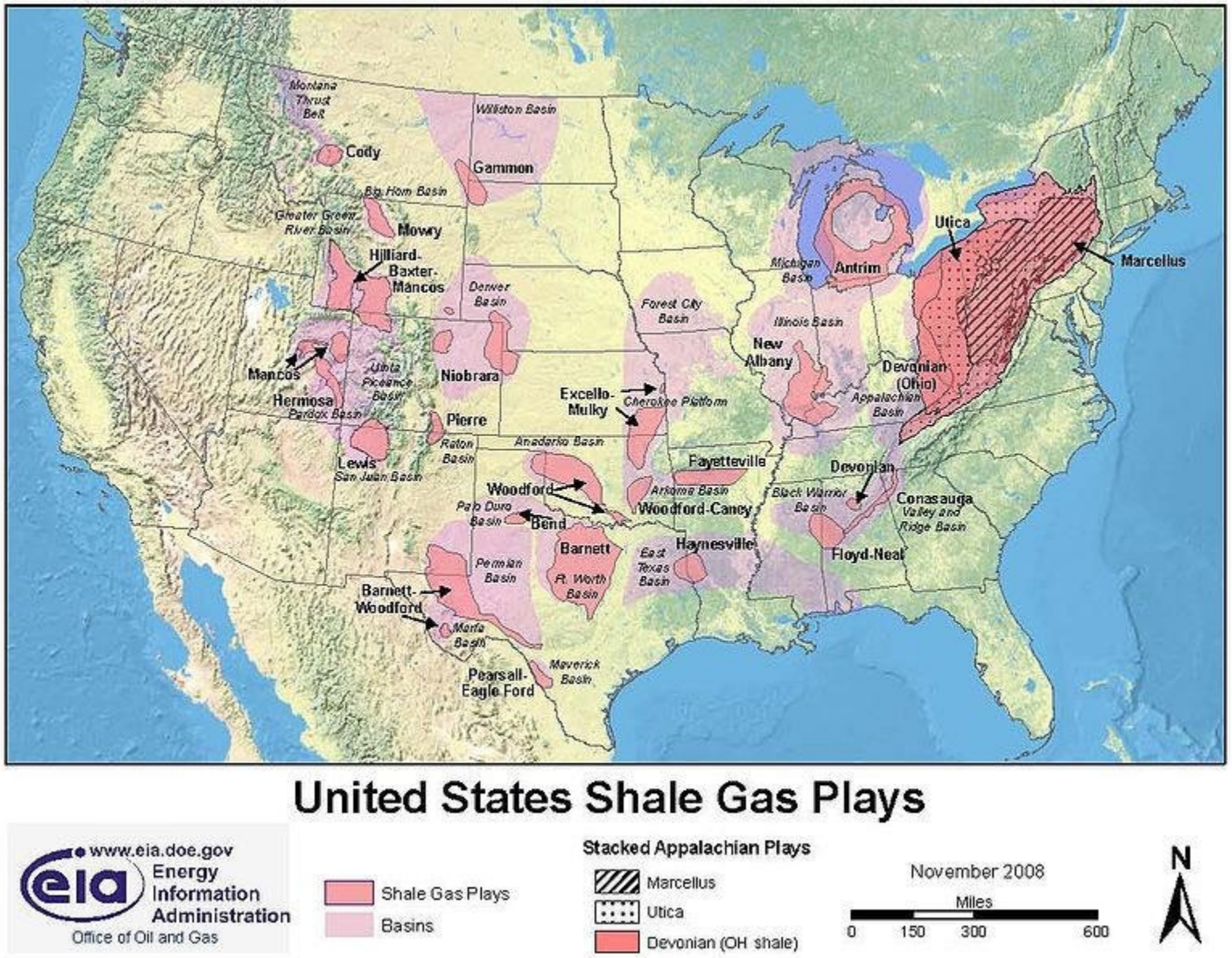
The Marcellus

Lecture 20
Fundamentals of Earth Resources

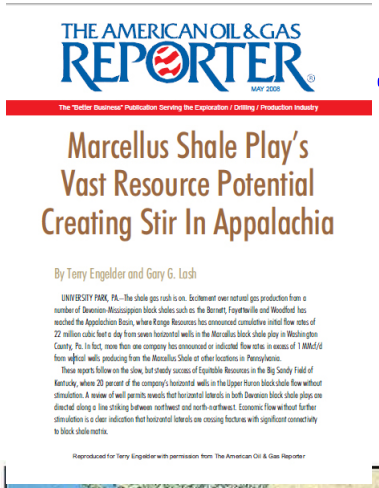
L. M. Cathles
2017

The Marcellus is a gas-rich shale that underlies NY, PA, OH,VA, WVa



http://www.energyindustryphotos.com/shale_gas_map_shale_basins.htm

The resource is unconventional and significant


THE AMERICAN OIL & GAS REPORTER

The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

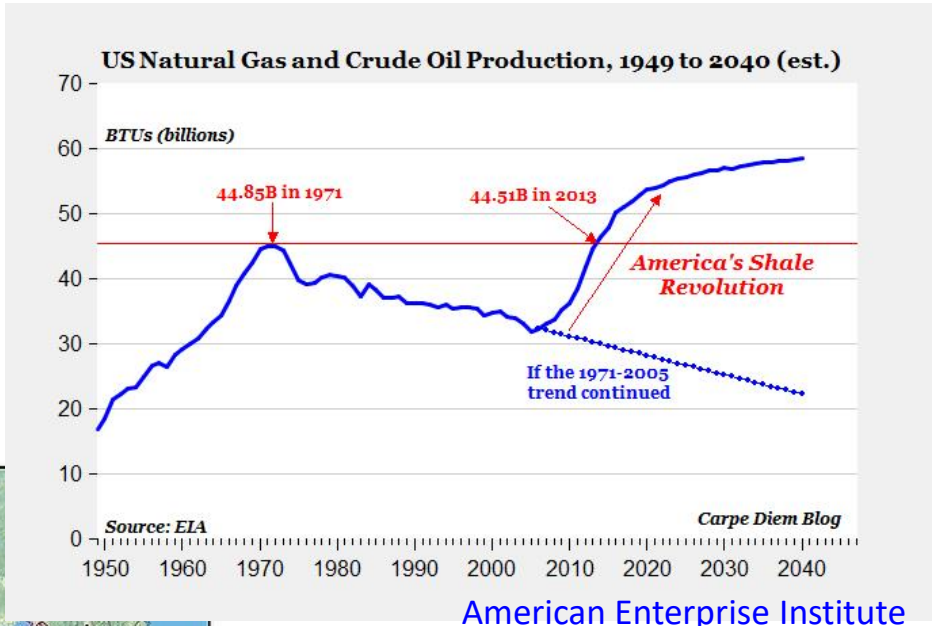
Marcellus Shale Play's Vast Resource Potential Creating Stir In Appalachia

By Terry Engelder and Gary G. Lash

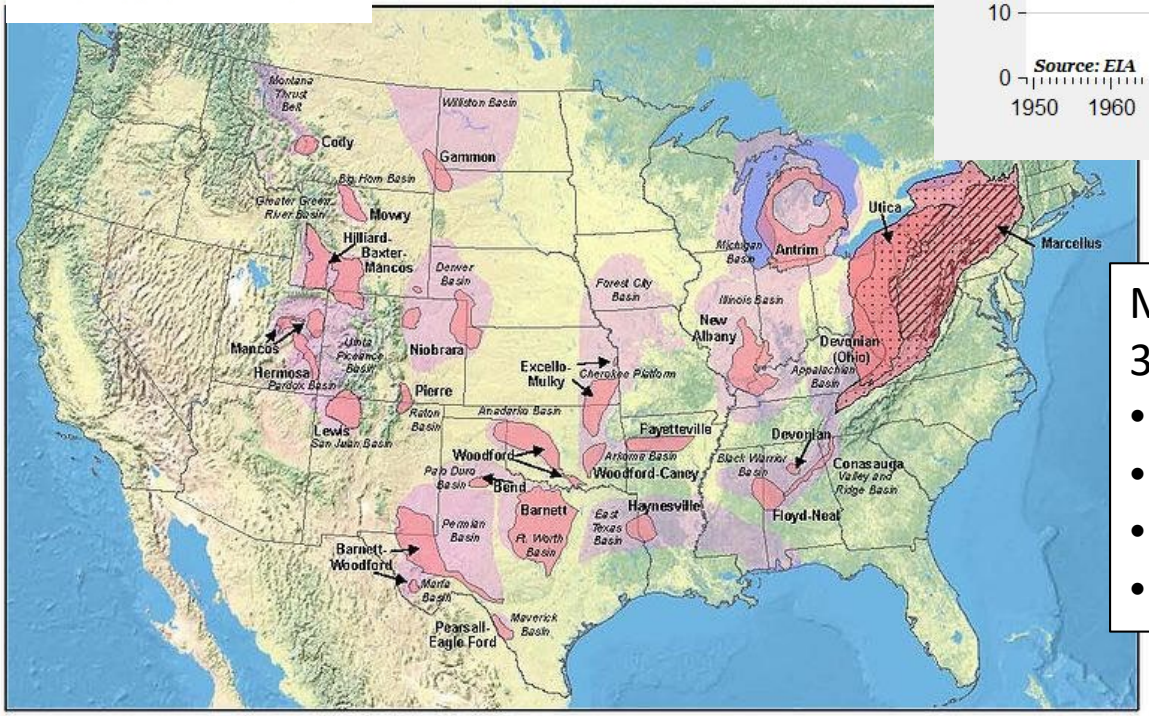
UNIVERSITY PARK, PA.--The shale gas rush is on. Excitement over natural gas production from a number of Devonian-Mississippian black shales such as the Barnett, Fayetteville and Woodford has reached the Appalachian Basin, where Range Resources has announced cumulative initial flow rates of 22 million cubic feet a day from seven horizontal wells in the Marcellus black shale play in Washington County, Pa. In fact, more than one company has announced or indicated flow rates in excess of 1 MMcf/d from vertical wells producing from the Marcellus Shale at other locations in Pennsylvania.

