2 fractures

Dual porosity gas reservoir where fractures drain rapidly and matrix drain slowly

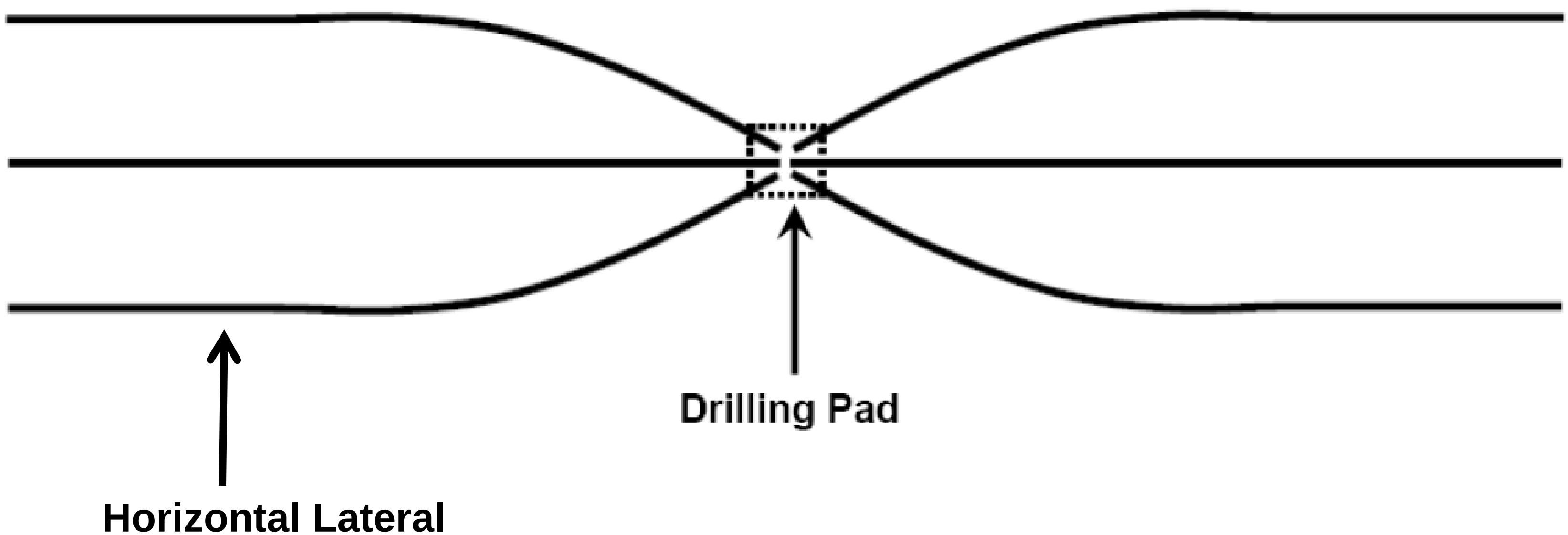
Free gas and adsorbed gas in matrix

Connect matrix porosity to the wellbore by intersecting multiple J1 fractures

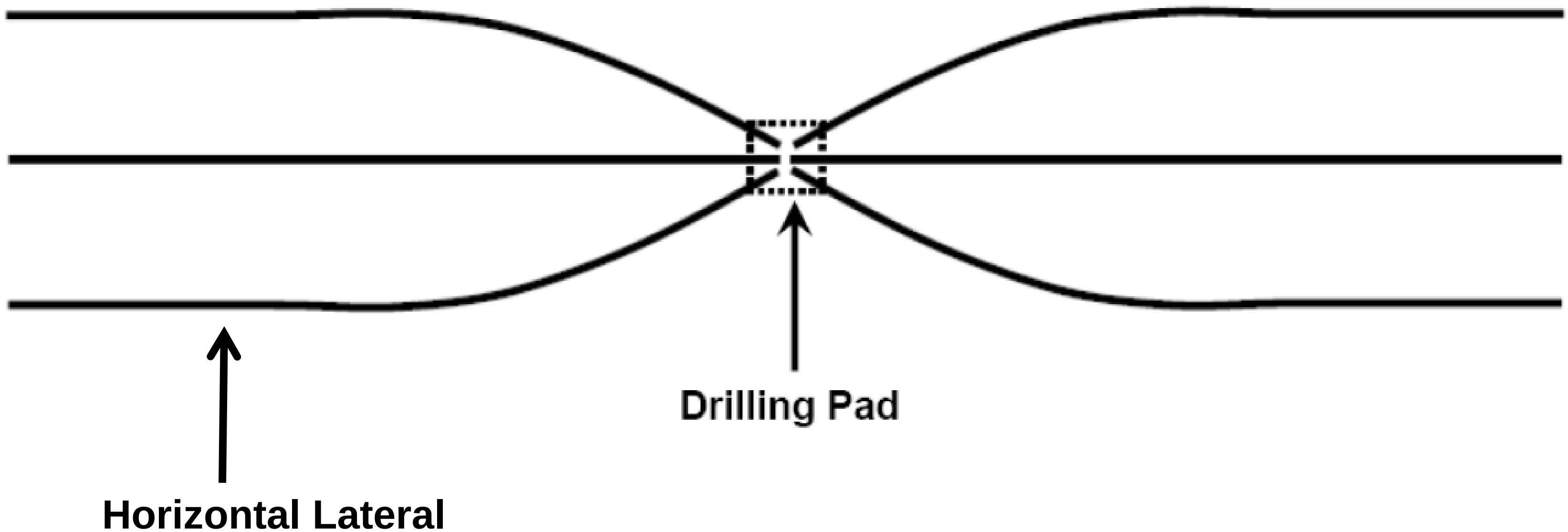

Drill horizontal wells to the north-northwest or south-southeast perpendicular to major horizontal stress and J1 fractures

Terry Engelder PSU

# Multi-Well Drilling Pad Site
# With Six Horizontal Laterals



# Multi-Well Drilling Pad Site
# With Six Horizontal Laterals



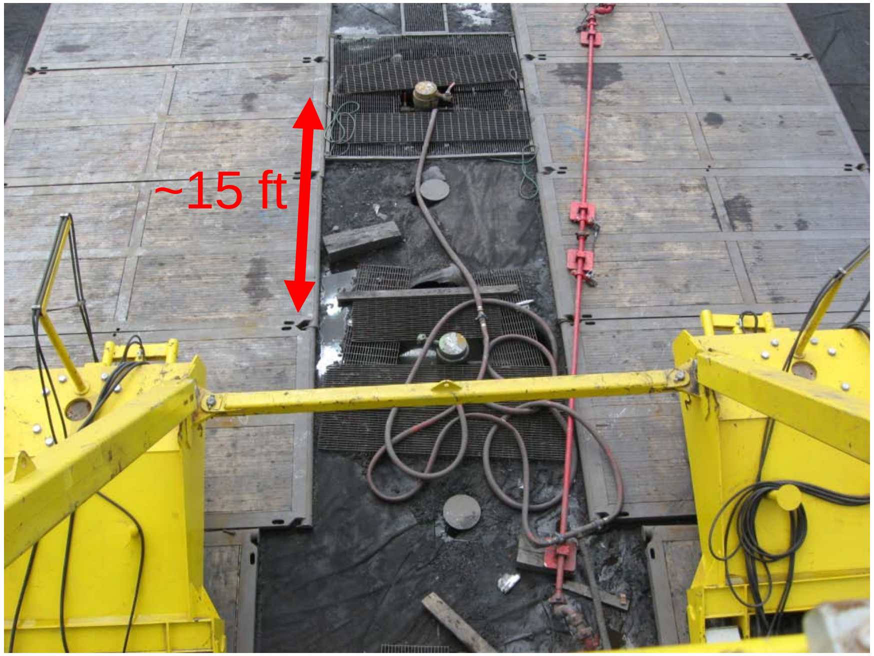

**Minimizes surface disturbance but concentrates industrial activity**

**Top-set rig for drilling vertical surface- and intermediate-cased interval**

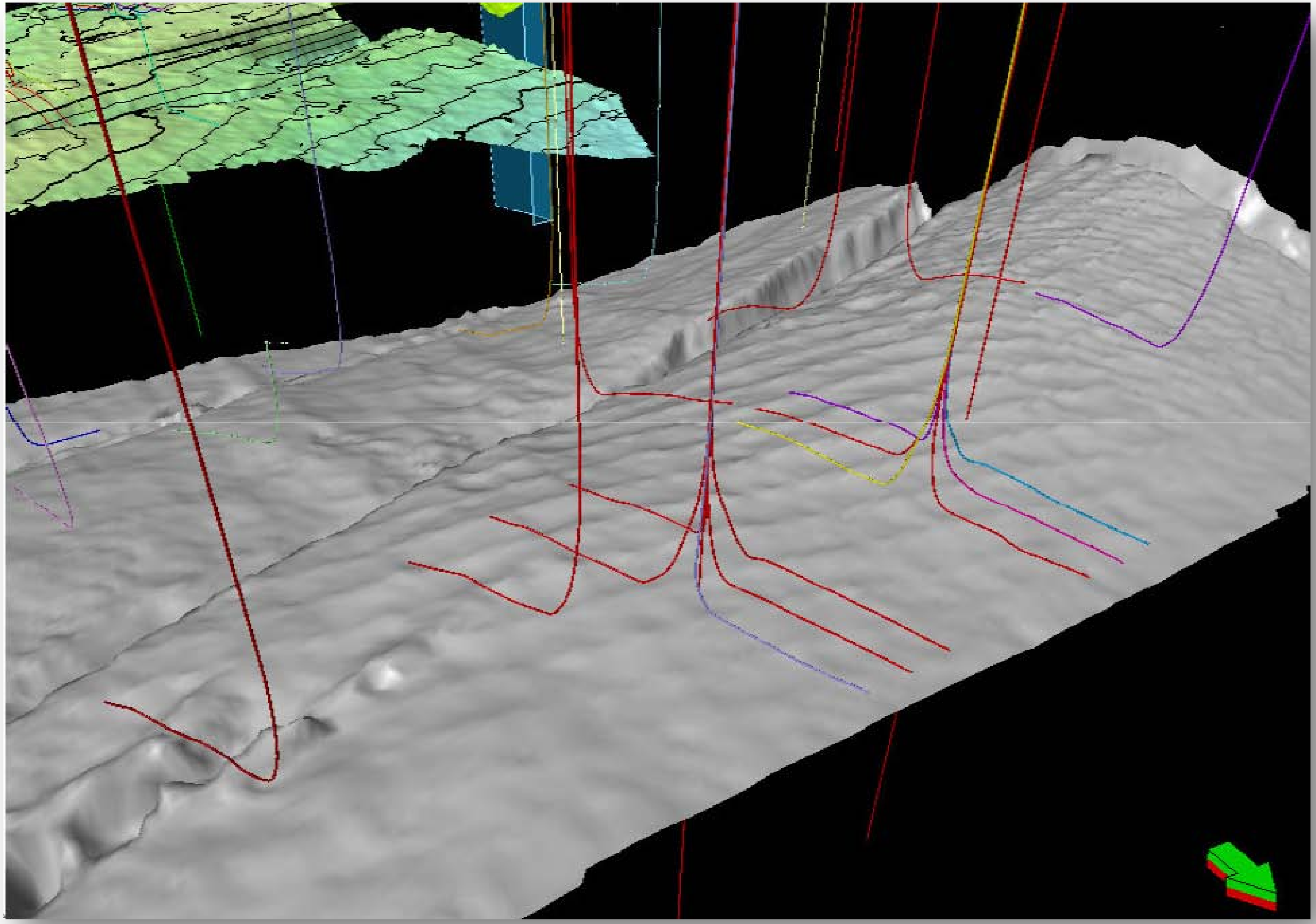
**Directional rig for drilling horizontal leg**

Walking legs on directional drilling rig

Wellheads of first two of six horizontal wells

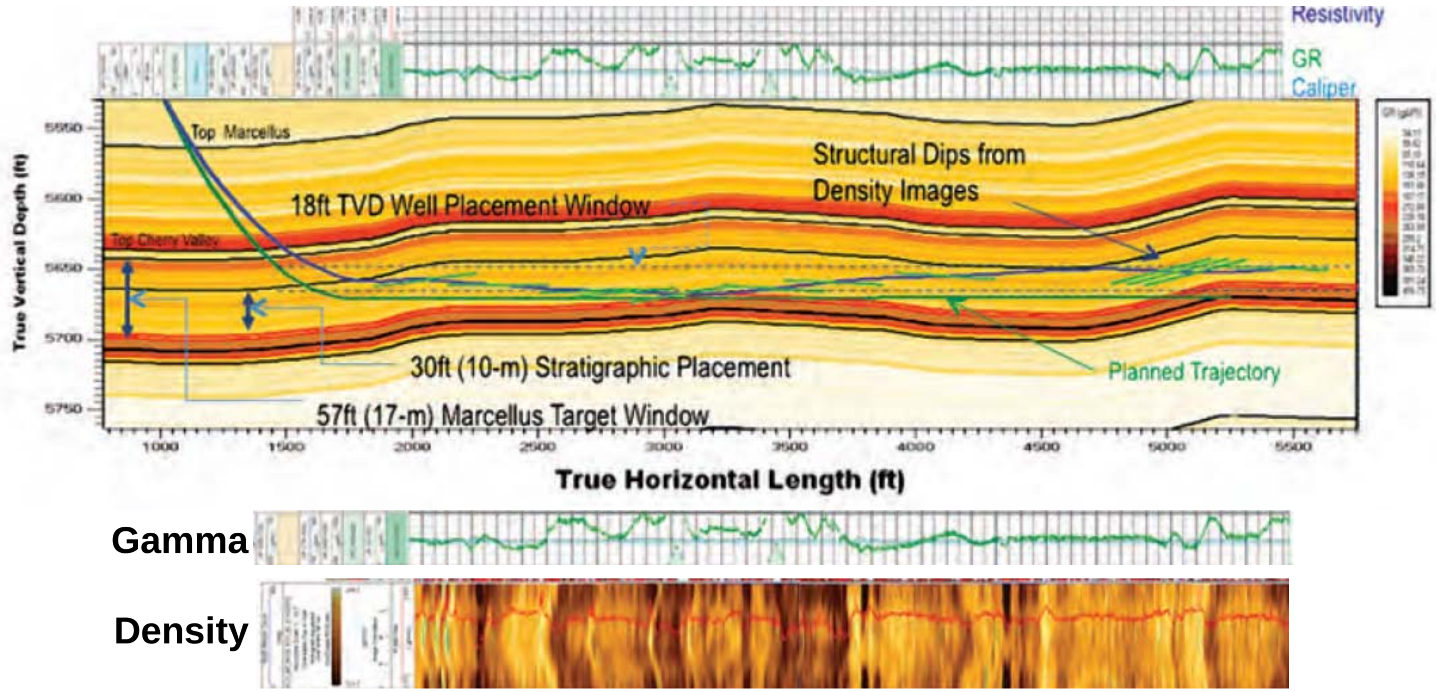


# Horizontal wells target basal Marcellus Shale



Teff (2011)

# Target horizon (Union Springs Shale) mapped using offset well logs and seismic



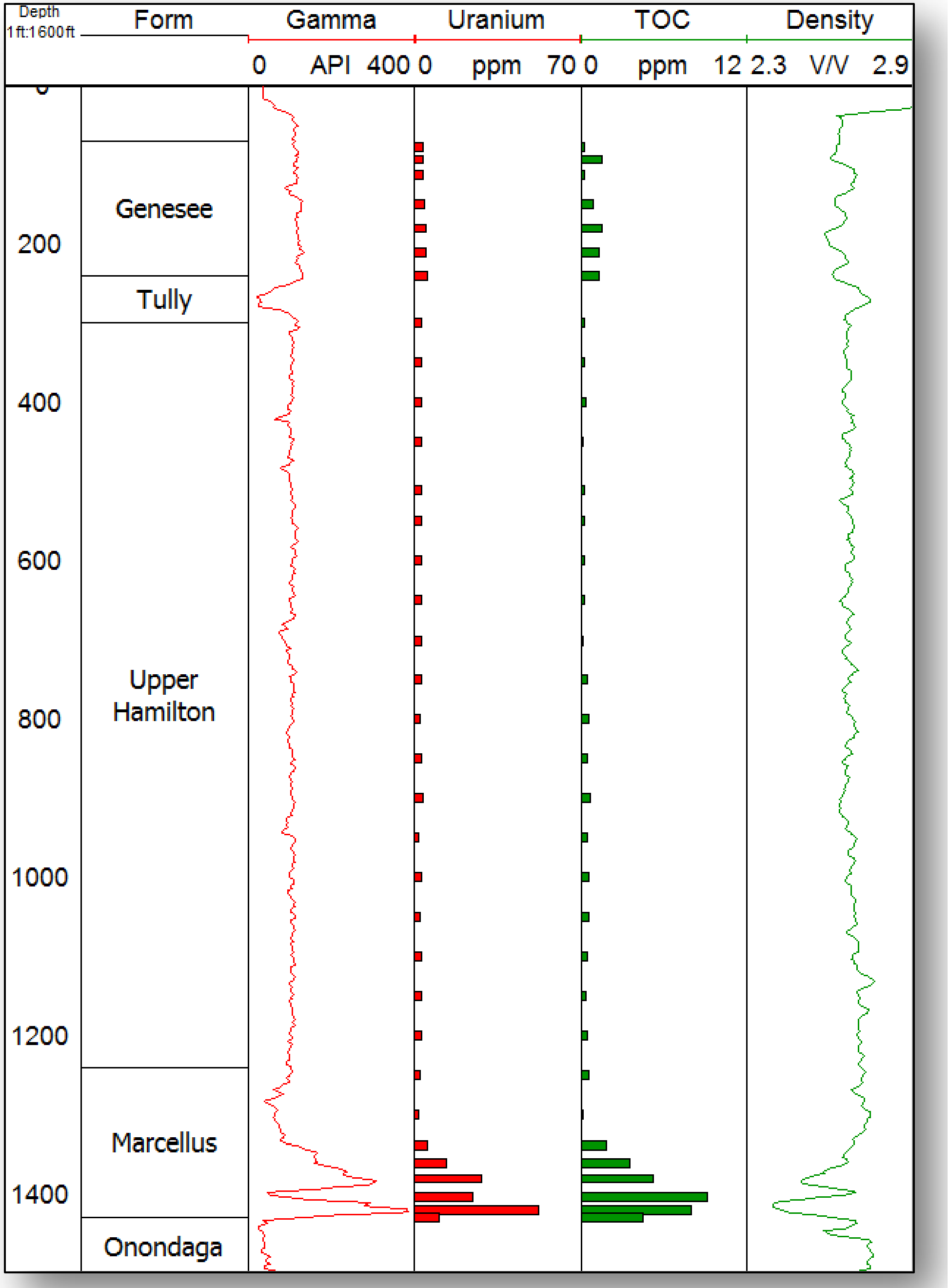

# Logging-while-drilling used to steer lateral within target beds

Schlumberger (2010)

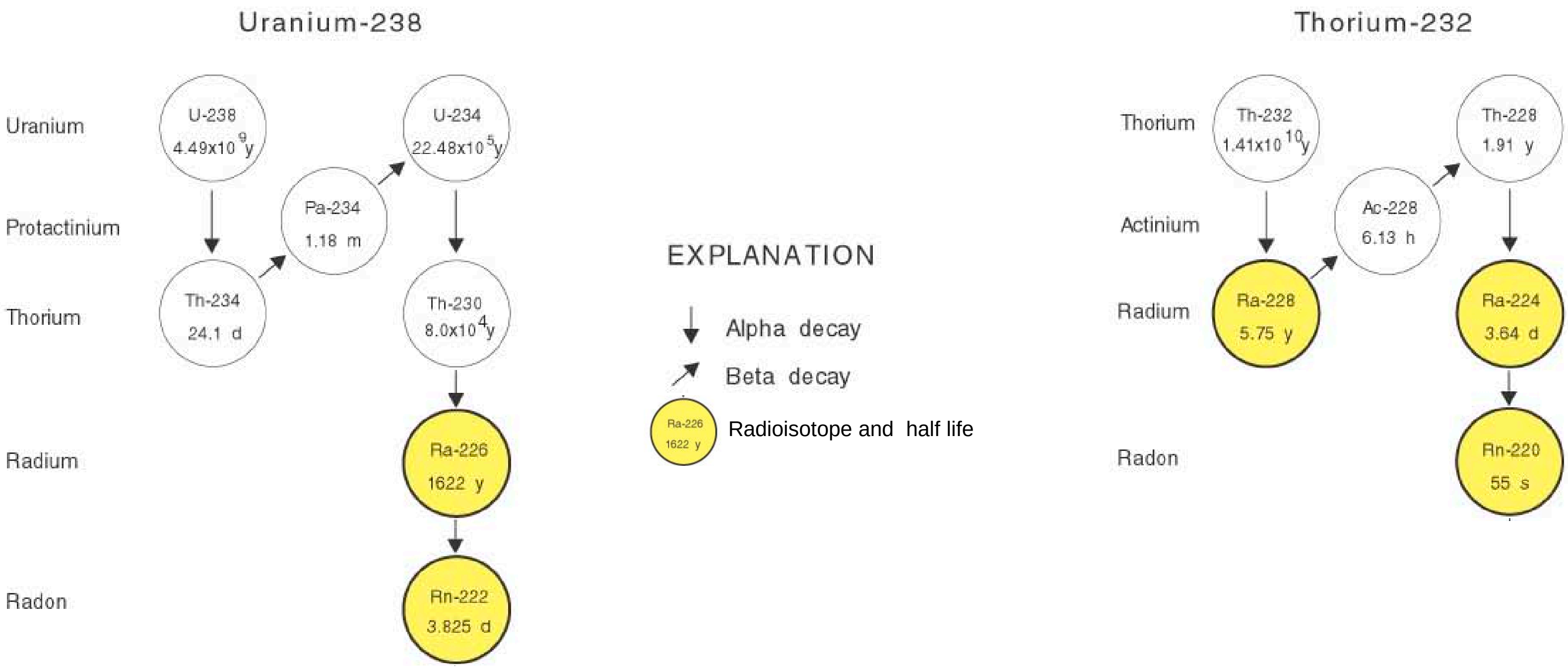
# High TOC and elevated radioactivity in basal Marcellus Shale

| Location of the Core | Uranium Content (ppm) |
|---|---|
| Allegheny, NY | 8.9 – 67.7 |
| Tompkins County, NY | 25 – 53 |
| Livingston County, NY | 16.6 – 83.7 |

Levanthal and others (1981)

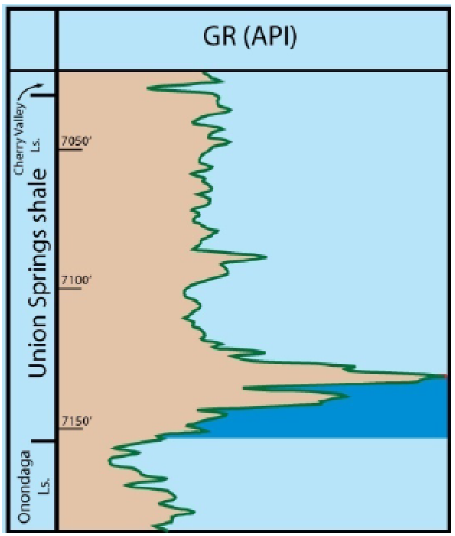


# Uranium & Thorium to Radium & Radon Radioactive Decay Series

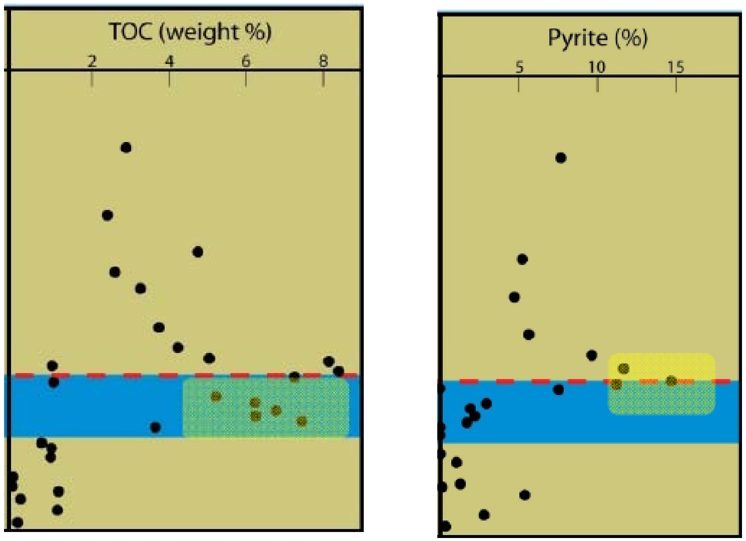


# High TOC and abundant pyrite in basal Marcellus Shale

Gamma Log




Drill Core Sample Analysis




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

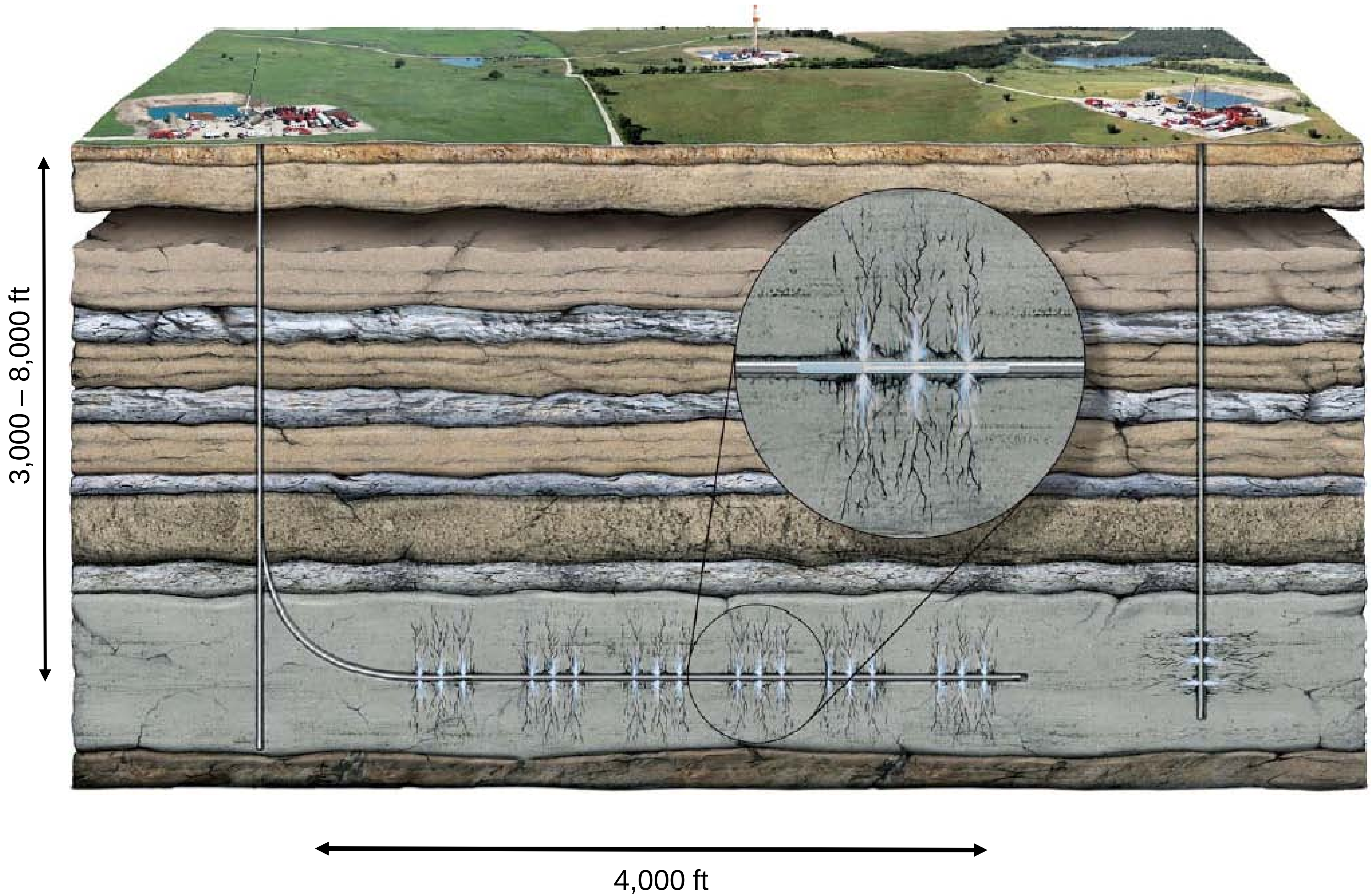
Closed-loop system

Mixed with sawdust

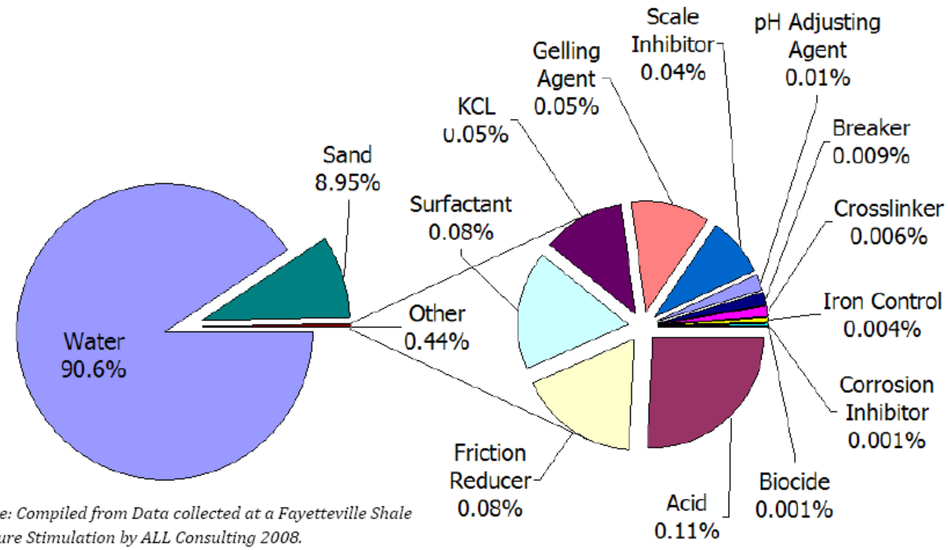
Offsite disposal in landfill

# Marcellus Shale Gas Development

## Multi-Stage High-Volume Hydraulic Fracturing of Horizontal Laterals



**3 to 5 million gallons of water for hydraulic fracturing of each horizontal lateral**




*Source: Compiled from Data collected at a Fayetteville Shale Fracture Stimulation by ALL Consulting 2008.*

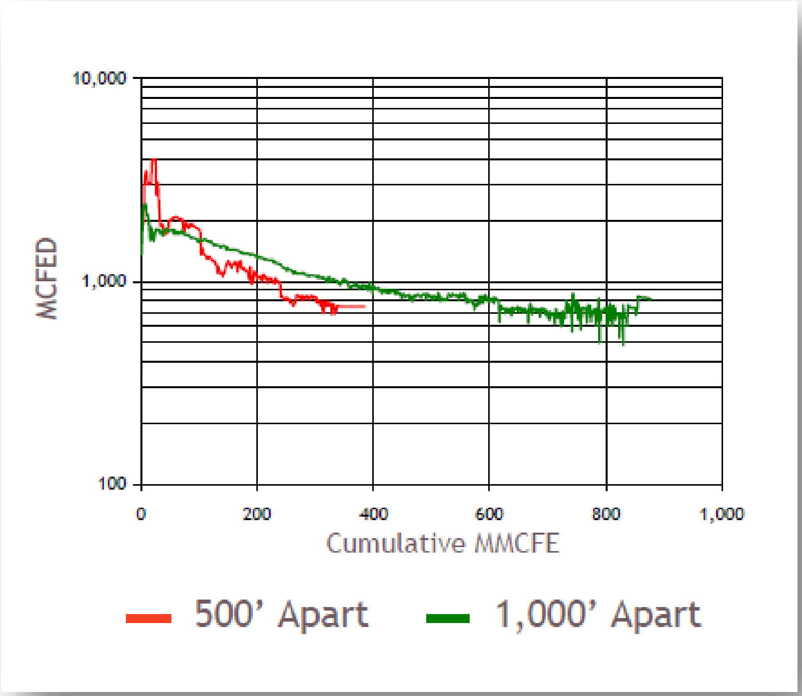
# Typical Components of Frac Fluid

• For a 3 million gallon frac job, the 0.5 percent is equivalent to 15,000 gallons of “chemistry”

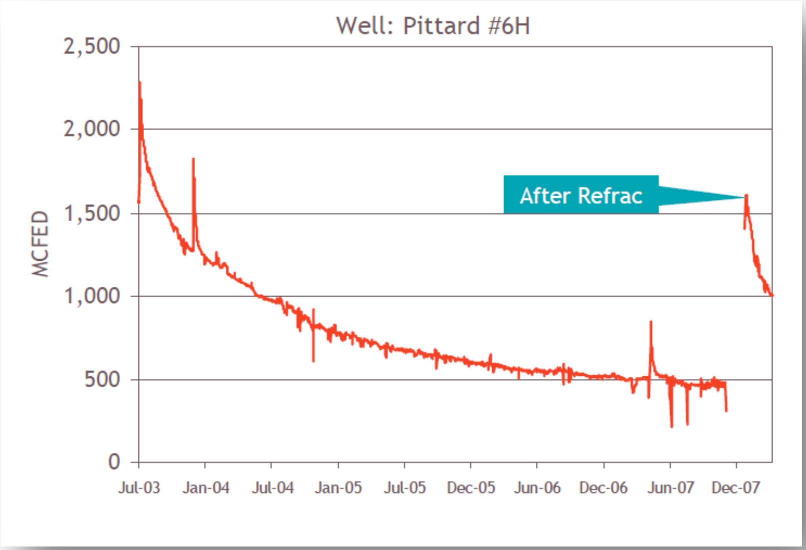
•Re-fracing may be needed due to proppant crushing, scale, etc.