These reports follow on the slow, but steady success of Equitable Resources in the Big Sandy Field of Kentucky, where 20 percent of the company's horizontal wells in the Upper Huron black shale flow without stimulation. A review of well permits reveals that horizontal laterals in both Devonian black shale plays are directed along a line striking between northwest and north-northwest. Economic flow without further stimulation is a clear indication that horizontal laterals are crossing fractures with significant connectivity to black shale matrix.

Reproduced for Terry Engelder with permission from The American Oil & Gas Reporter



American Enterprise Institute



United States Shale Gas Plays

www.eia.doe.gov
Energy Information Administration
Office of Oil and Gas

Shale Gas Plays
Basins

Stacked Appalachian Plays
Marcellus
Utica
Devonian (OH shale)

November 2008
Miles
0 150 300 600

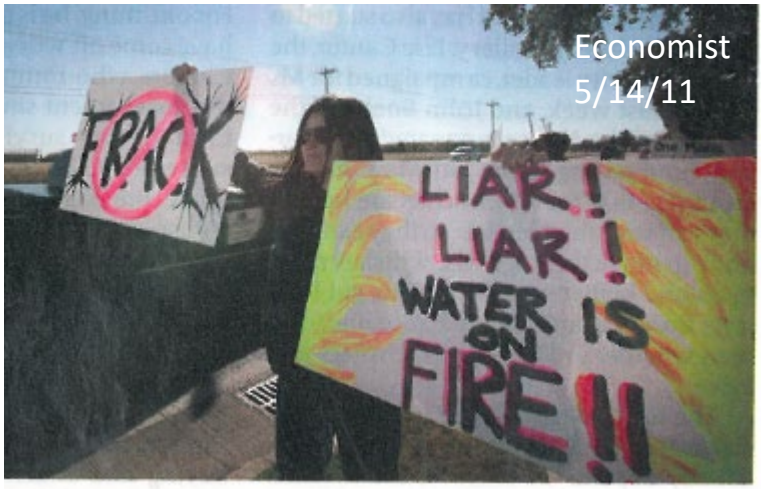
N

Marcellus
363 TCF , 246 x10^9 m^2

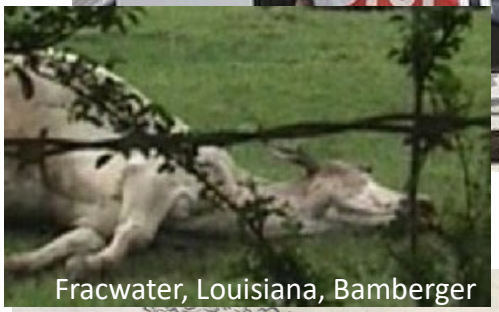
- = 1.6 W m^{-2} over 30 years
- = Wind turbines over whole area
- = $200 bn/yr imports
- = 400, 1 GW nuclear power plants

http://www.energyindustryphotos.com/shale_gas_map_shale_basins.htm

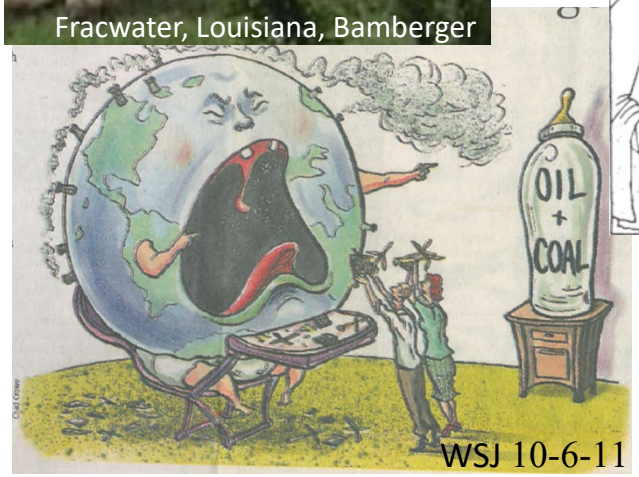
…but the resource is highly controversial



Economist
5/14/11



Fracwater, Louisiana, Bamberger



WSJ 10-6-11

Outline

- Geology & Technology
- Gas
- Worries
- Puzzles
- Community

The Marcellus

- 50-200 ft (net) thick
- organic rich (12% TOC)
- Devonian (~390 Myr) shale
- matured to dry gas stage
- expelled all water (and then gas-dried further)
- water held at bay by capillary seals
- lots of gas in over/underlying stratigraphy

Tight gas resource

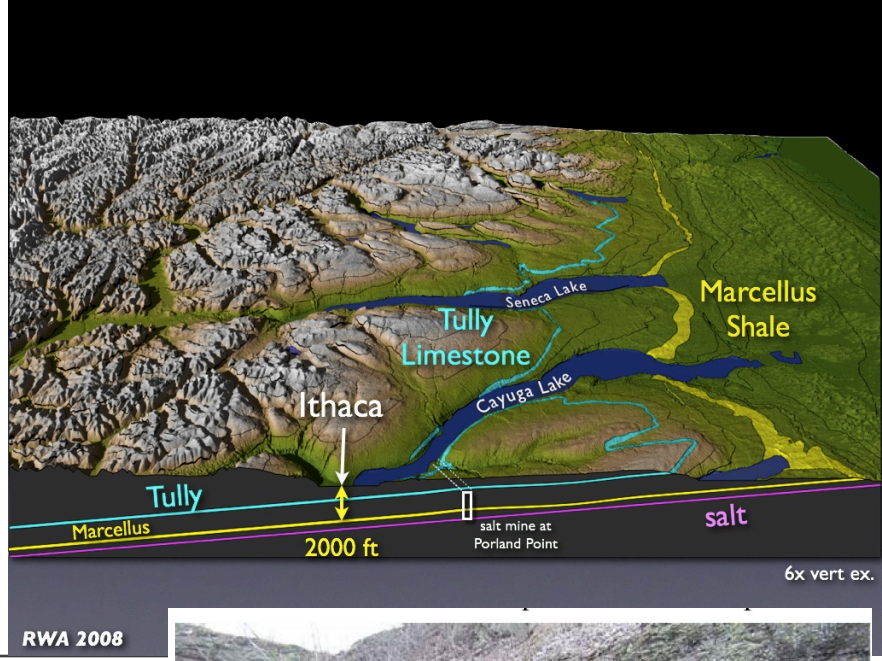
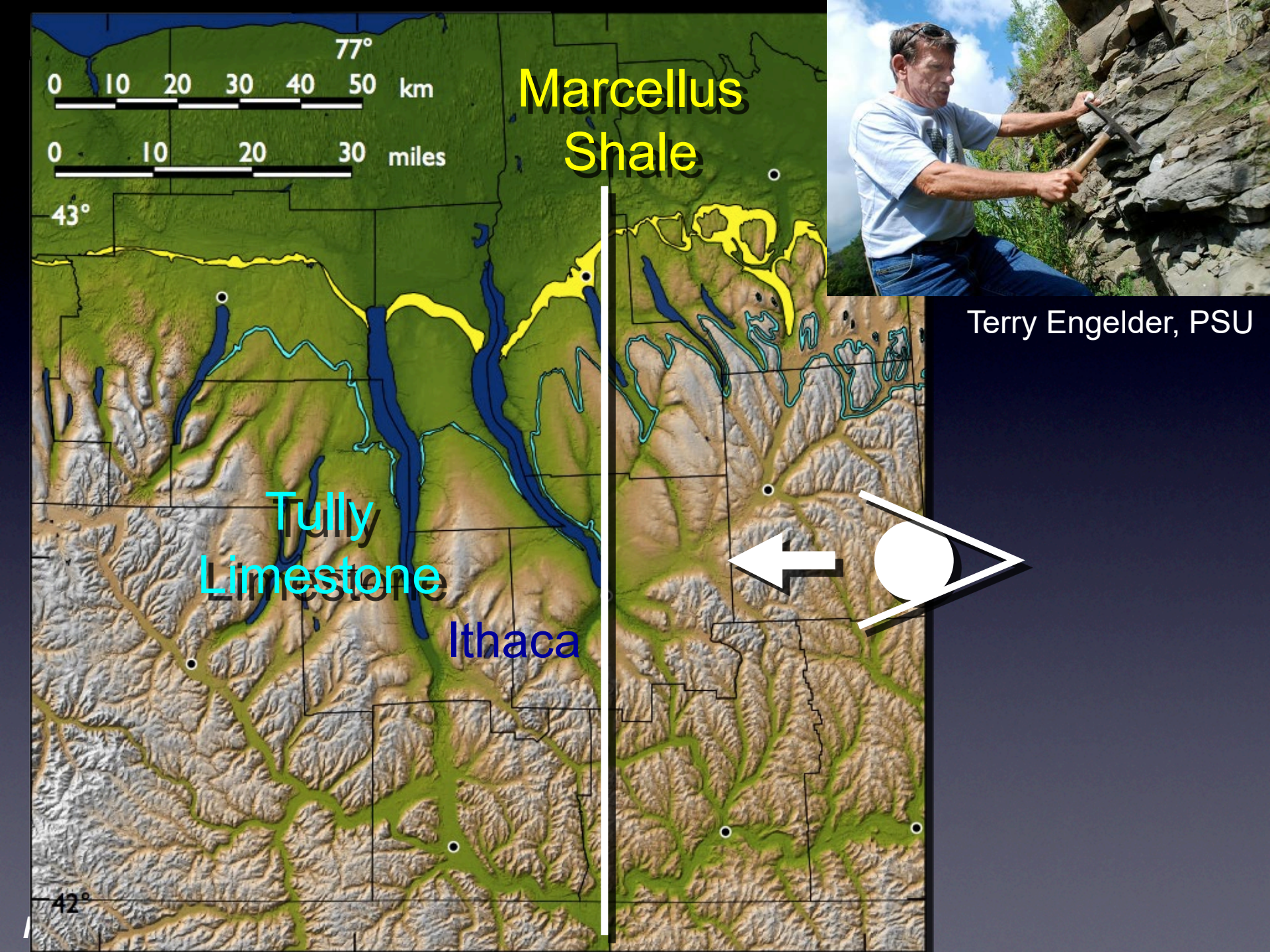


Figure 3: General Stratigraphic Column of Southwestern New York State.