# Barnett Shale

## Infill Drilling

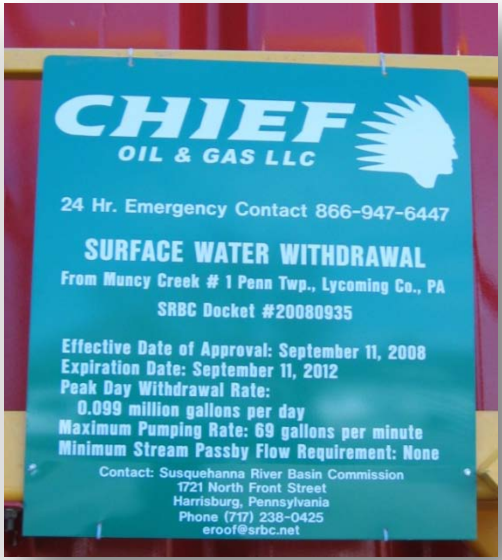



## Refrac

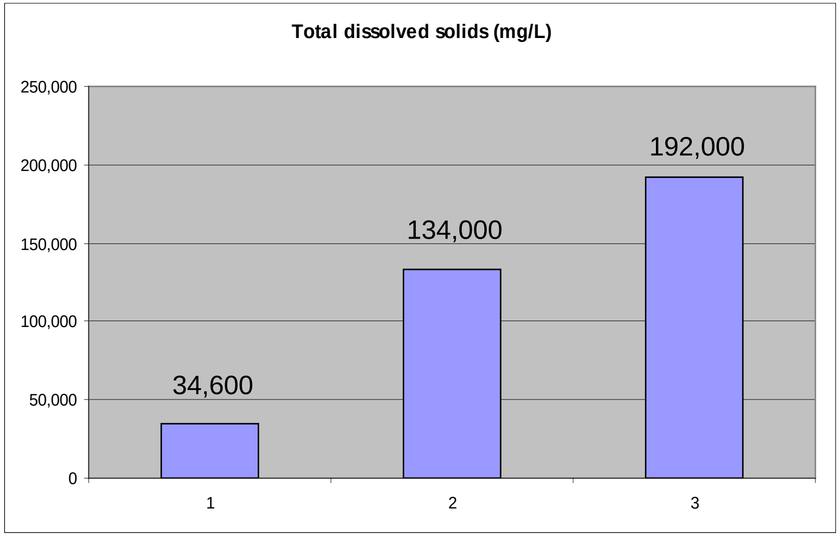


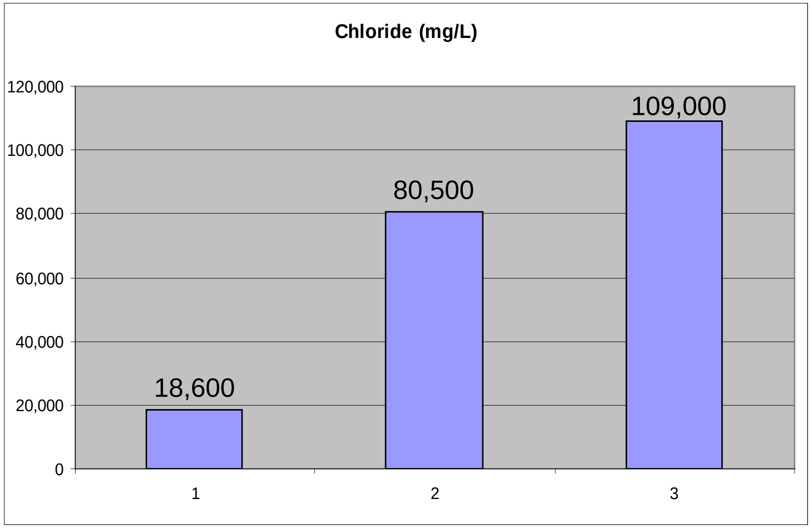

*Devonenergy.com*

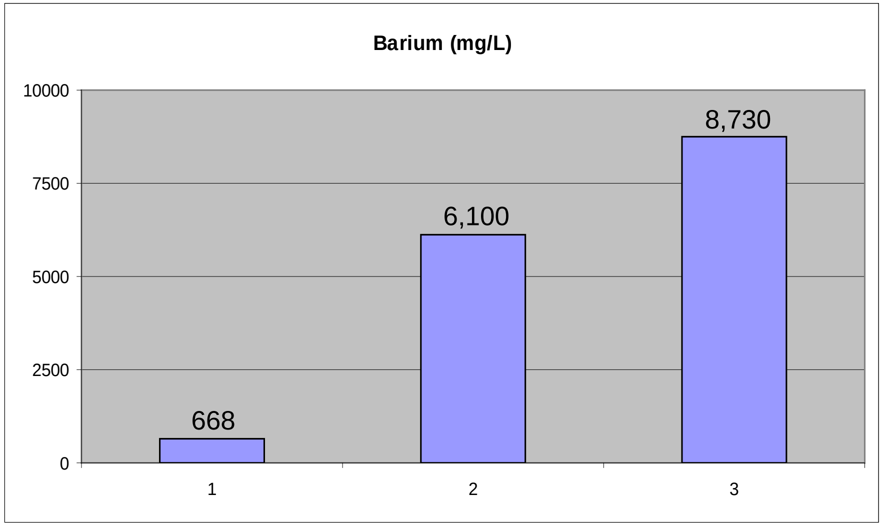
# Water Withdrawals for Frac Water

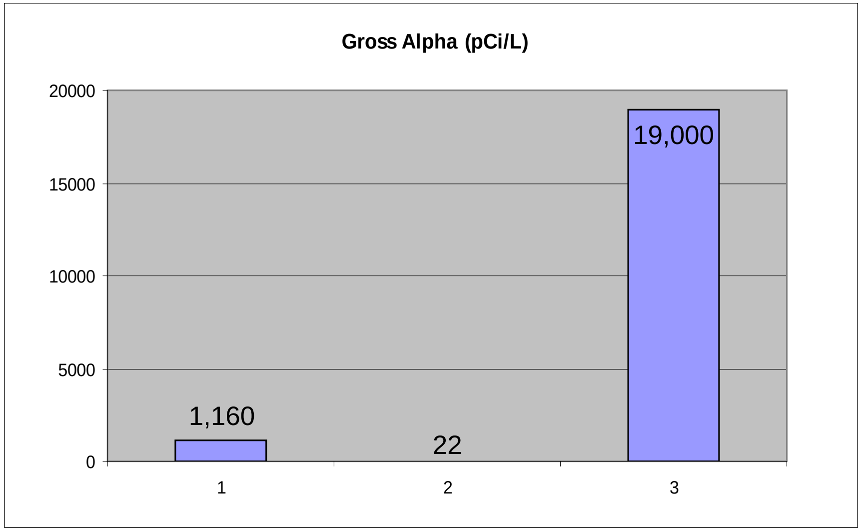



- Surface-water withdrawals and municipal supply in PA
- Water-availability issues are seasonal in nature
- Withdrawal of 5 MGD during high water insignificant, during low water exceeds 10 percent of flow
- Cumulative impacts of multiple withdrawals
- If surface water becomes more restrictive, industry will look to groundwater
- Surface water and groundwater – a single resource



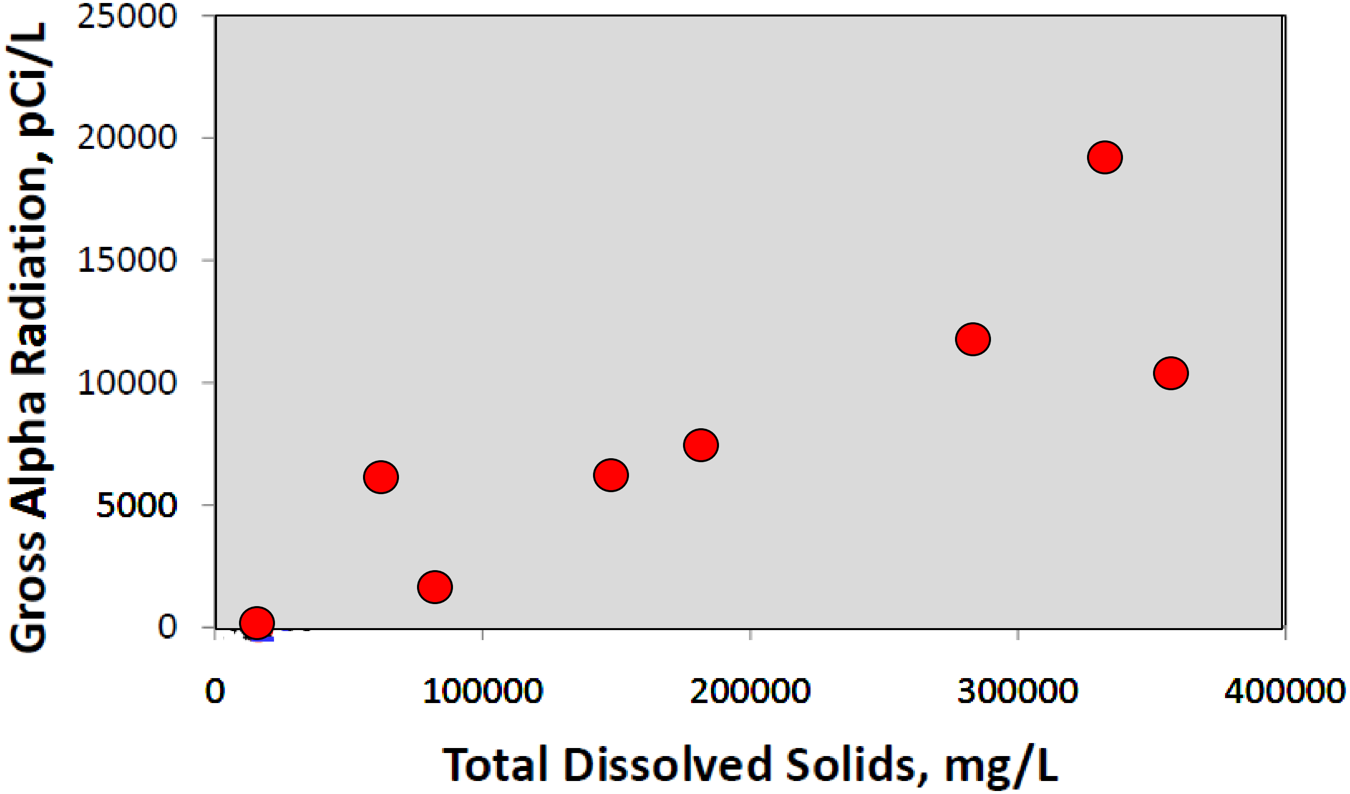




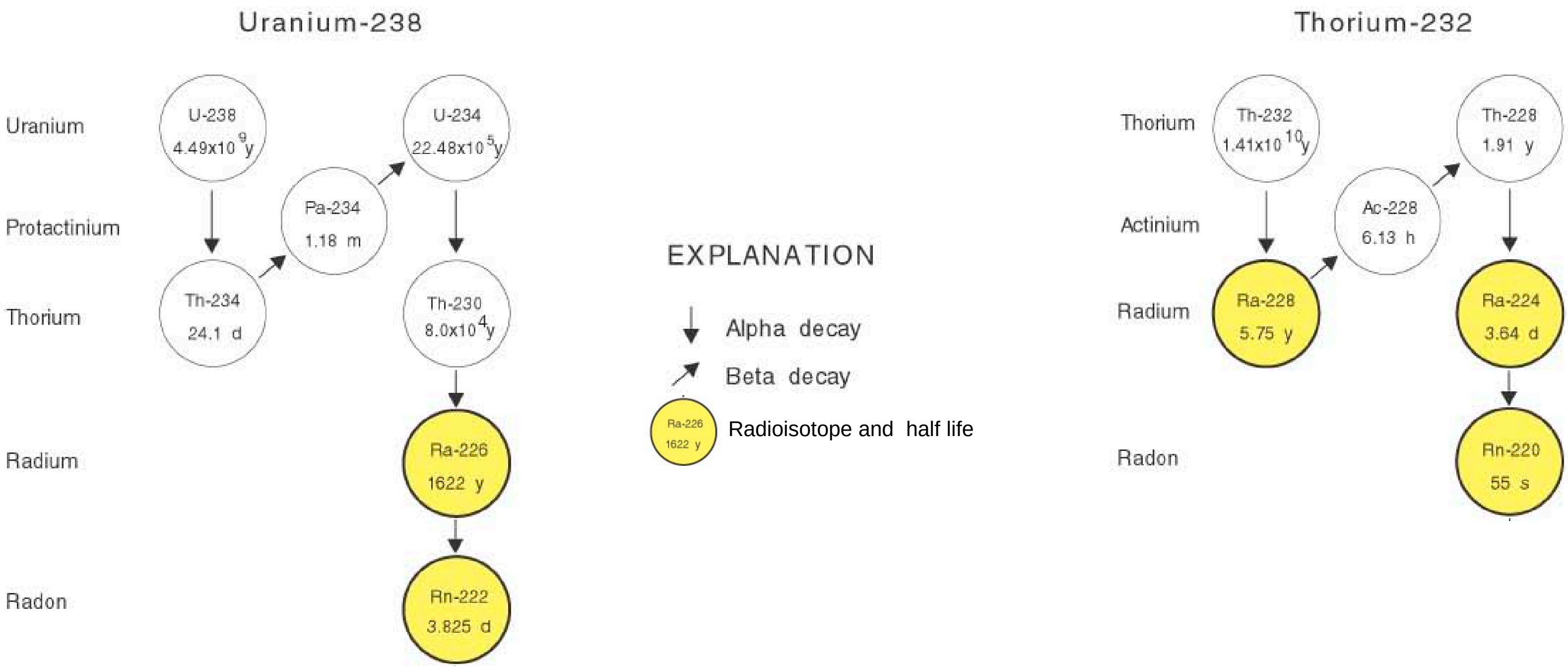



**Water quality of flowback (1.5 million gallons) from Marcellus shale well after completion of hydraulic fracturing (Samples were taken at 1, 2, and 3 third intervals of the 2-week flowback period, PADEP)**

# TDS and Radioactivity of Flowback Water



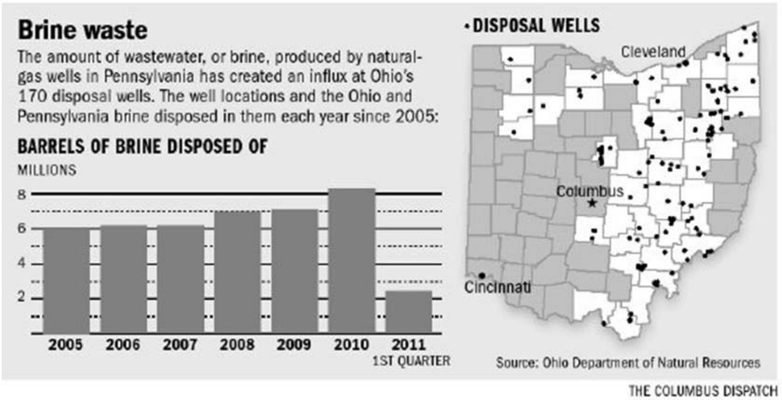
# Uranium & Thorium to Radium & Radon
# Radioactive Decay Series




## Brine from a Marcellus Shale-Gas Well

| | |
|---|---|
| Gross Alpha | 20,800 pCi/L |
| Gross Beta | 2,390 pCi/L |
| Radium 226 | 10,200 pCi/L |
| Radium 228 | 1,250 pCi/L |
| Thorium 228 | 47.5 pCi/L |
| Thorium 232 | 0.0 pCi/L |
| Uranium 234 | 0.5 pCi/L |

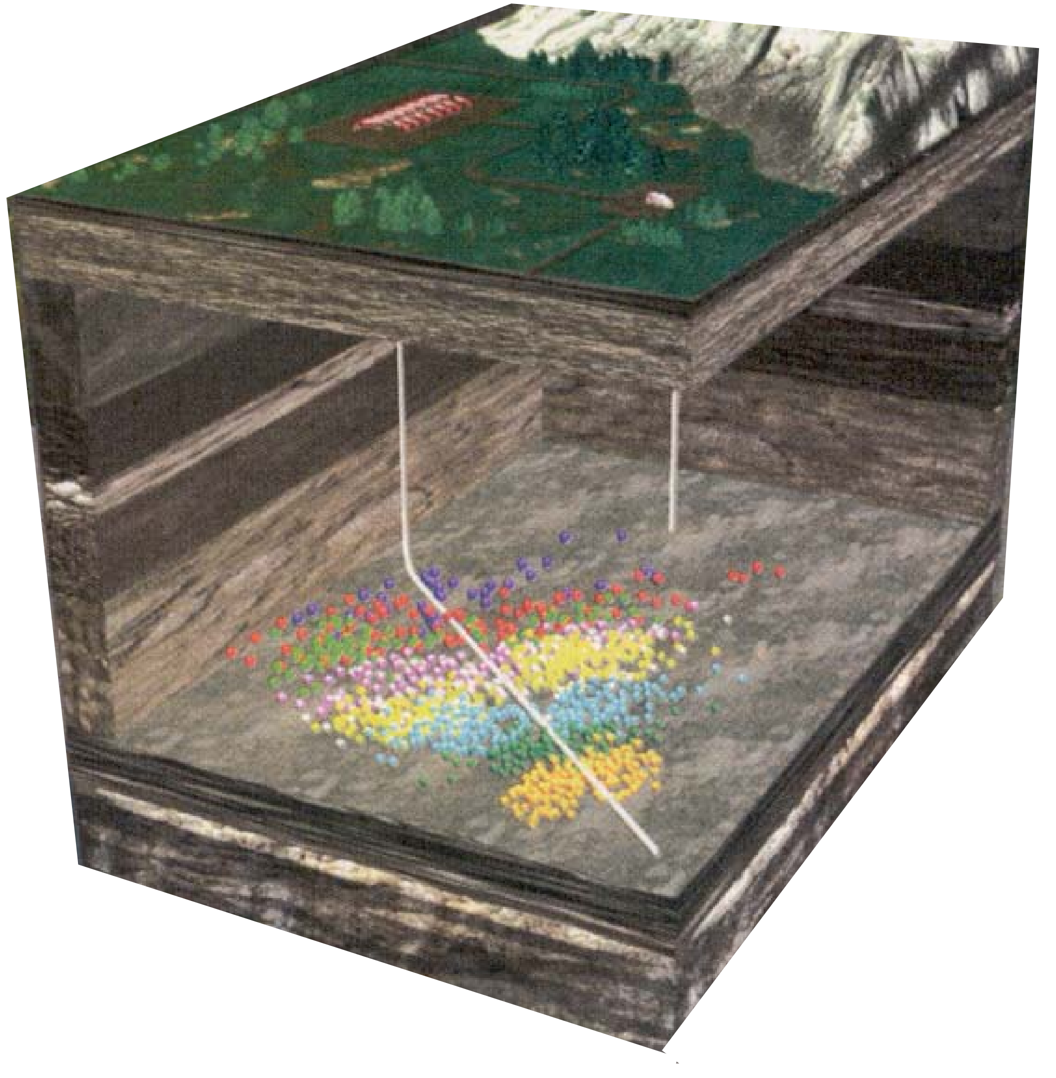
**Municipal wastewater treatment plants not designed to handle flowback chemistry**