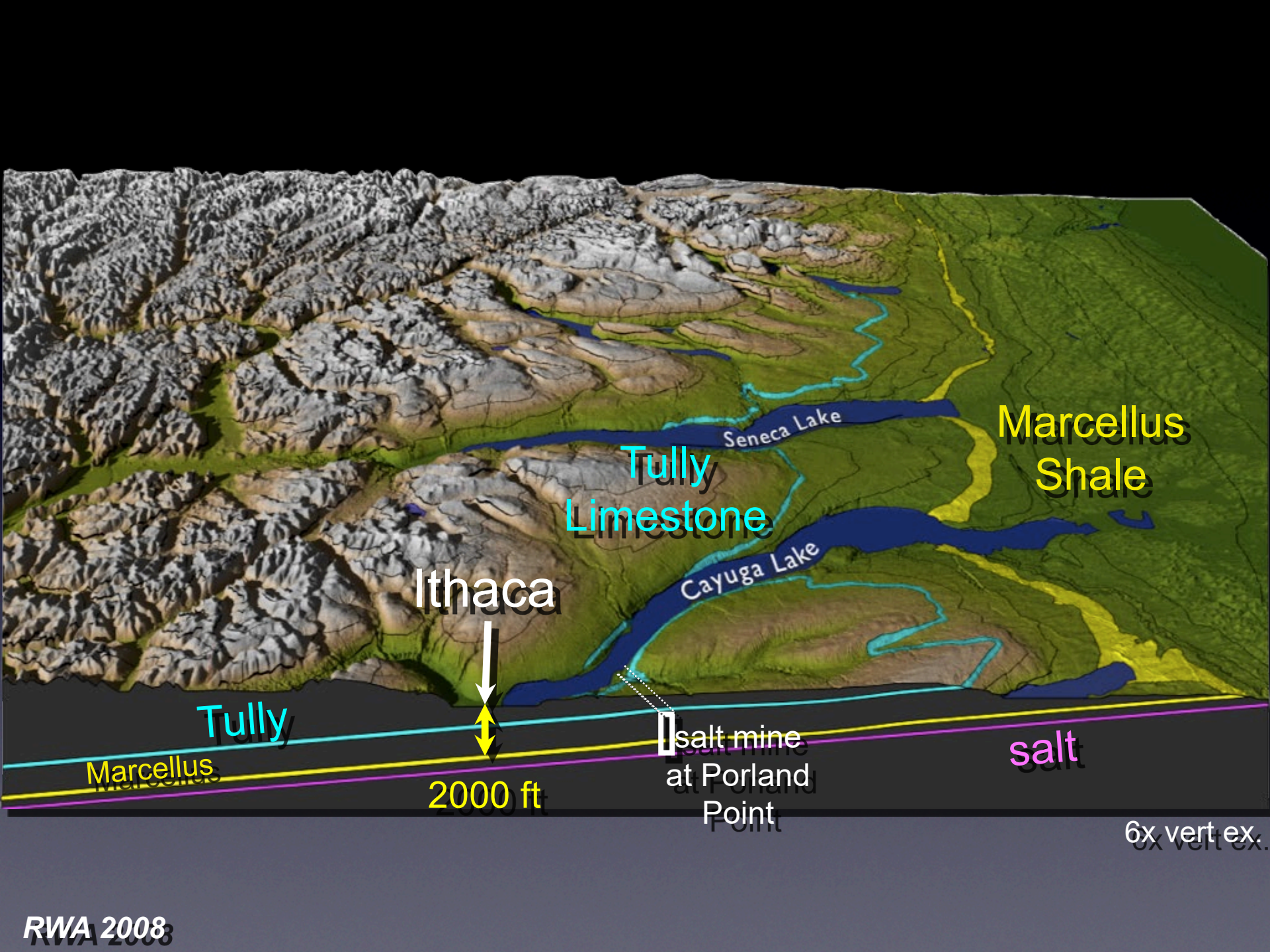
Period		Group	Unit		Lith
Penn		Pottsville	Olean		Q
Miss		Pocono	Knapp		Conglomerate and Sands Sandstor
Devonian	Upper	Conewango			Shale and Sandsto
		Conneaut	Chadakoin		Shale and Sandsto
		Candadaway	Undifferentiated	▪▫	Shal
			Perrysburg	▪▫	Mir
		West Falls	Java	▪▫	Shal
			Nunda	▪▫	
			Rhinestreet		Mir
		Sonyea	Middlesex	▫	Shale and Siltstone
		Genesee			Shale with Minor Siltstone and Limestone
	Middle		Tully	▫	Limestone with minor Siltstone and Sandstone
		Hamilton	Moscow	▫	Shale with minor Sandstone and Conglomerate
			Ludlowville		
			Skaneateles		
			Marcellus		
			Onondaga	▪▫	Limestone

gas

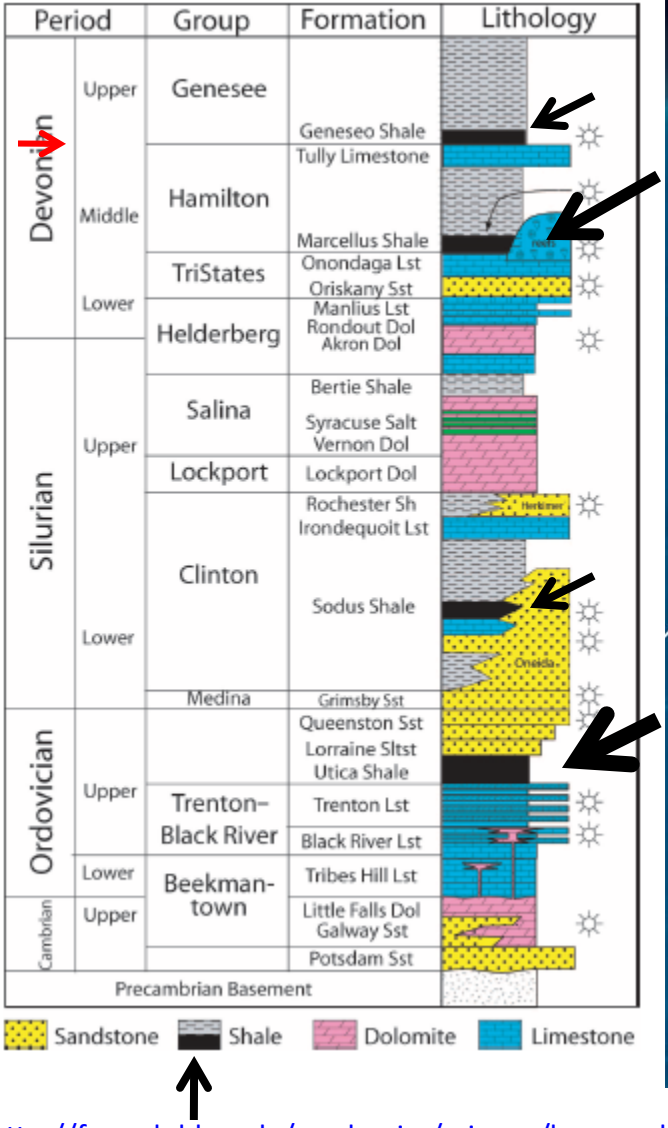

Marcellus shale, Engelder home page

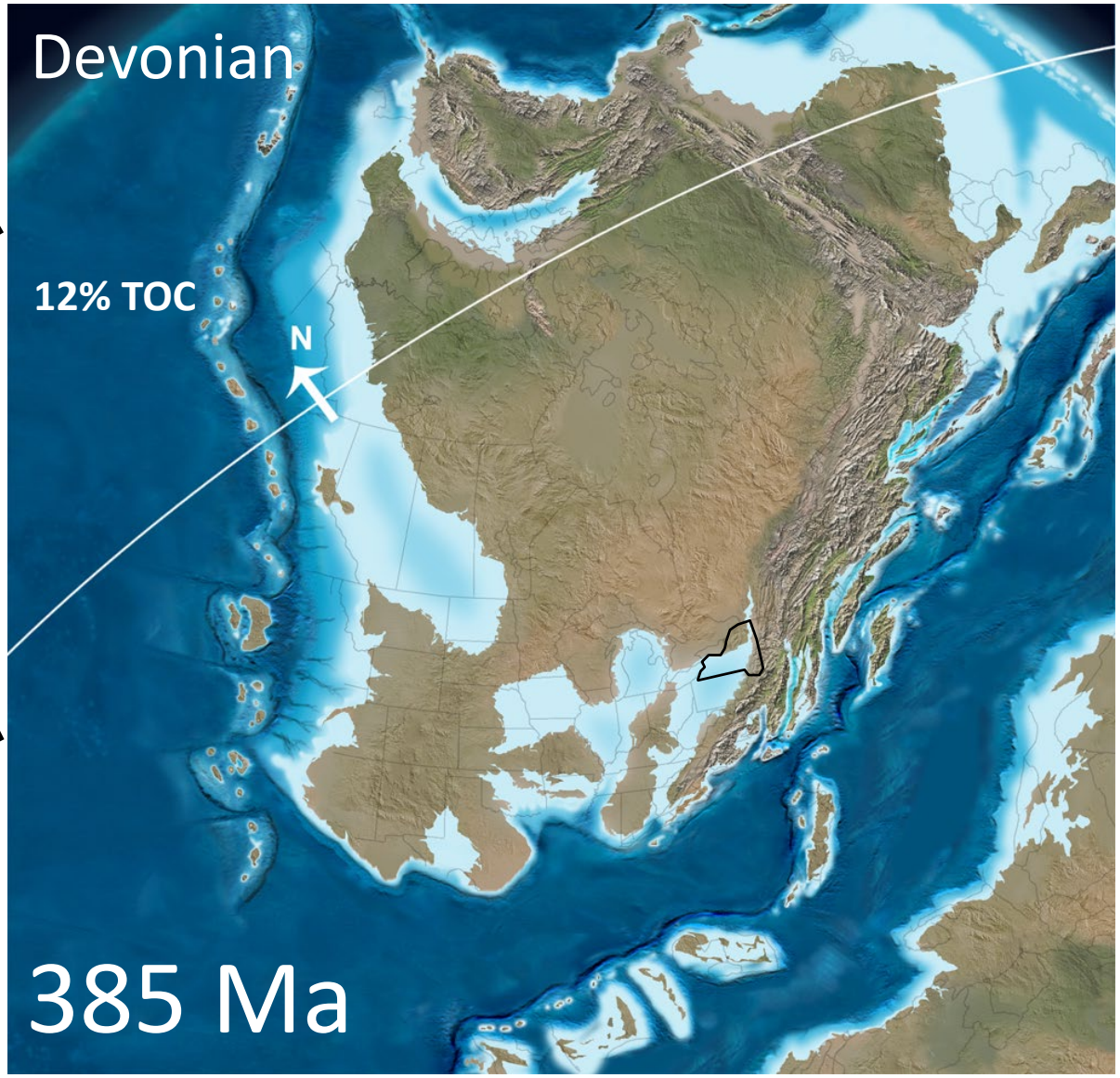


Terry Engelder, PSU


Seneca Lake
Tully
Limestone
Marcellus
Shale
Cayuga Lake
Ithaca
Tully
Marcellus
2000 ft
salt mine
at Porland
Point
salt
6x vert ex.
RWA 2008

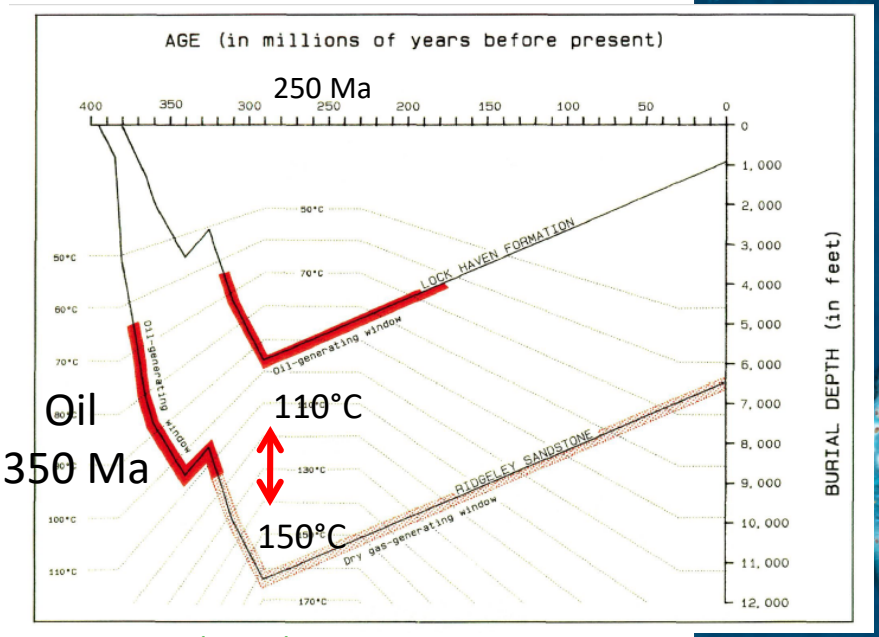
Deposited ~400 Ma, very organic rich



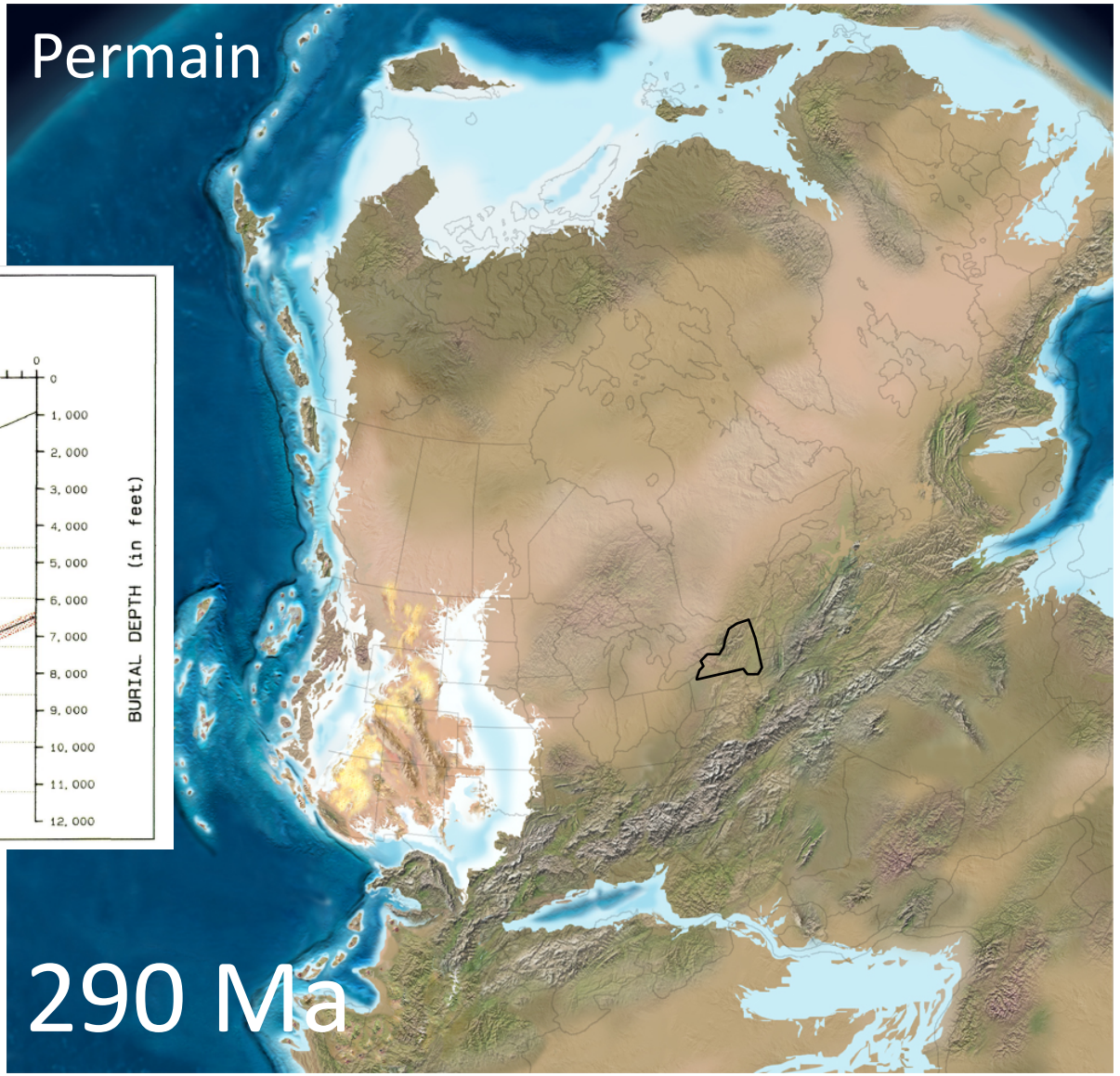


http://facweb.bhc.edu/academics/science/harwoodr/geol102/study/paleozo2.htm

Oil generated ~350 Ma, dry gas ~300 Ma



JA Harper(1990)



http://facweb.bhc.edu/academics/science/harwoodr/geol102/study/paleozo2.htm

A natural hydraulic fracture driven by gas with the compressibility of methane. The rupture propagated from right to left as indicated by plumose morphology showing two increments with surface roughness increasing until arrest.

Engelder web site

…forming joints

{Como Park, Lancaster, NY} Crosscutting joints in the Marcellus black shale exposed on the Appalachian Plateau where outcrops are nearly horizontal. In contrast to the photo along Oatka Creek (above), the J1 and J2 joint sets do not cross at right angles. This is so because J1 has the same orientation regardless of position around the oroclinal bends of the Appalachian Mountains whereas J2 propagation in cross-fold orientations and thus change orientation to remain normal to the oroclinal bend. The arrow on the scale does NOT indicate north.