**Limited number of disposal wells in Ohio**

**Reuse flowback, onsite treatment for solids / blend with 70 % freshwater**

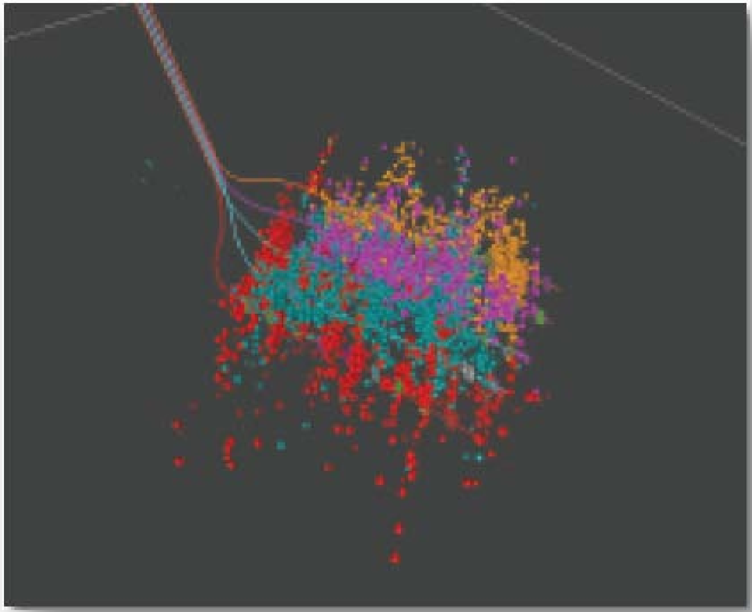
# Microseismic Monitoring of Hydraulic Fracturing



# Marcellus Hydraulic Fracturing

- Produces readily detectable microseismic events (400 per frac)
- Frac half lengths greater than 1,000 feet
- Frac azimuths typically east-northeast parallel to J1 joint sets
- Reactivation of pre-existing joints by strike-slip failure

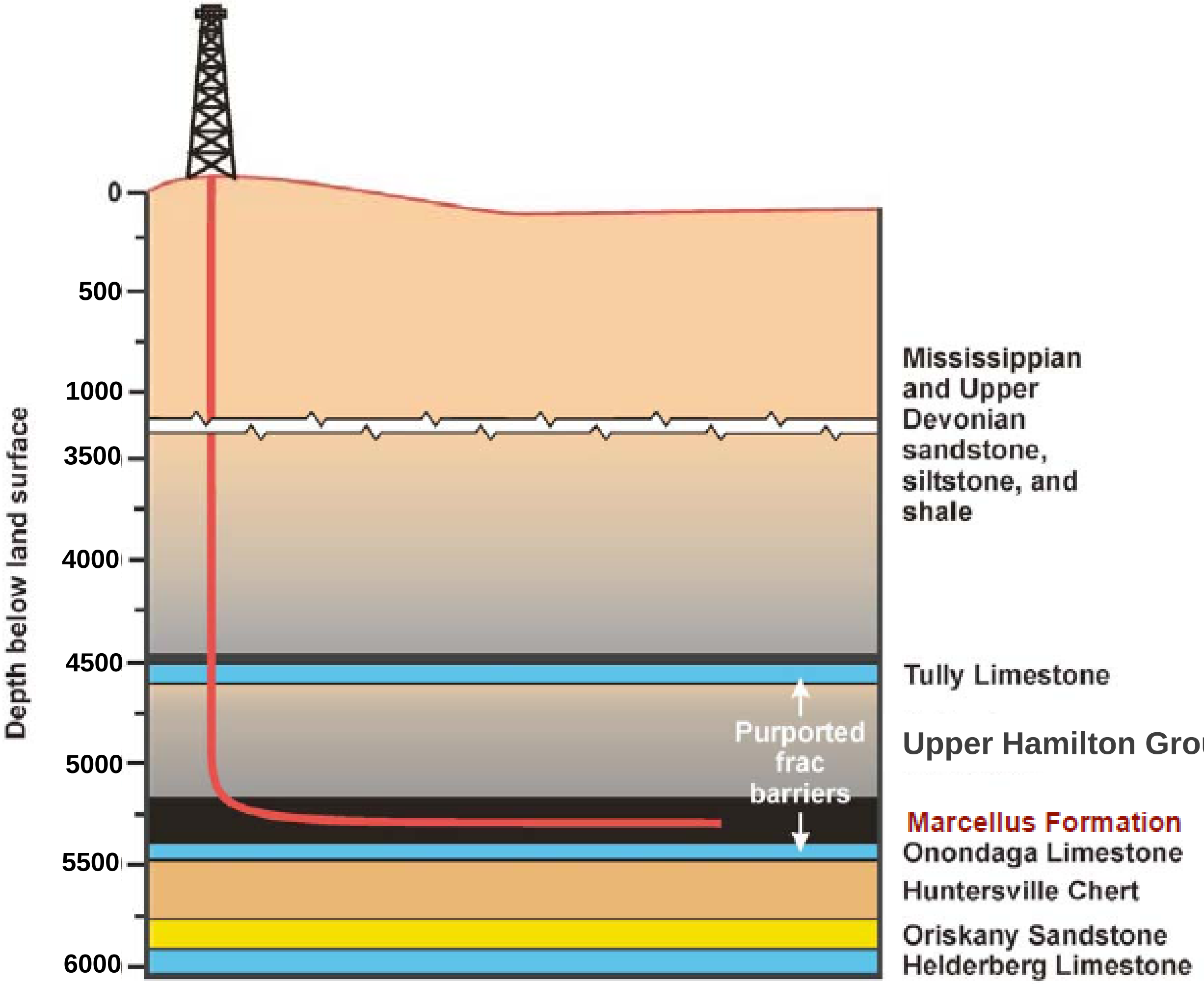
Duncan and Williams-Stroud (2009)



Microseismic for five Marcellus laterals

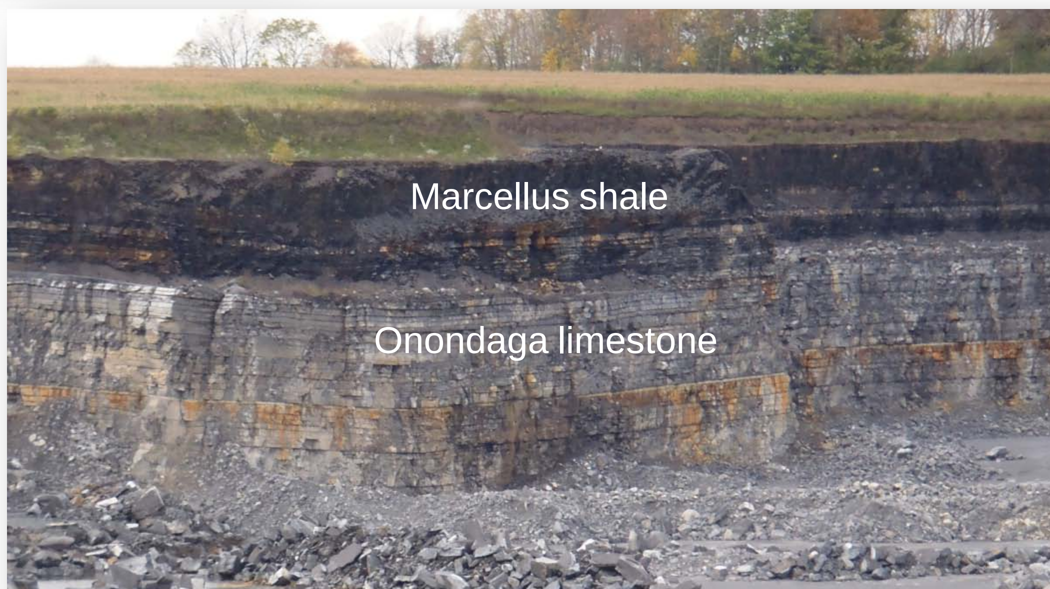

Joint sets in the Appalachian Basin

# Stratigraphy and Frac Barriers



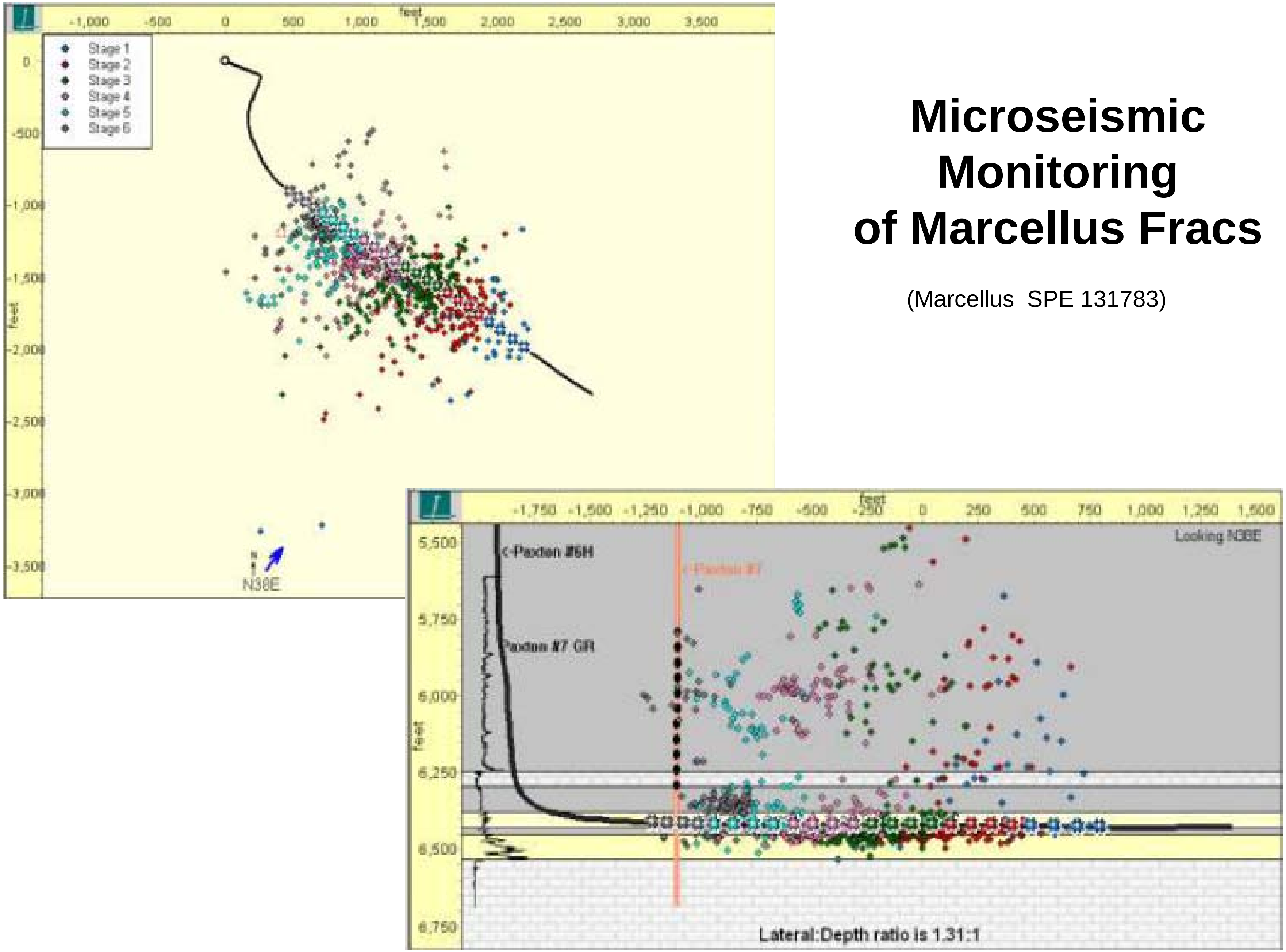

Modified from Kostelnick (2010)


Tully limestone
Upper Hamilton shale


Marcellus shale
Onondaga limestone

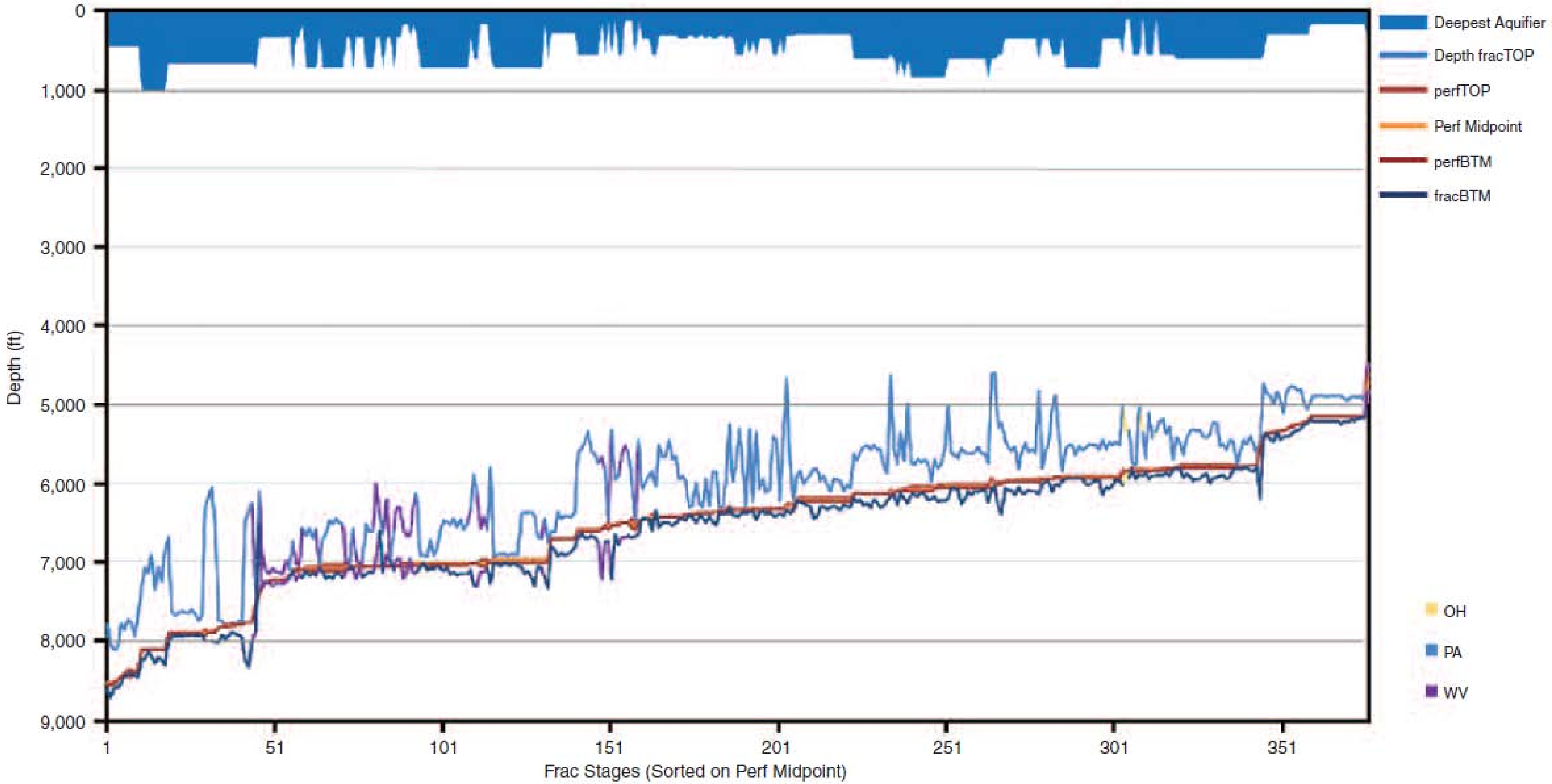
# Microseismic Monitoring of Marcellus Fracs

(Marcellus SPE 131783)



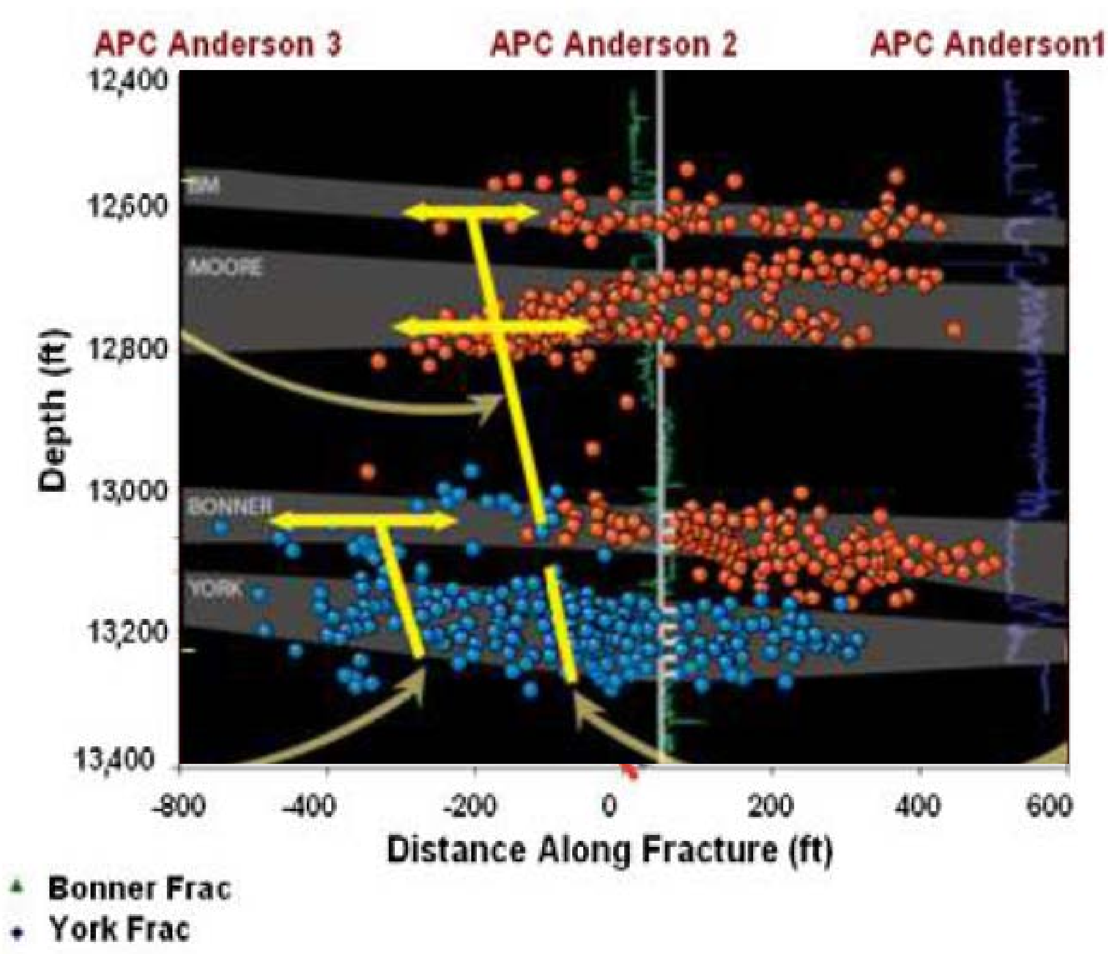
# Microseismic Mapped Frac Tops and Bottoms