Engelder web site

… and also connected pores in organics

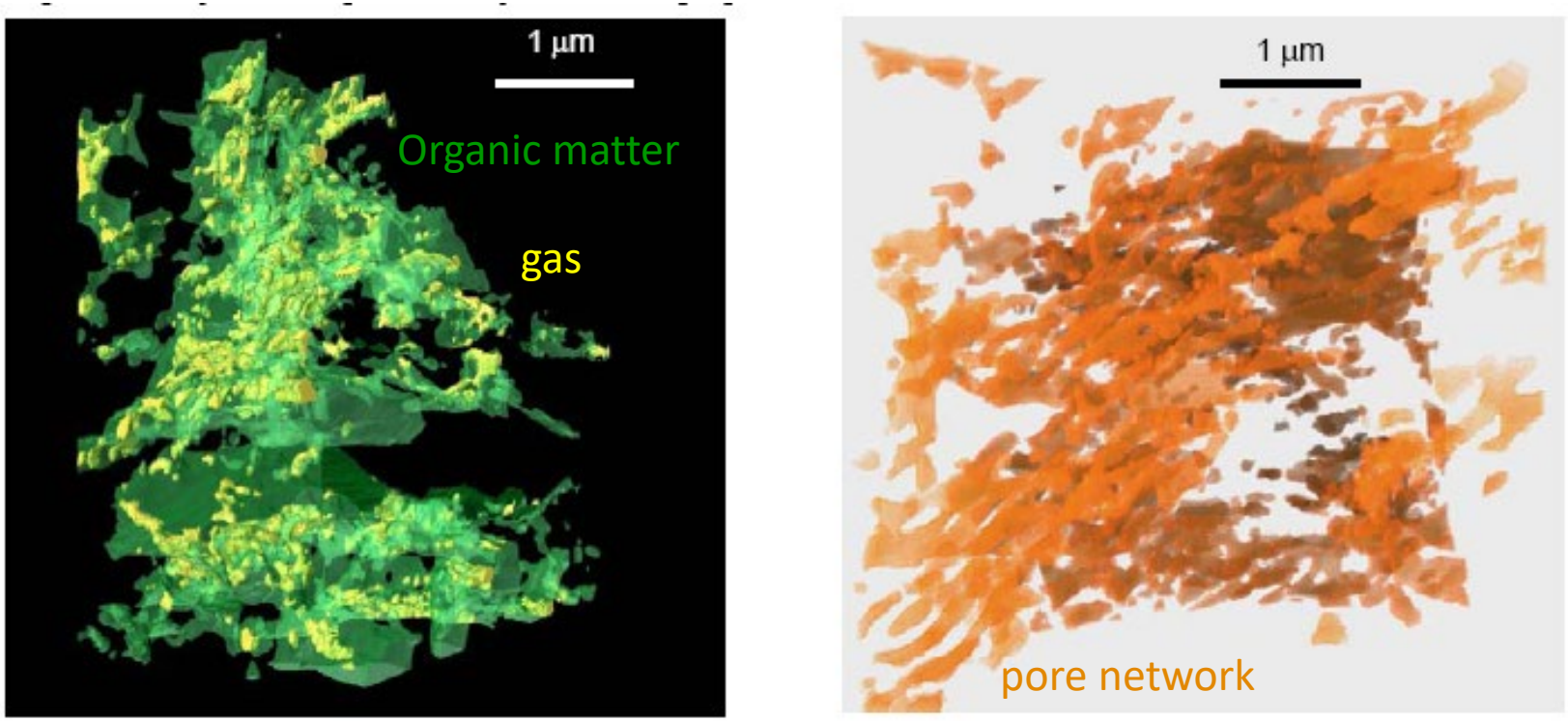


Figure 28 – a) 3D visualization of the organic network (green) and porosity (yellow) (courtesy FEI Company). b) Image of the connected pore network from the sample shown in (a) (courtesy Mark Knackstedt and Trondt Varslot, ANU). Note the planar alignment of the pore network in this particular 3D view.

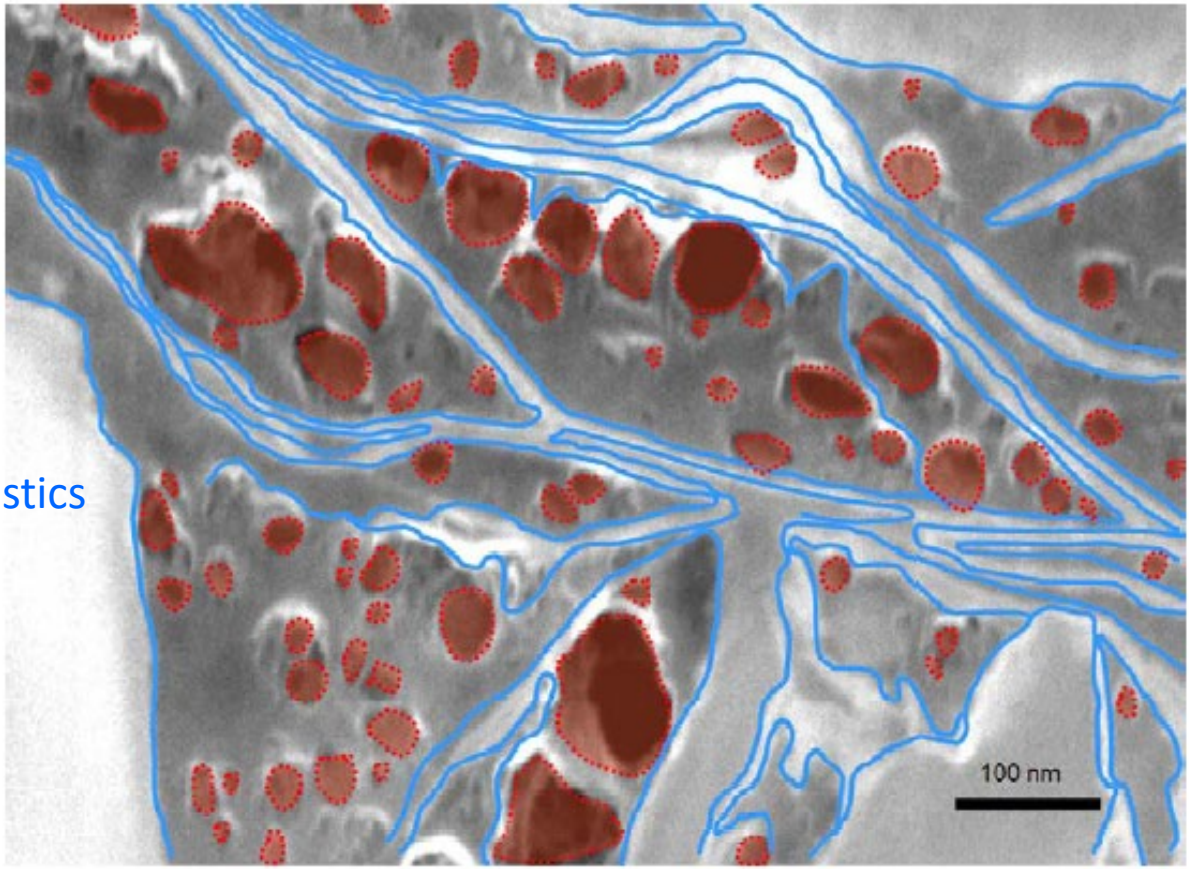
Porosity correlates with TOC

Passey, et al., From oil-prone source rock to gas-producing shale reservoir… (2010) SPE 131350

Gas bubbles remain in organic residua; water wets the silicates

Gas on organic pores

water on siliclastics



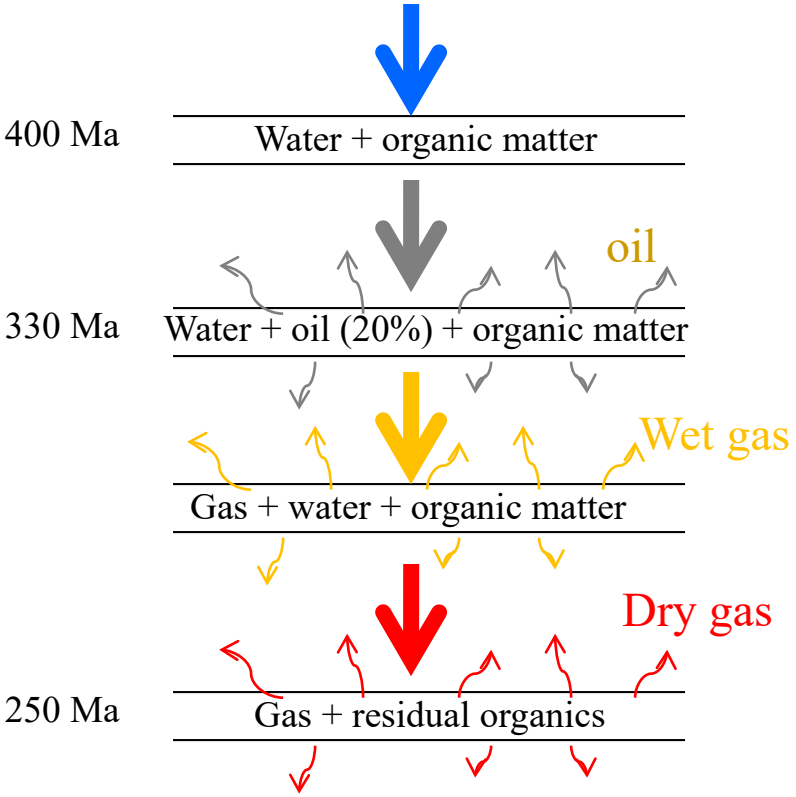
Recovery uses the fractures created when gas was expelled

Figure 30 – Hypothetical distribution of gas (red) and water (blue) in organic matter (gray) in this image of an ion-milled Barnett Shale sample. Note that adsorbed gas likely resides on the pore wall (as shown by the small red dots lining each pore). The nominal size of a methane molecule is 0.37 nm, so each small red dot is about 10 times actual size.

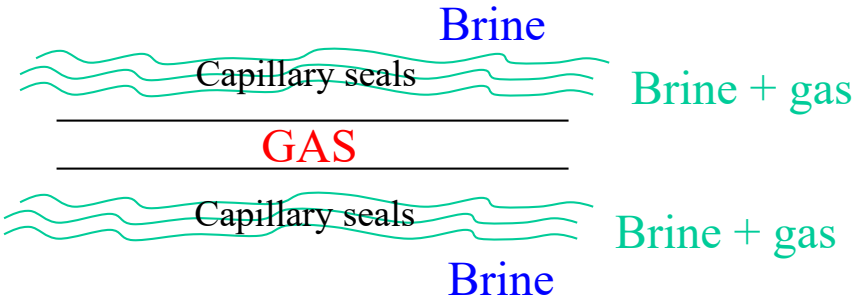
"The ultimate key for successful exploitation is in the understanding of how hydraulic fractures intersect with this gas-filled porosity." p.24.