## Marcellus Shale



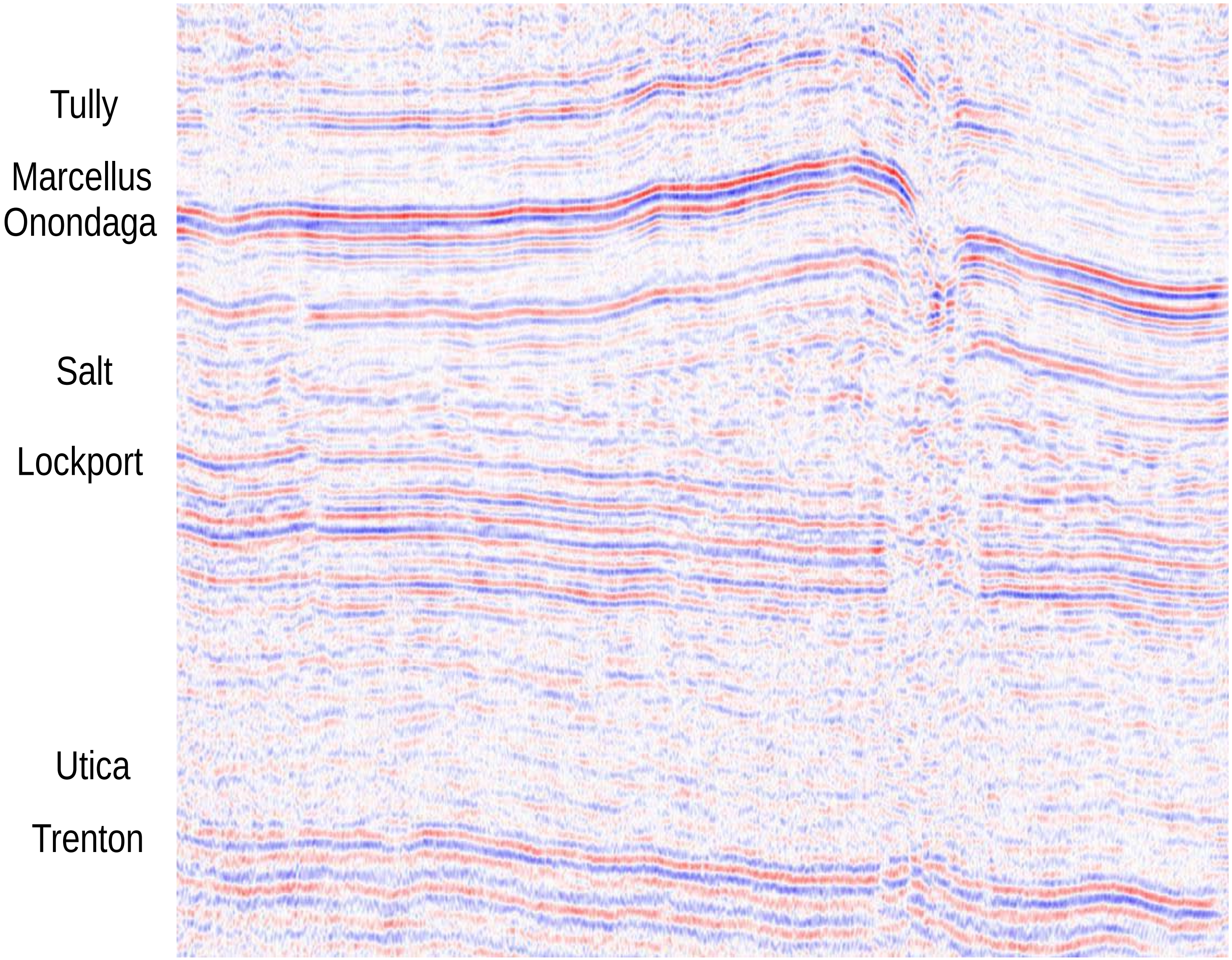

Fisher (2010)

# Fracing near faults



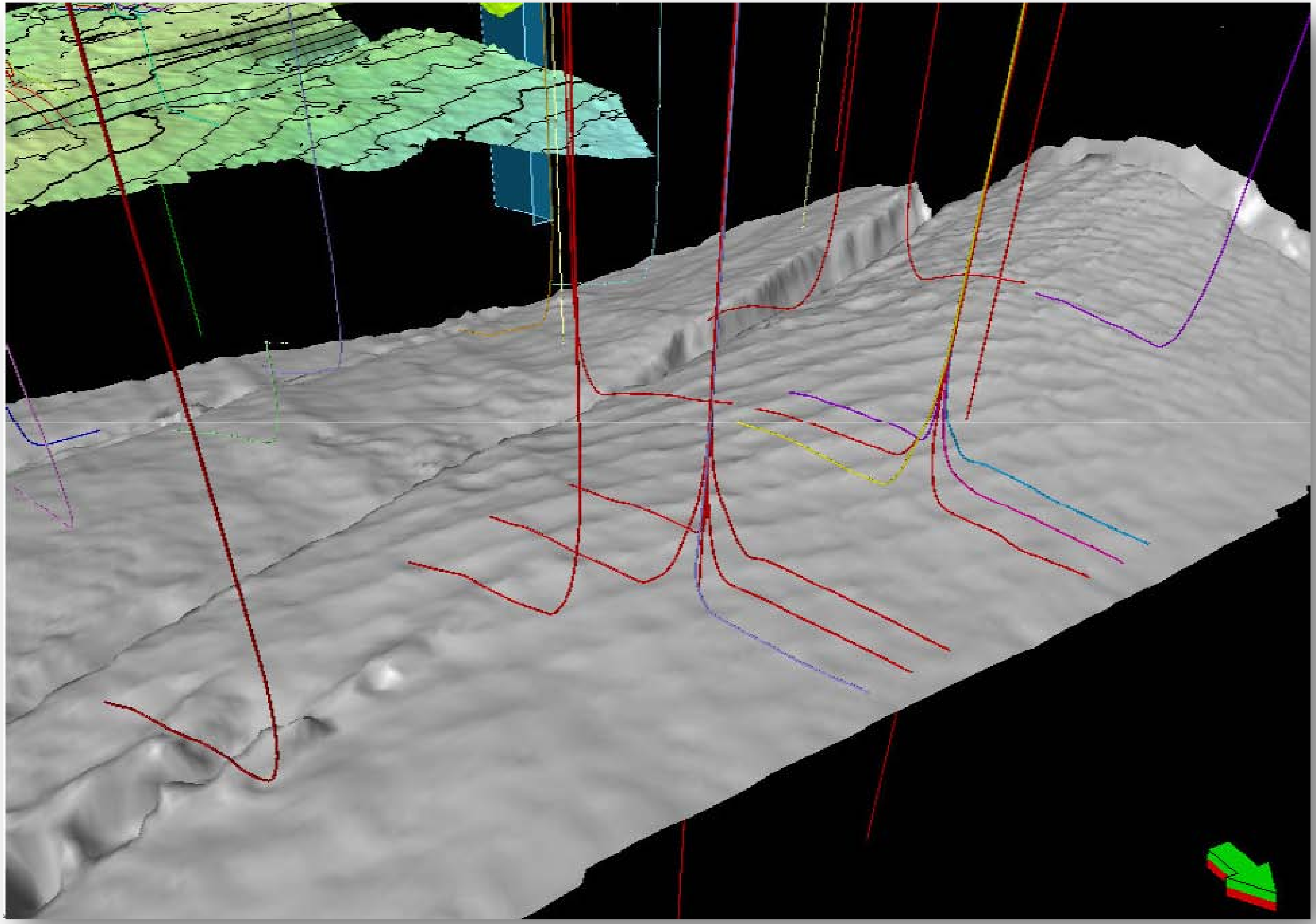

Sharma and others (2003)

# Seismic Line from South-Central New York



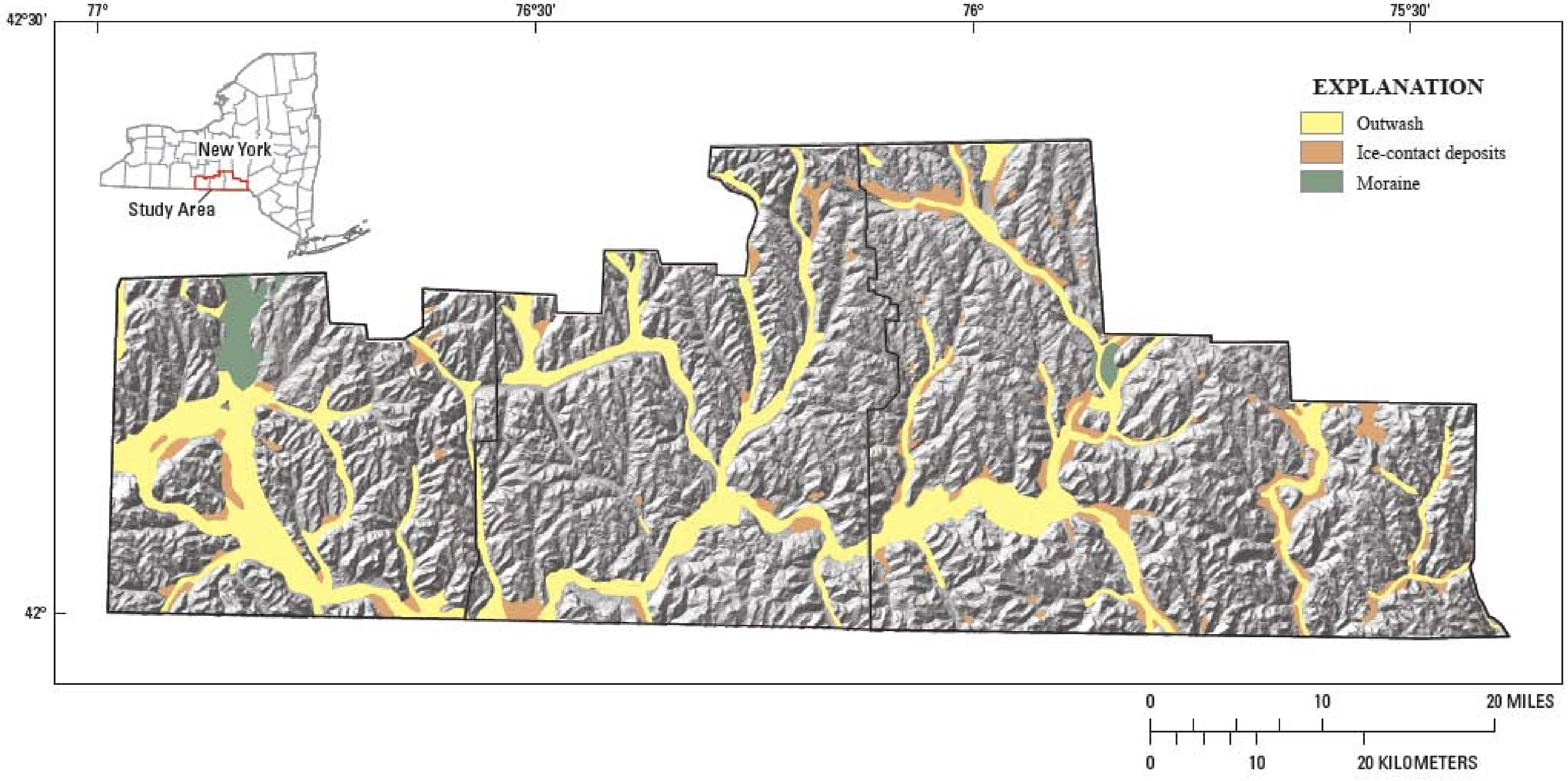

Smith (2010)

# Avoid Structures



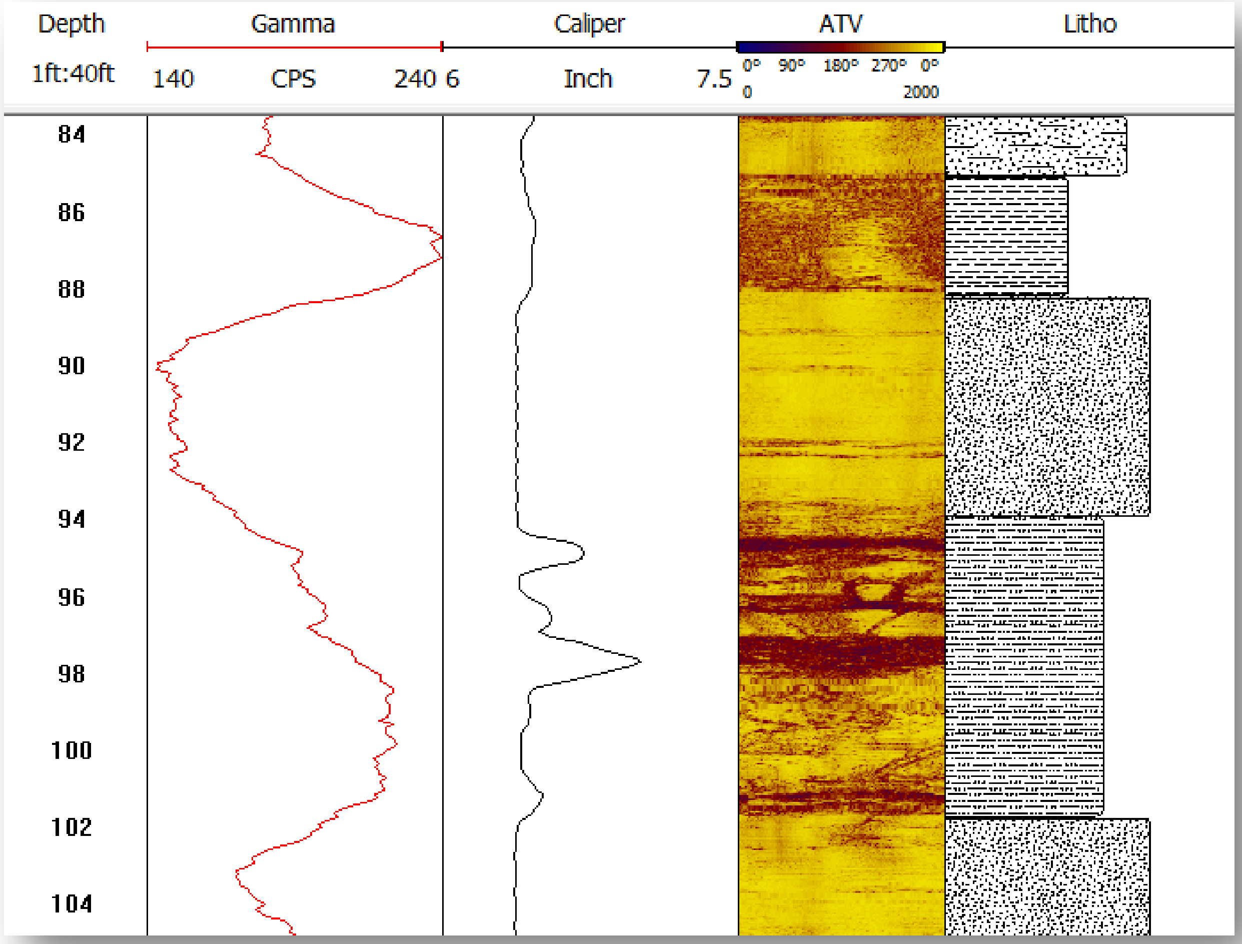
Teff (2011)

# Valley-Fill Aquifers



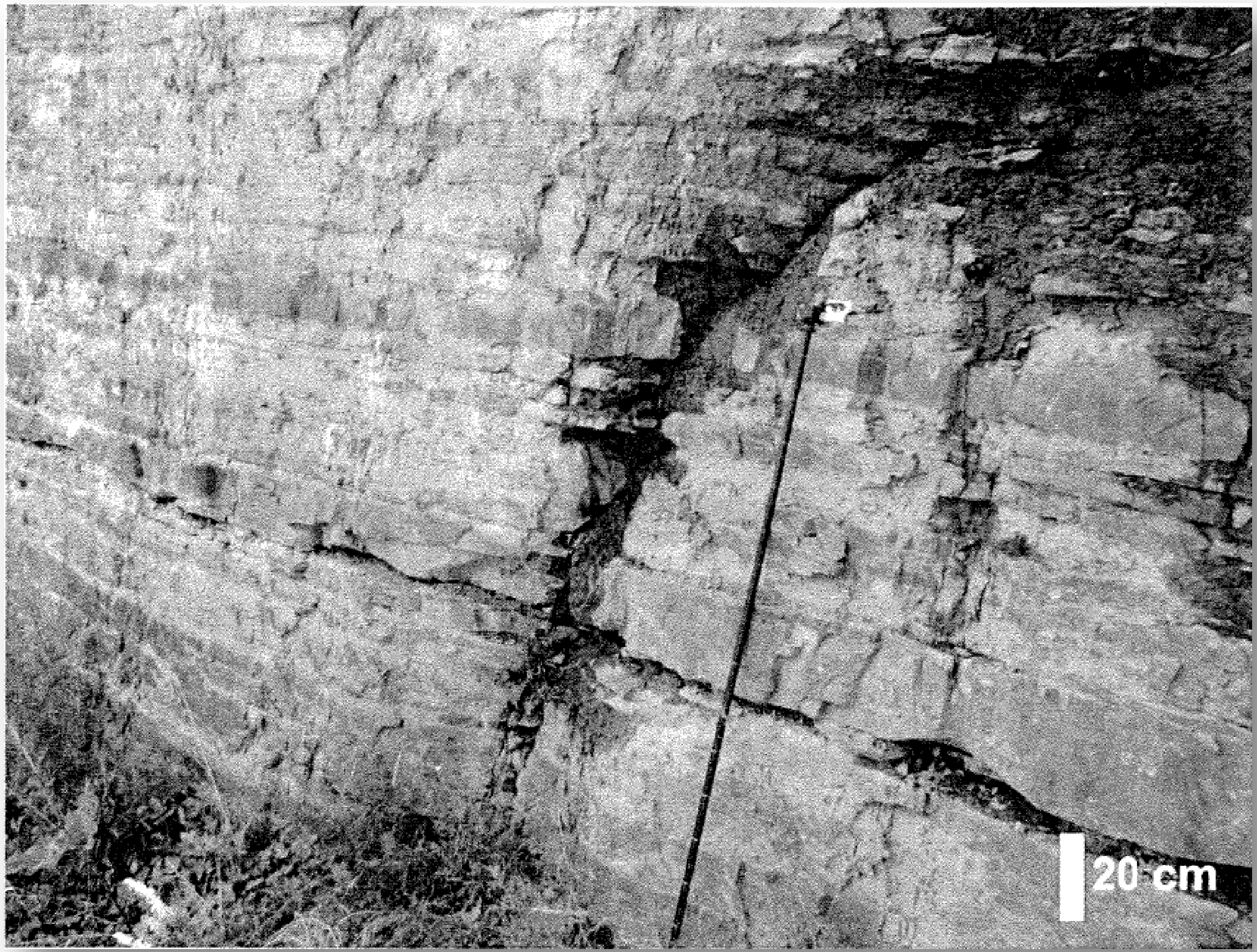

Saturated deposits of glacial sand and gravel

# Upper Devonian Fractured-Bedrock Aquifers



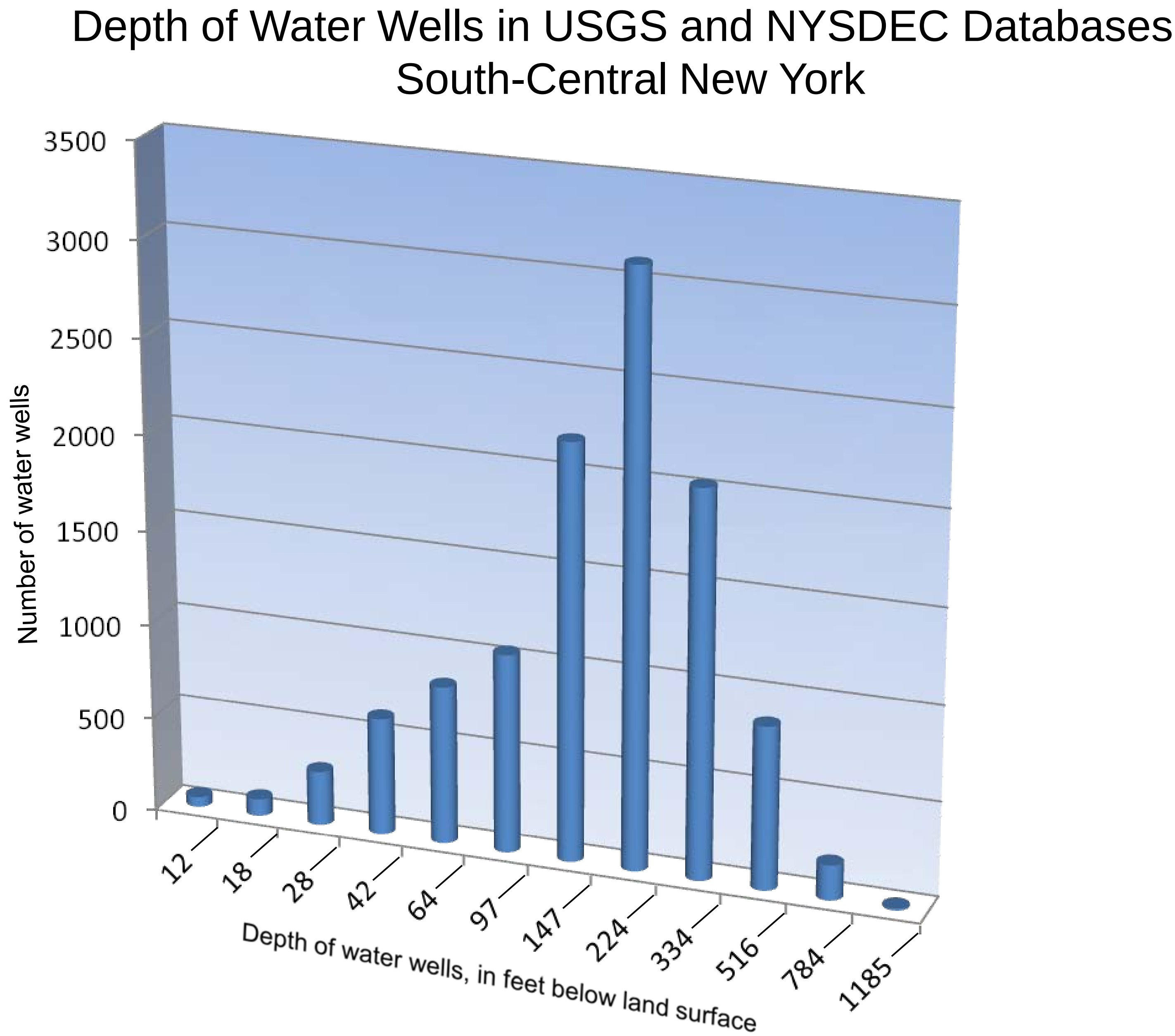

Fractured zone in Catskill Formation

# Upper Devonian Fractured-Bedrock Aquifers

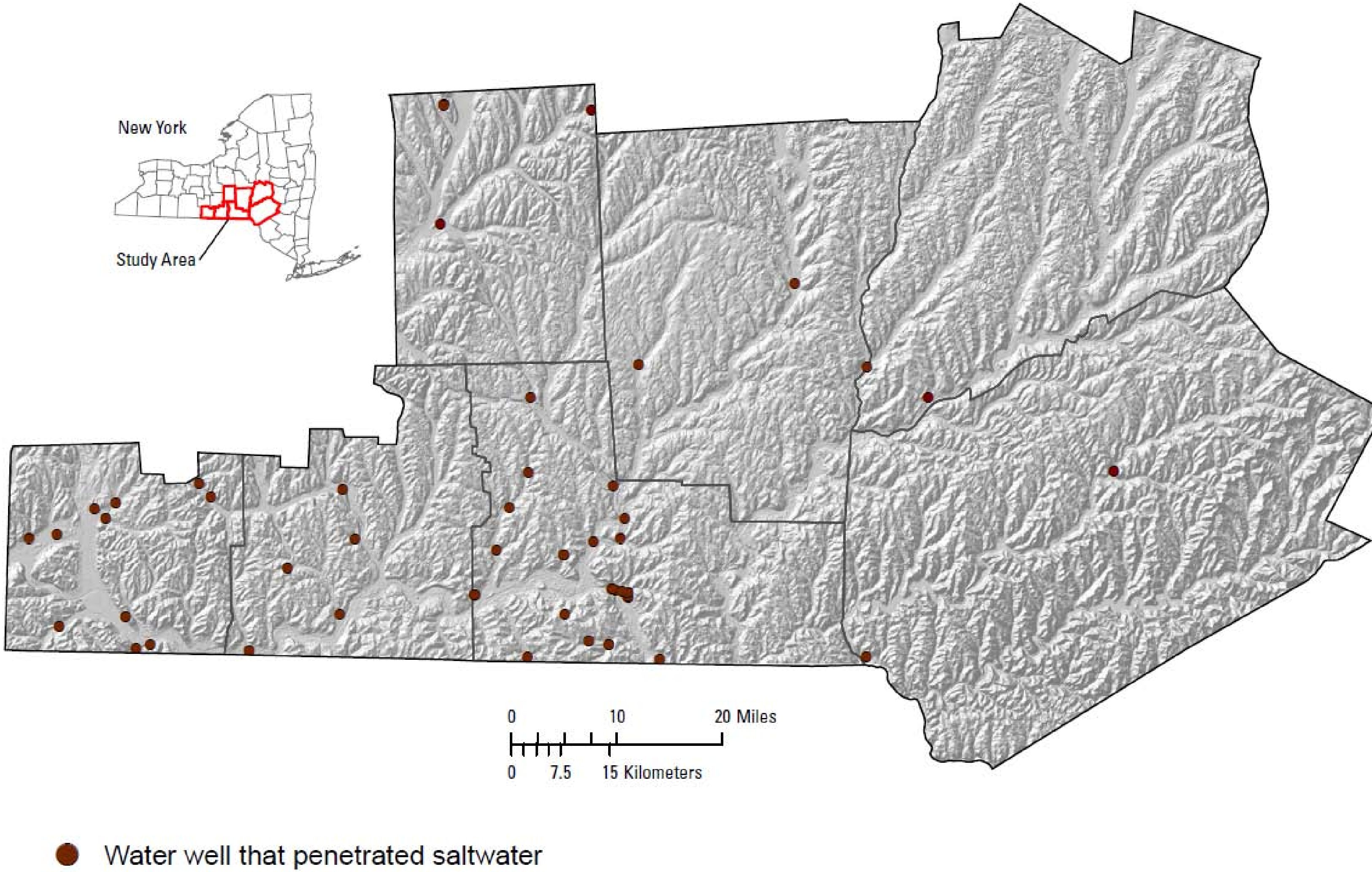



Bedding fracture and joint in Lock Haven Formation

Braun and others (2011)

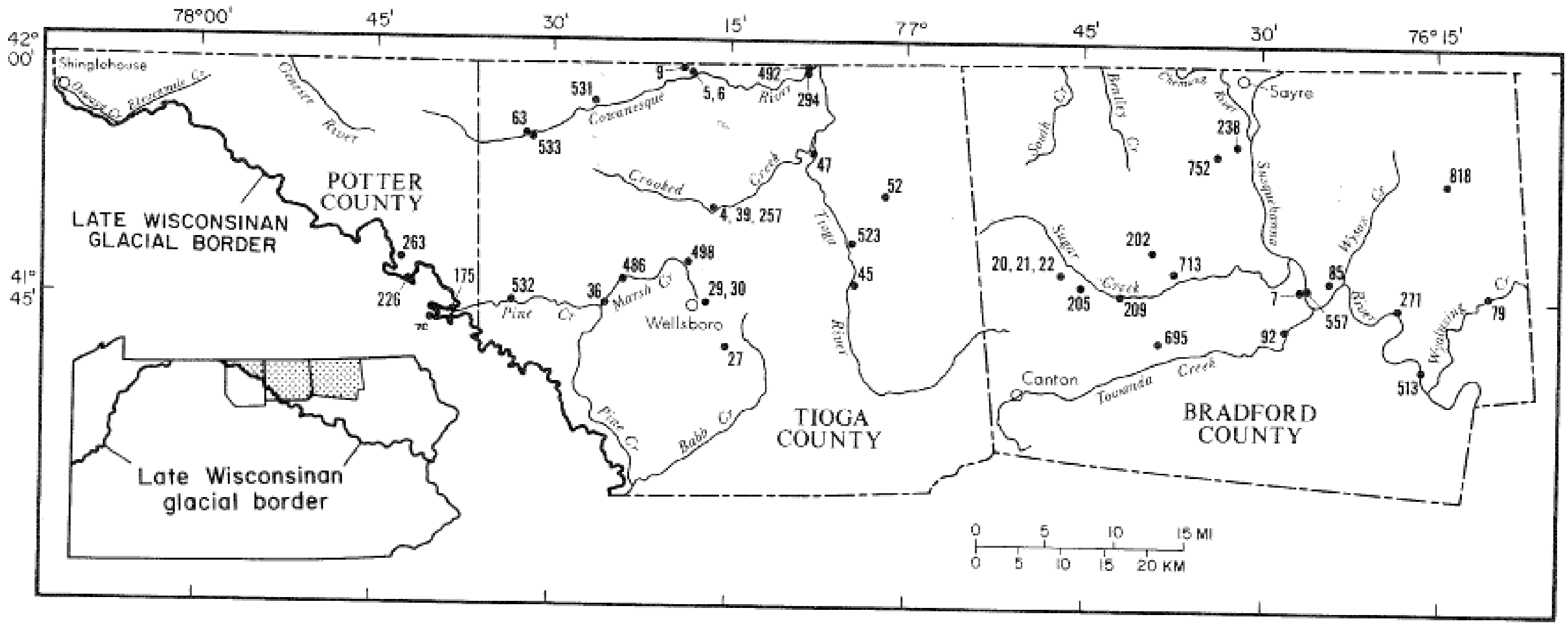

Depth of Water Wells in USGS and NYSDEC Databases
South-Central New York
Number of water wells
3500
3000
2500
2000
1500
1000
500
0
12
18
28
42
64
97
147
224
334
516
784
1185
Depth of water wells, in feet below land surface

# Water Wells that Penetrated Saltwater in South-Central New York



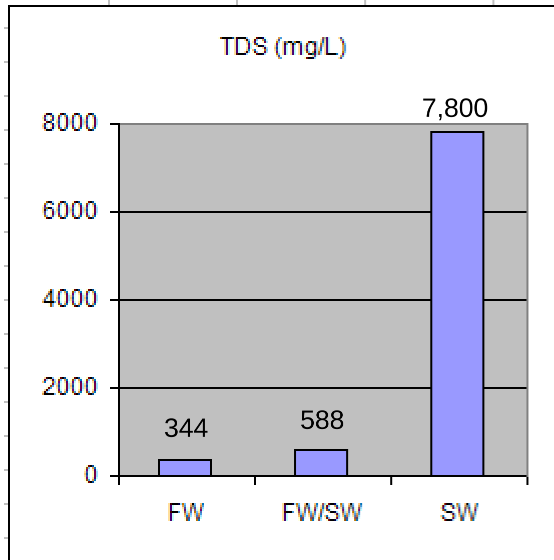

Modified from Williams (2011)

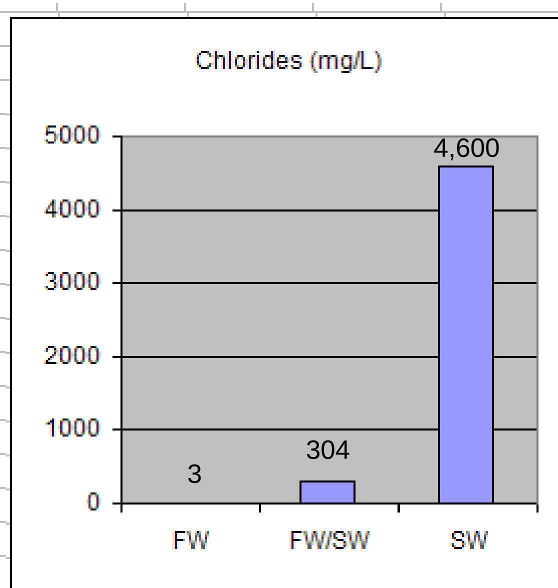
# Water Wells that Penetrated Saltwater in North-Central Pennsylvania

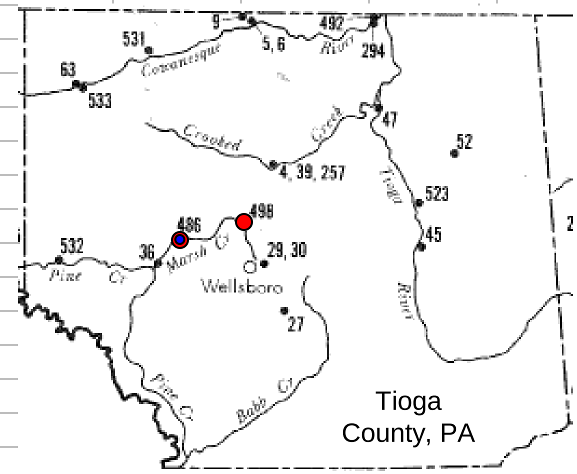



Williams and others (1998)

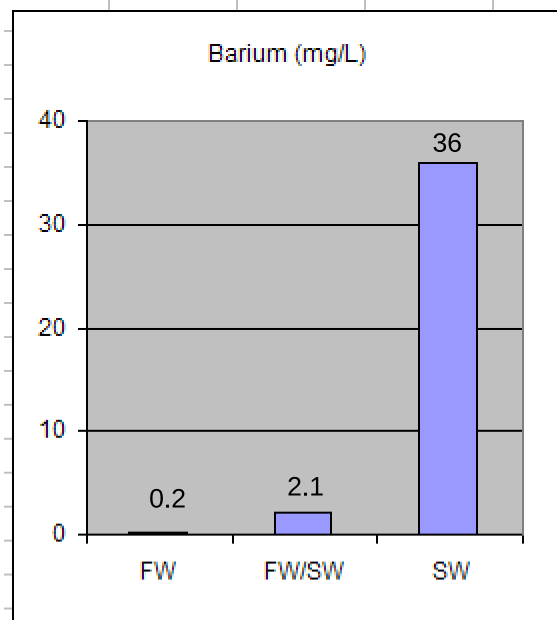
# Water Quality of Typical Freshwater and Salty Water Wells in Upper Devonian Bedrock