Passey, et al., From oil-prone source rock to gas-producing shale reservoir… (2010) SPE 131350

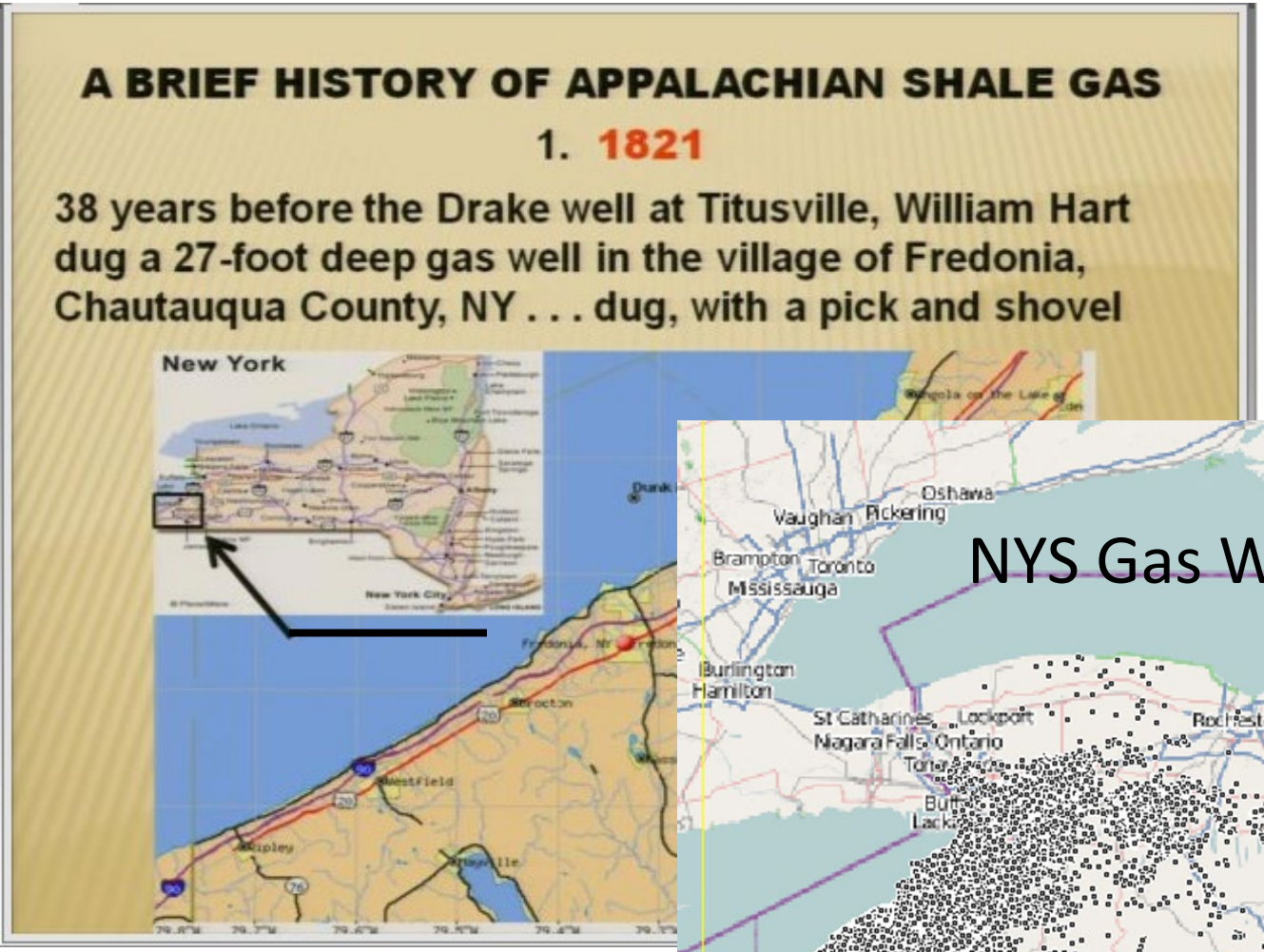
Preserved by capillary seals for >250Ma



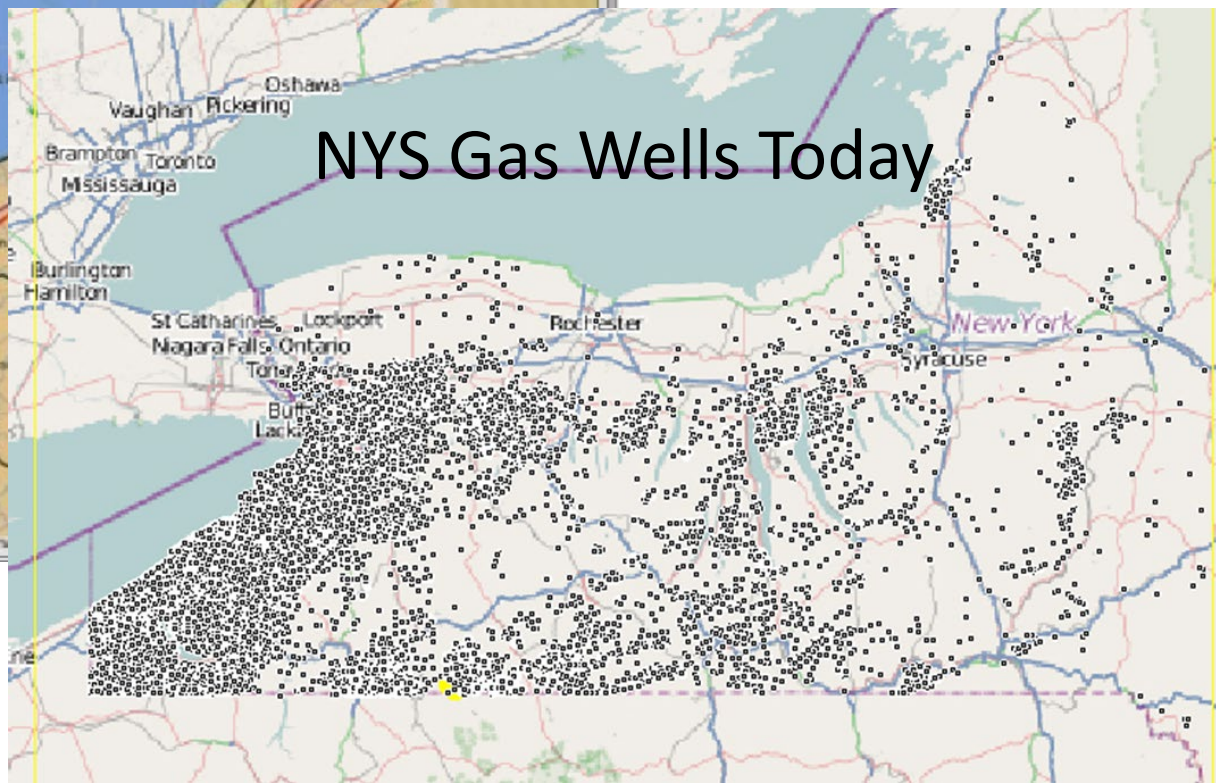
250 Ma to today gas trapped by capillary seals



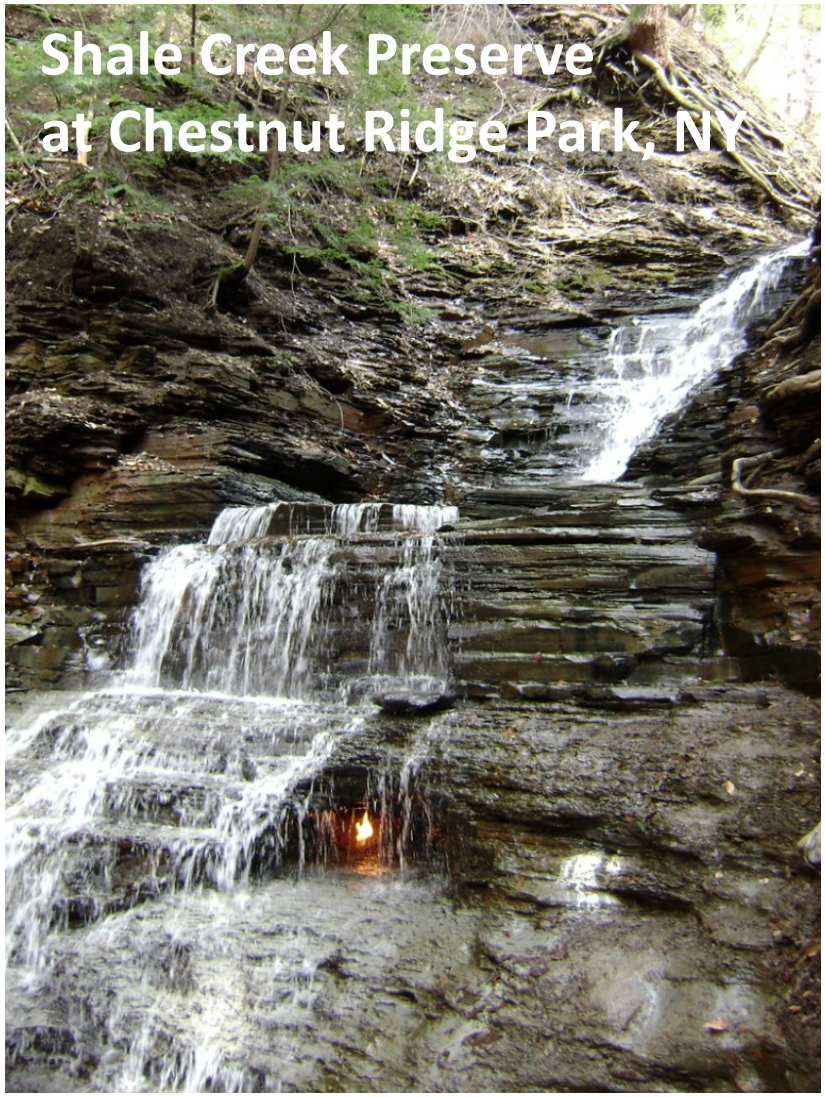
Oil and gas flooded the stratigraphy



JA Harper(2009)