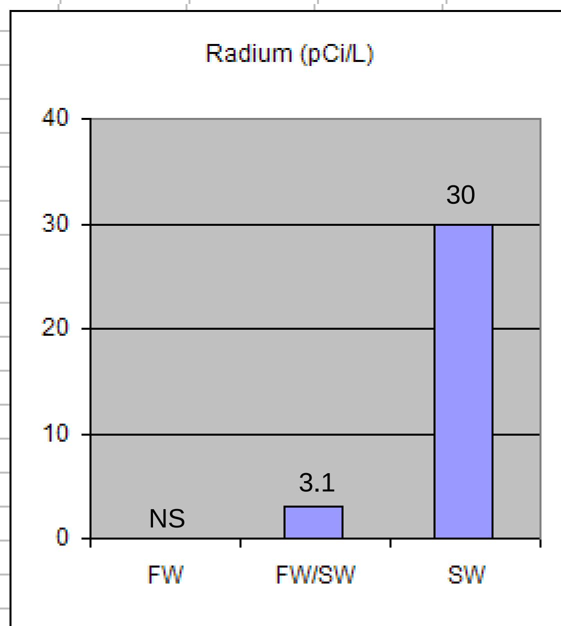


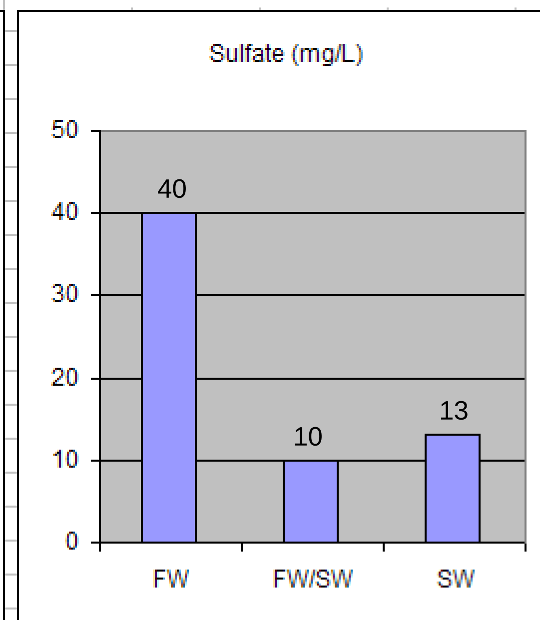



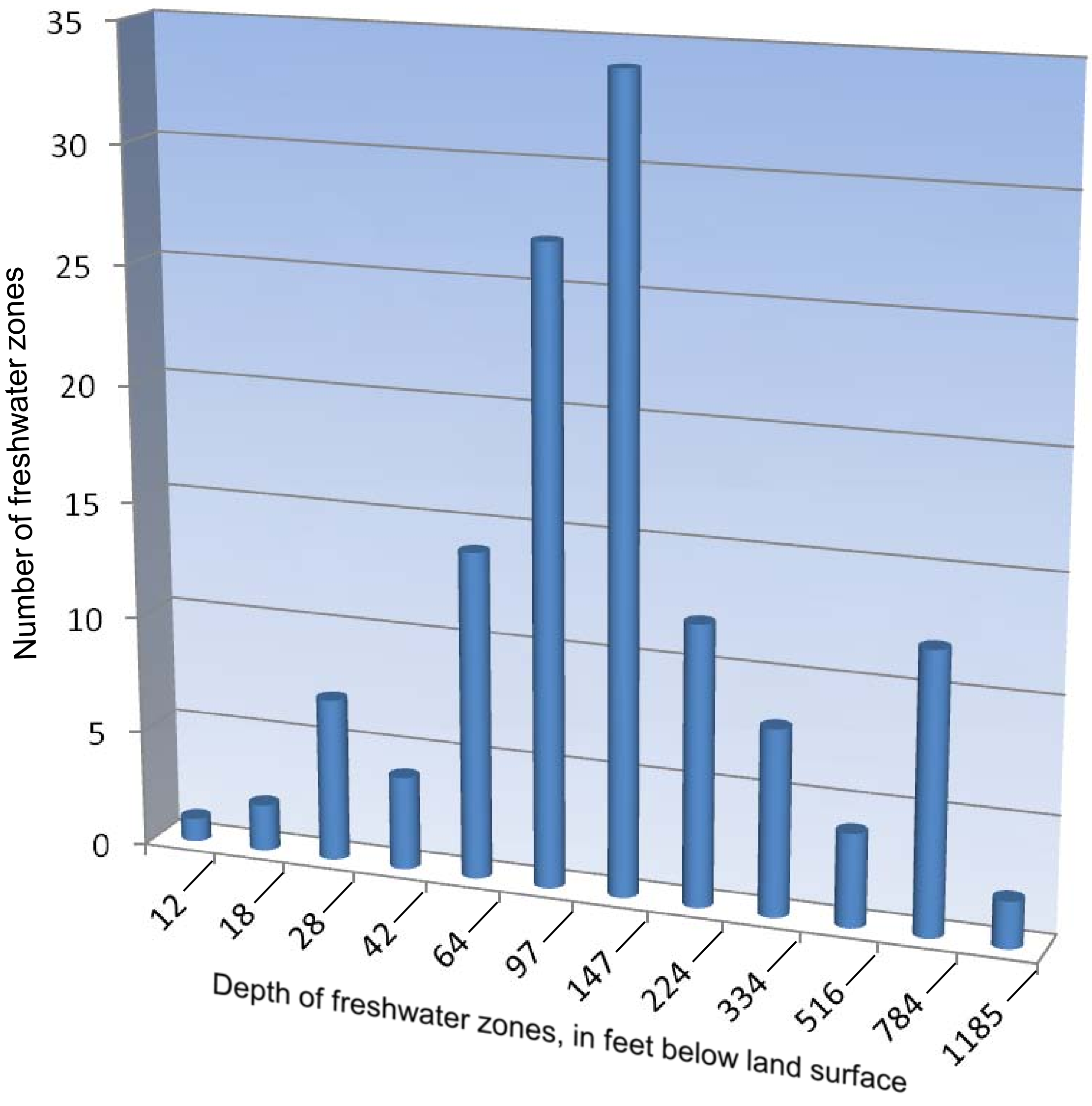

Salty water wells
(Williams and others, 1998)



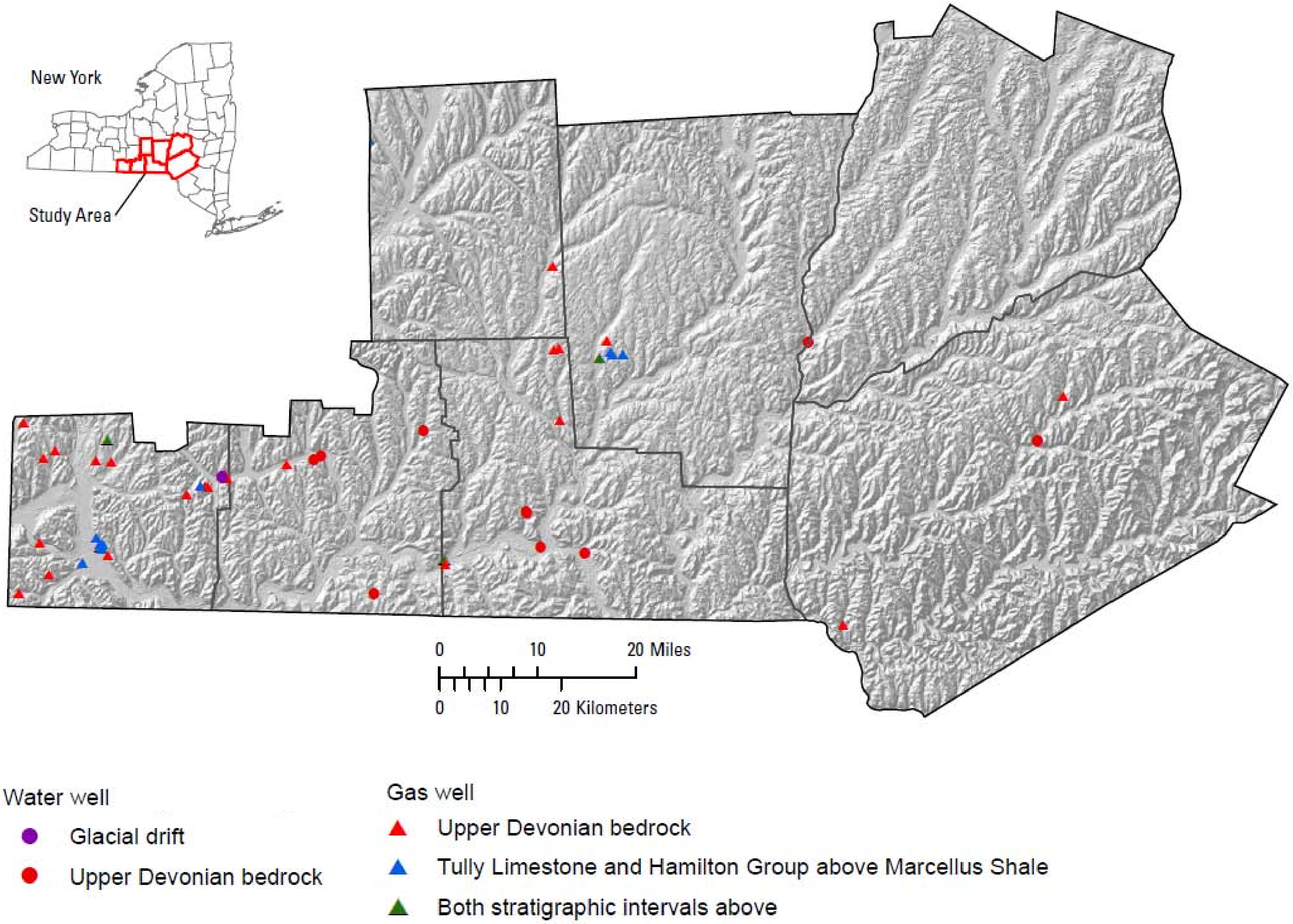



# Depth of Freshwater Zones Penetrated by Gas Wells
# South-Central New York

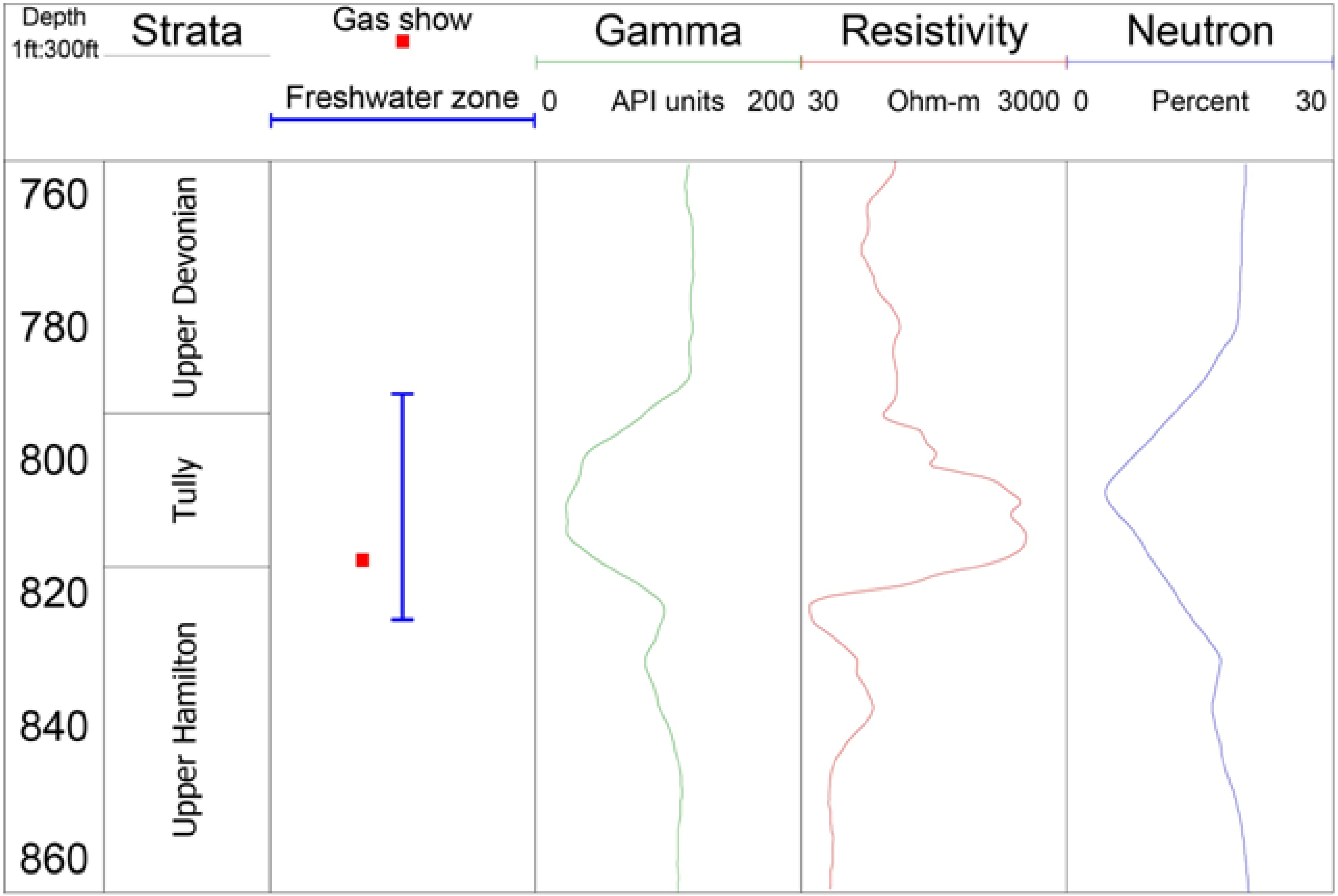


# Wells that Penetrated Gas above the Marcellus Shale
# South Central New York



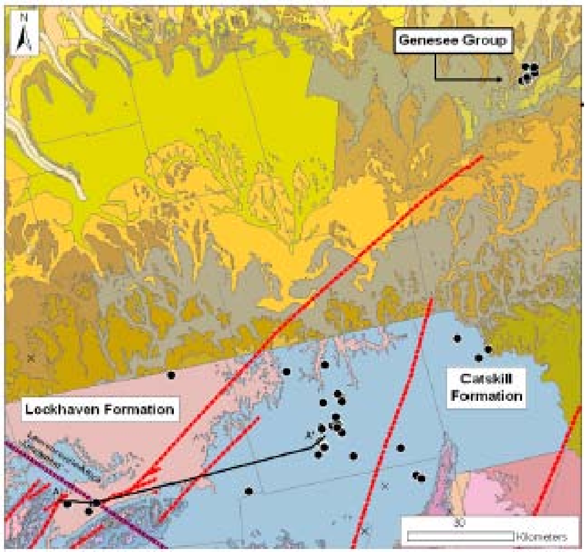

Modified from Williams (2011)