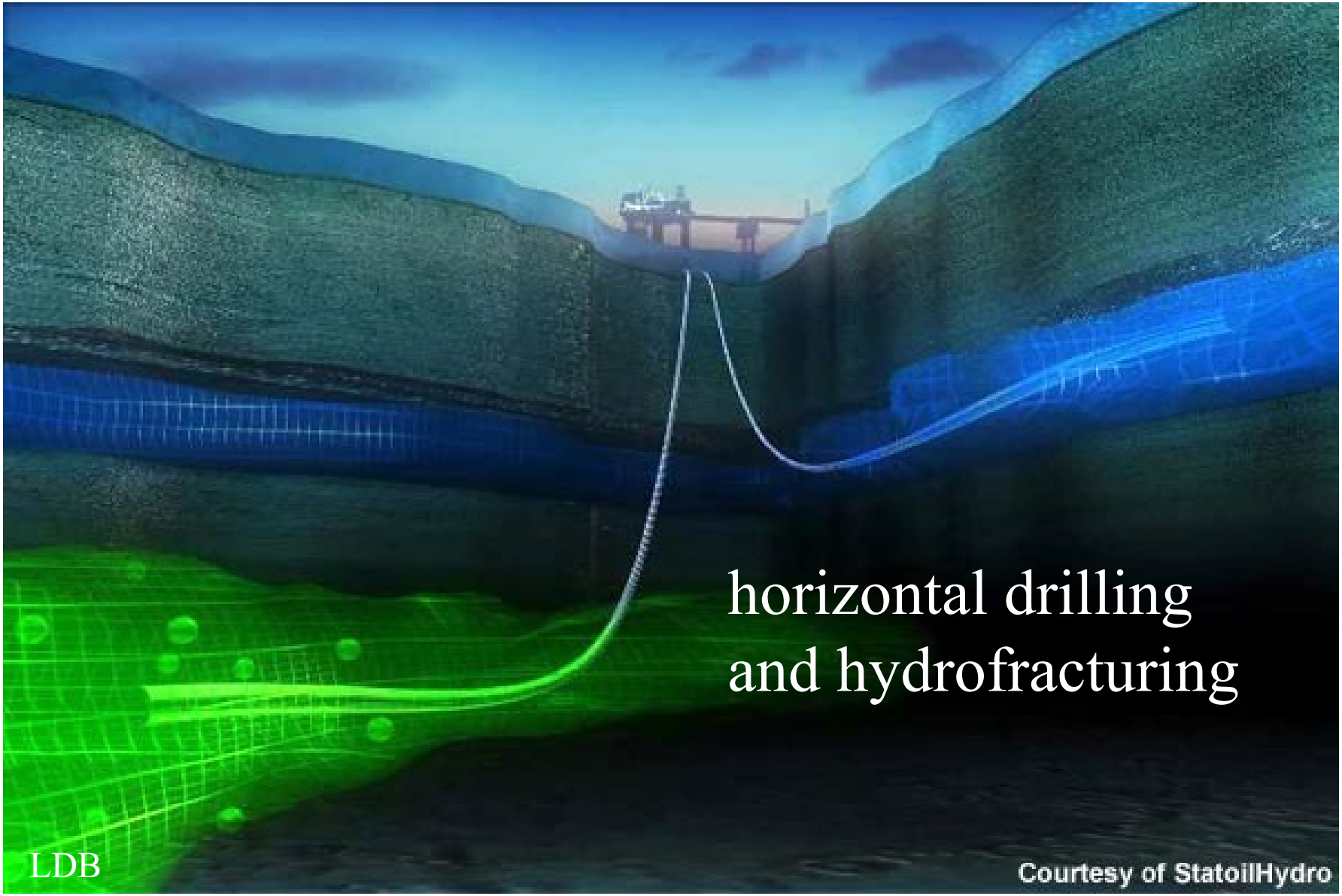
…gas still leaking out, sometimes a hazard



Well after methane explosion in Dimock, Pa

http://blogs.agu.org/magmacumlaude/2010/11/12/gas-seeps-in-western-ny/

New technology allows shale gas recovery



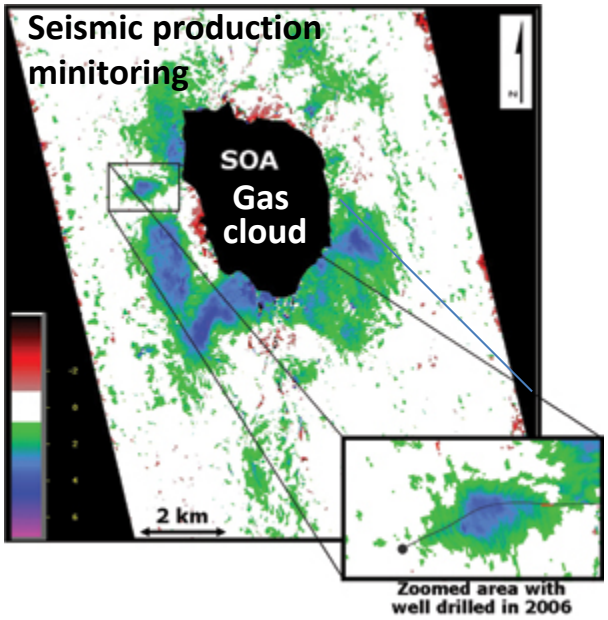
Outline

- Geology & Technology
- Gas
- Worries
- Puzzles
- Community

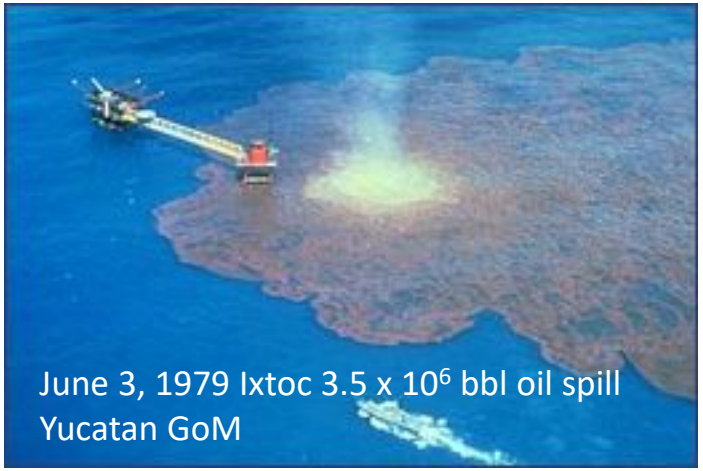
We have considerable experience with gas

Ekofisk is slowly leaking gas

www.epmag.com/Magazine/2009/7/item41420.php



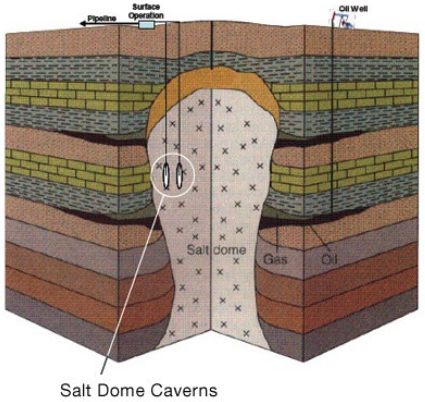
Oil spills generally related to gas leaks



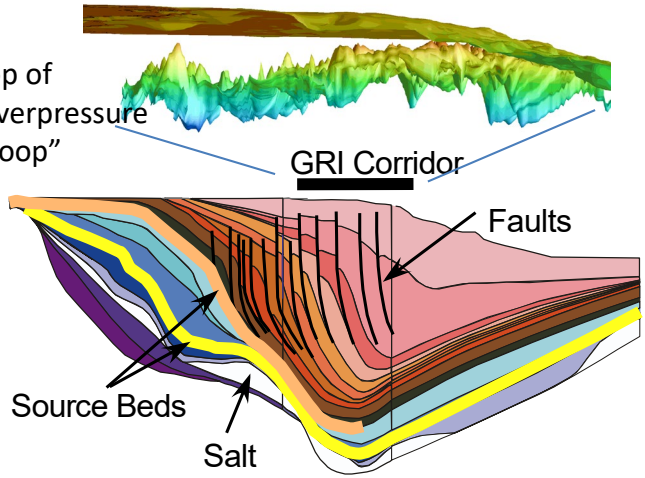
earth.tryse.net/oilspill.html

Storage of gas in salt

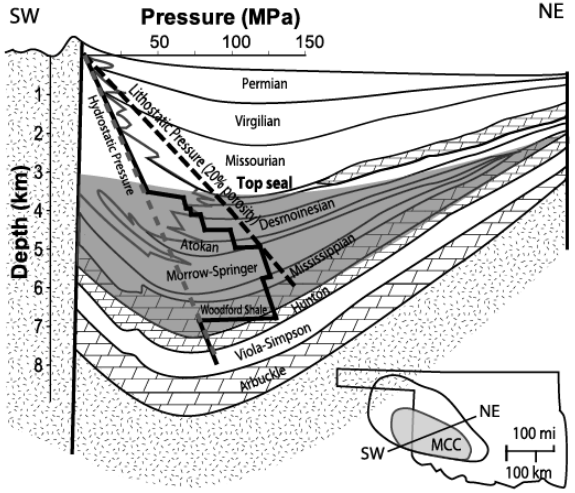
www.geostockus.com/what-we-do/natural-gas-sto...