# Freshwater and Gas in Close Vertical Proximity

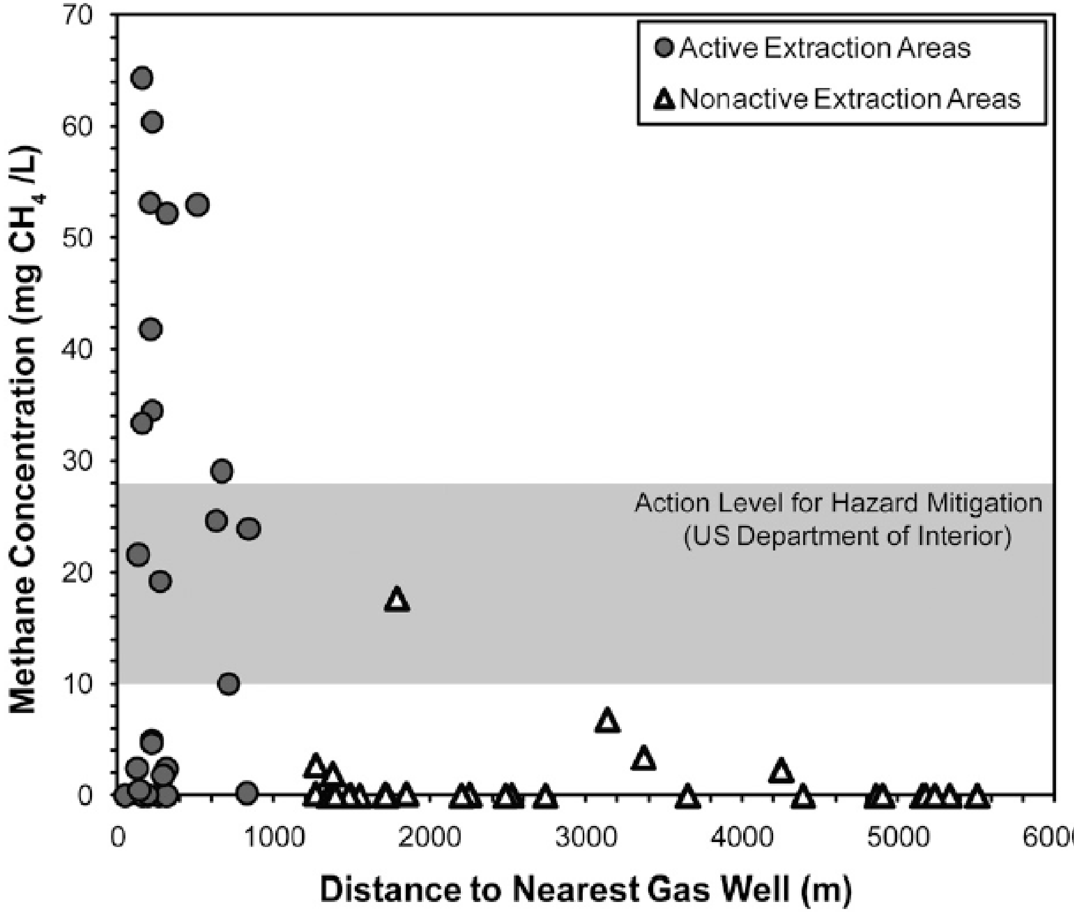


# Methane in Water Wells

**Marcellus/Utica Gas-Play Area**

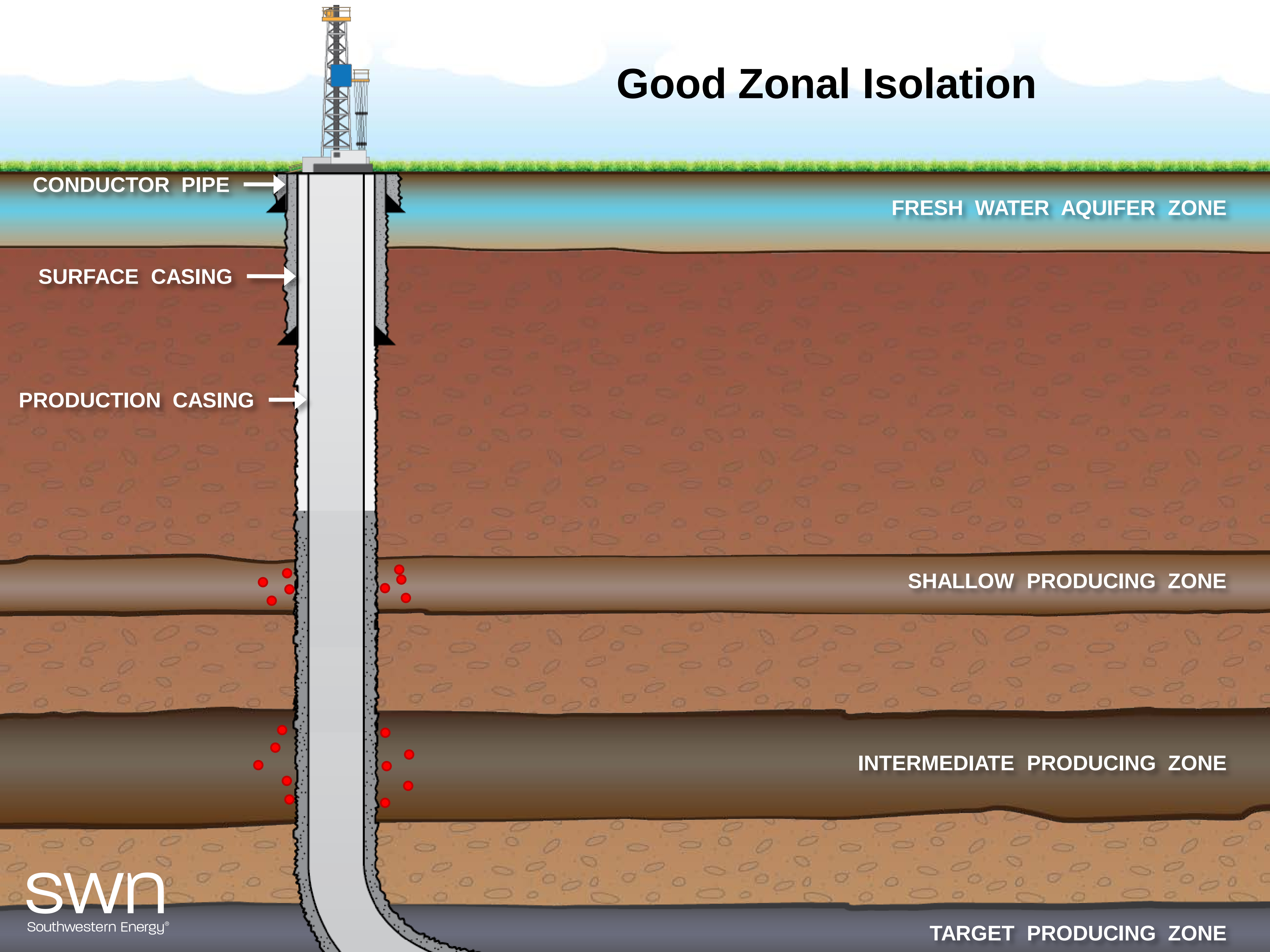



Sampling sites

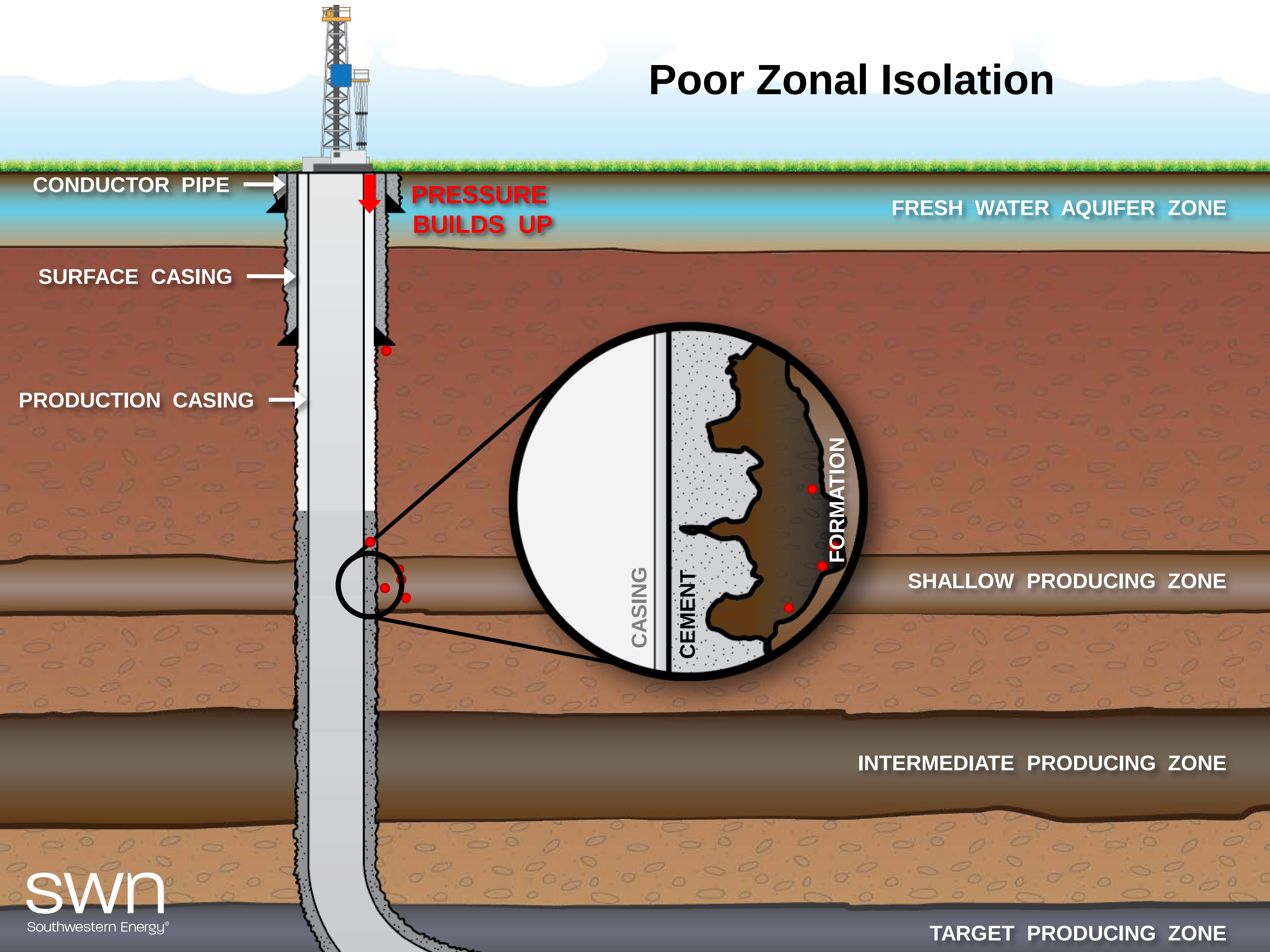



Osborn and others (2011)

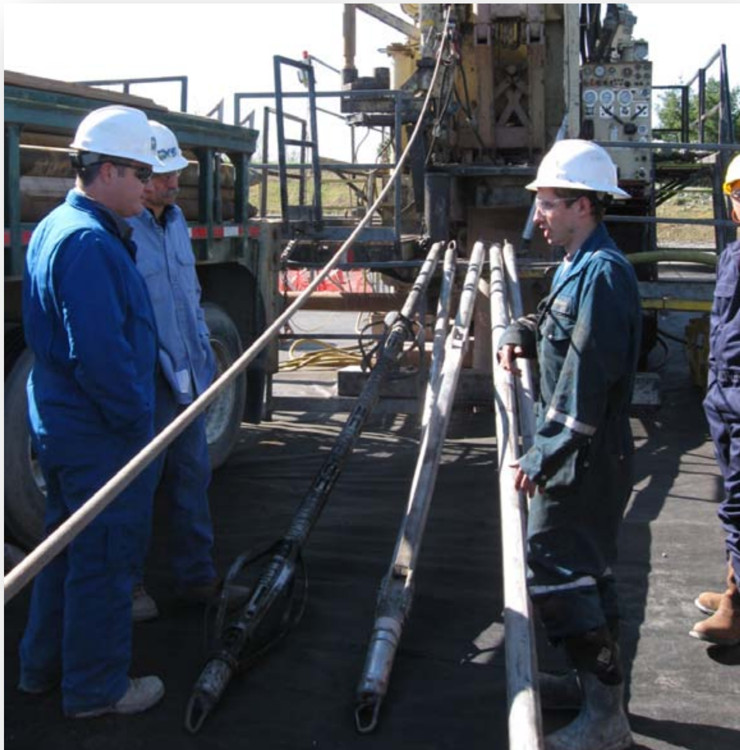
# Good Zonal Isolation



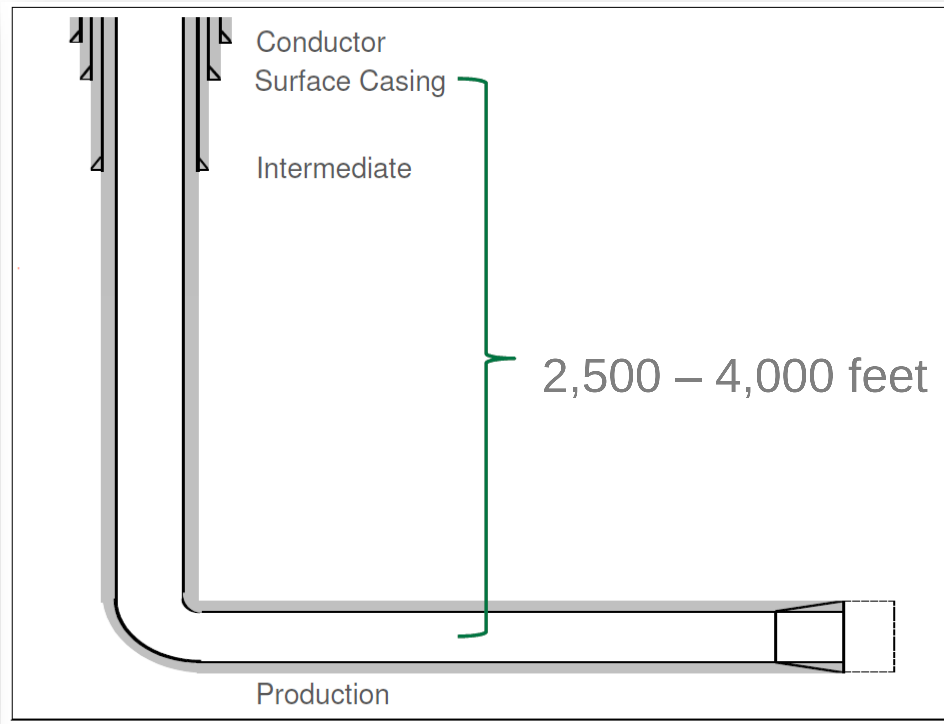
# Poor Zonal Isolation



# Protection of Freshwater Aquifer

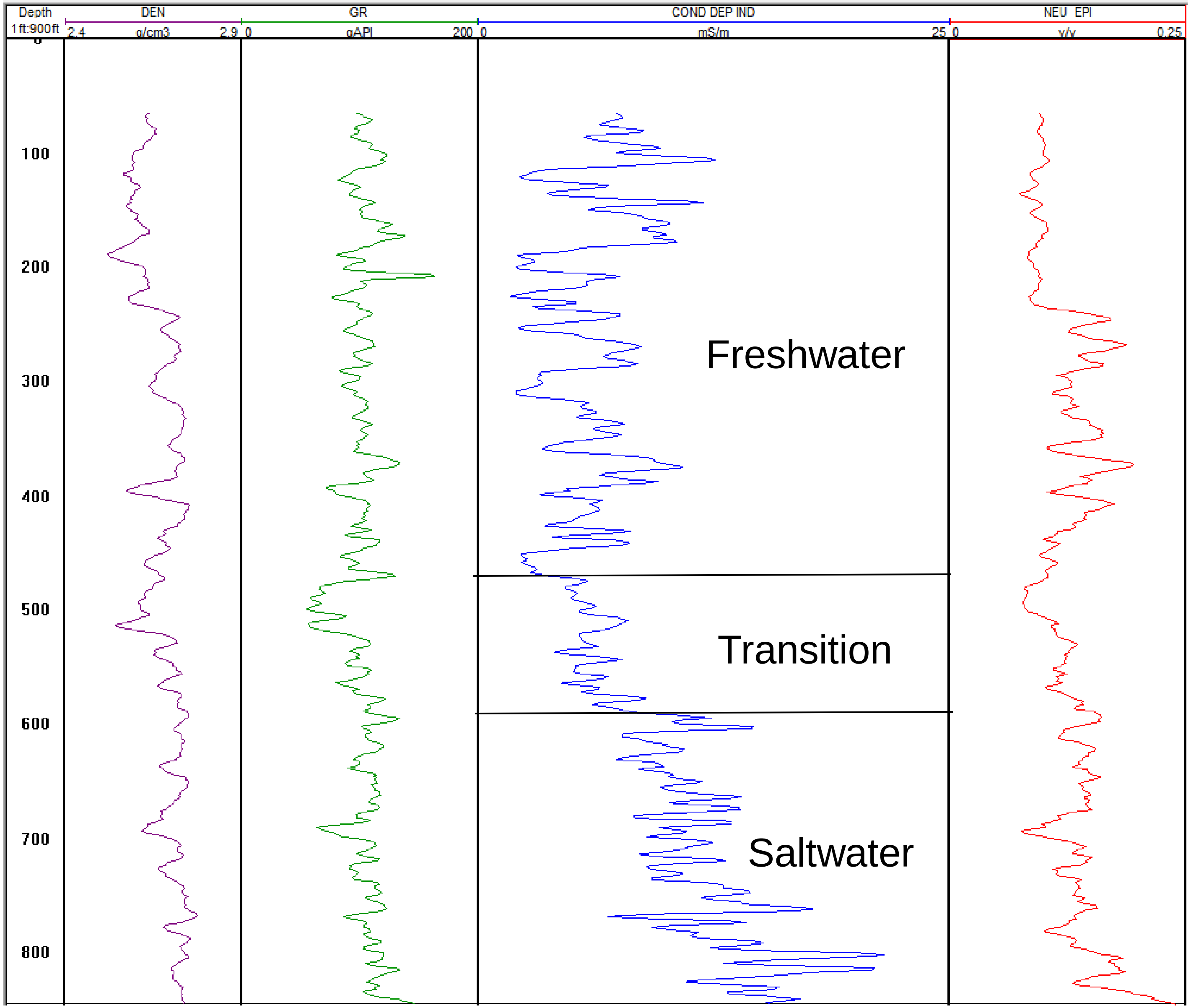


Characterization of deep freshwater and shallow gas and saltwater




Engineered zonal isolation by multiple casings, cement, packers, and venting

# Geophysical Logs and Base of Freshwater Aquifer

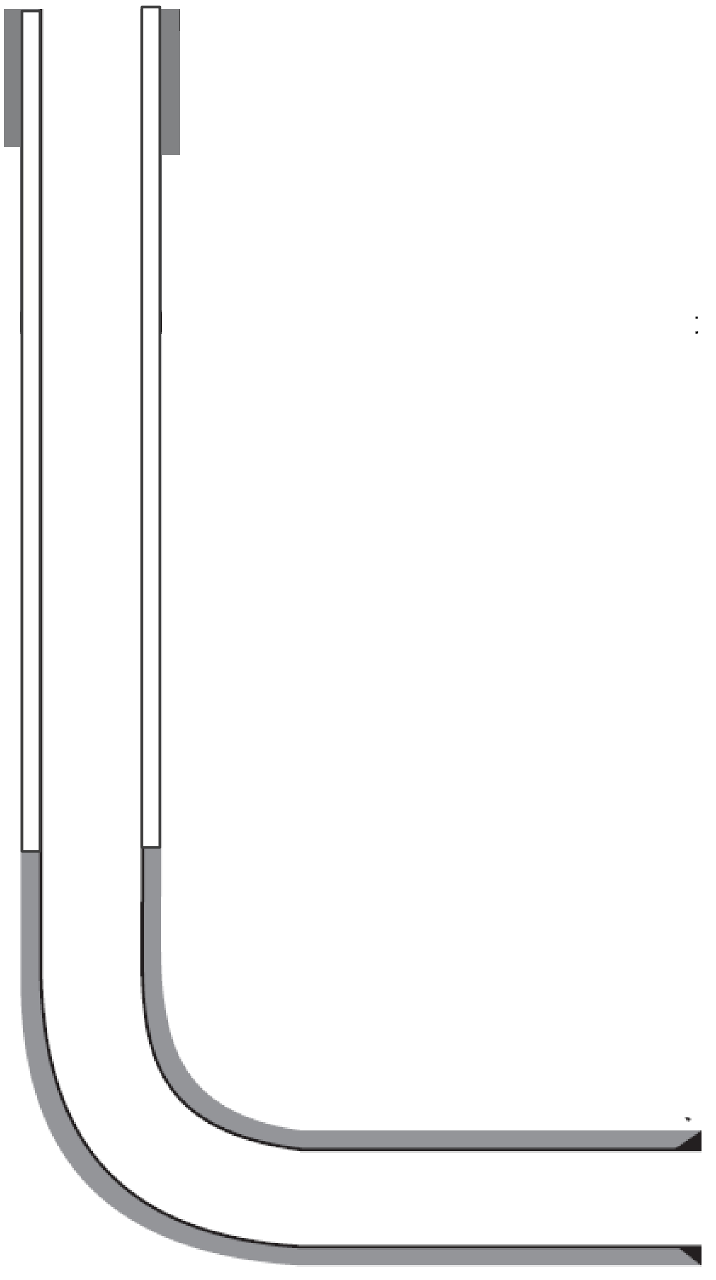



Log data courtesy
of Shell Appalachia

# Shale Gas Development

**Typical past practices**

- Cemented surface casing may not be deep enough to protect freshwater aquifer
- Open annulus interval between top of production casing cement to bottom of surface casing may allow upward migration of salty water and gas
- Drilling and frac fluid storage in surface impoundments and burial of drill cuttings onsite may contaminant shallow groundwater and surface water
- One-time use of frac fluid wasteful of freshwater resources and creates disposal issue
- No water-well sampling before drilling/hydraulic fracturing operation



# 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 salty water and 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"