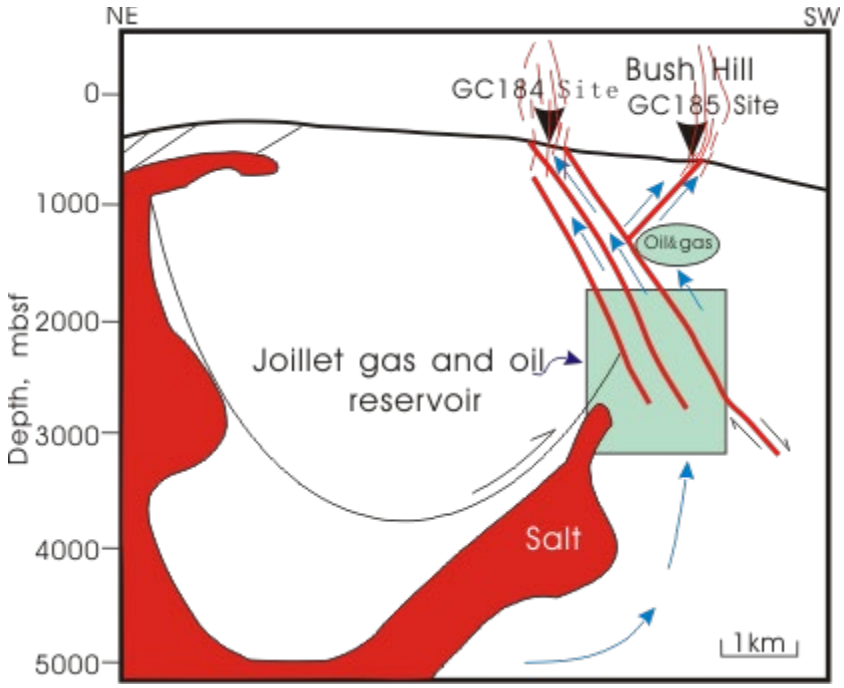
Gulf of Mexico

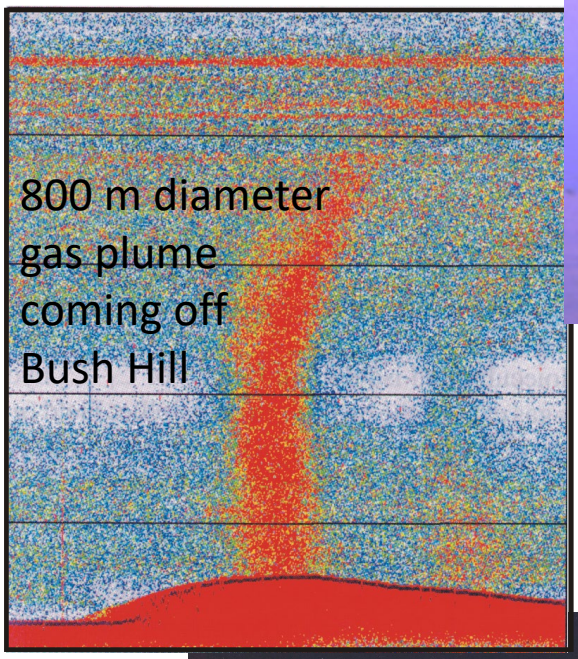


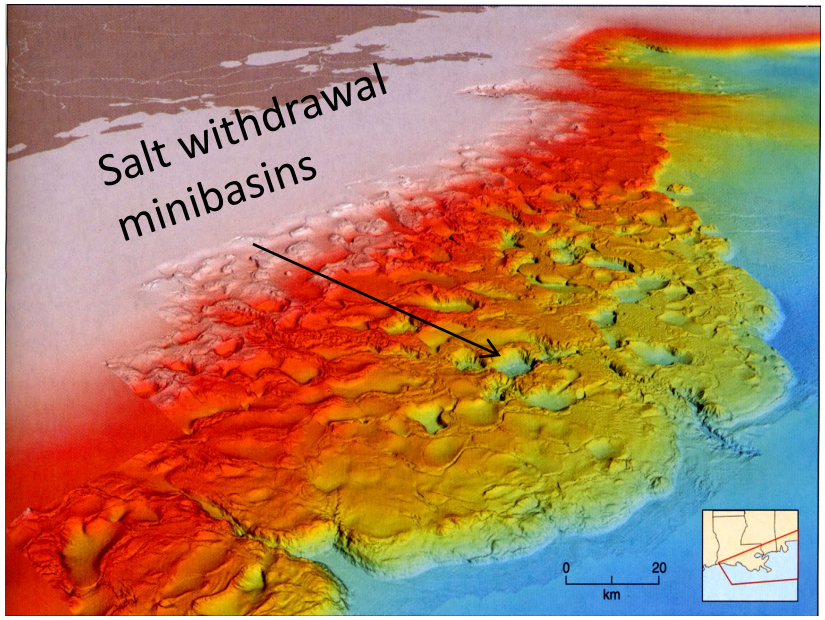
Anadarko B: overpressured 350 ma

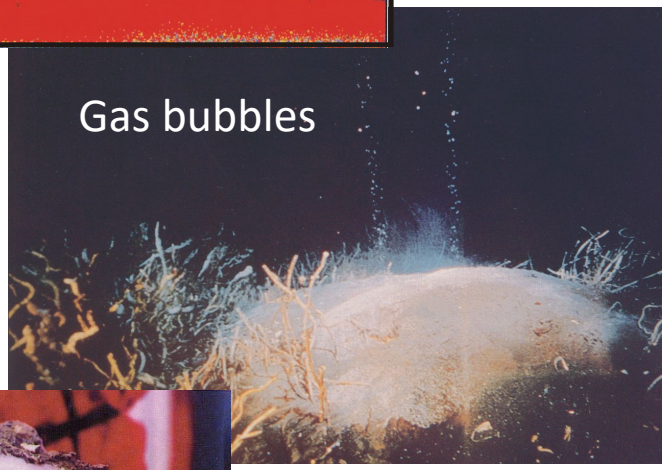


Zuhir Al Saieb



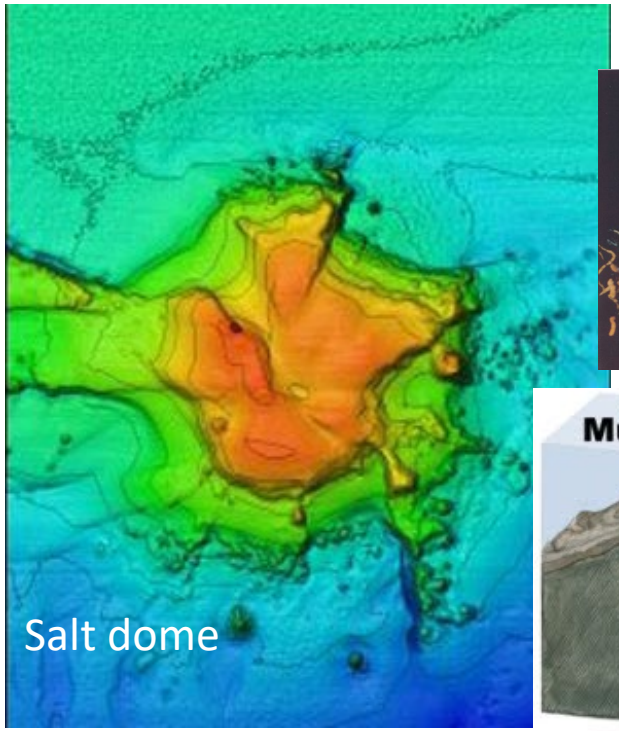


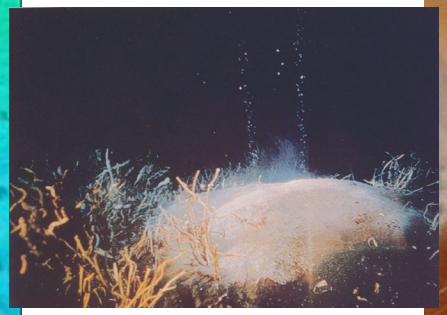


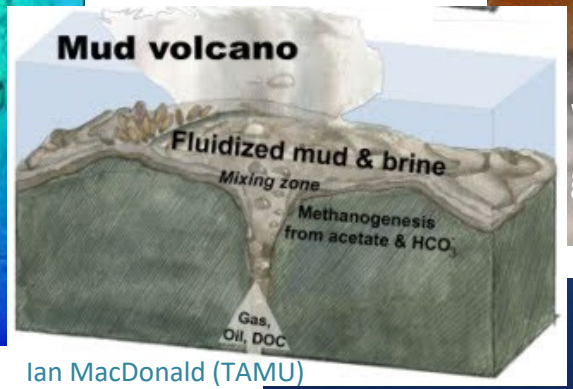


Gas hydrates-
frozen gas
The ice that burns

Images mainly from the Gulf of Mexico

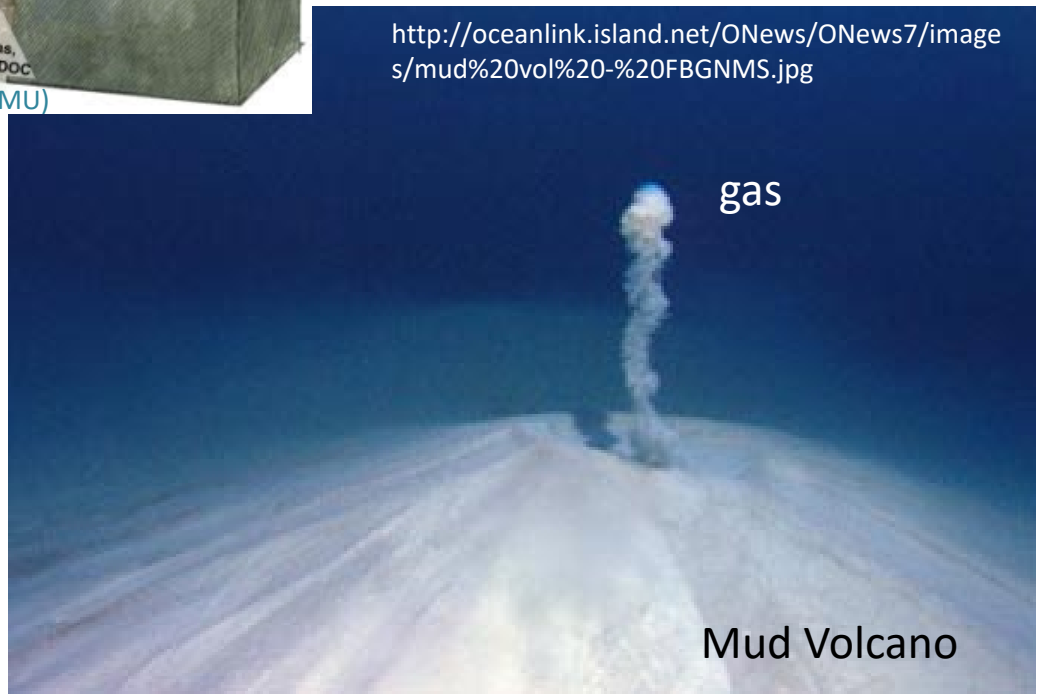




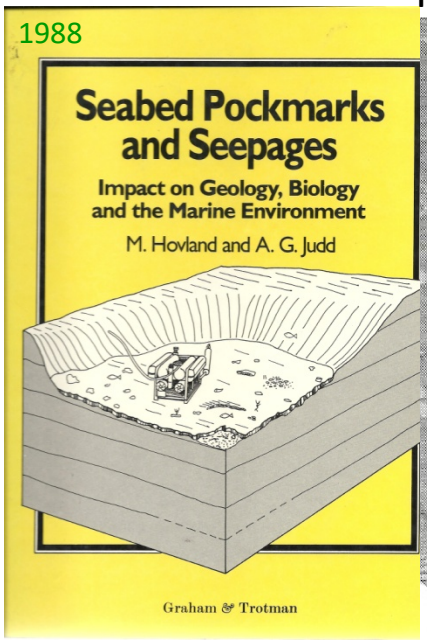


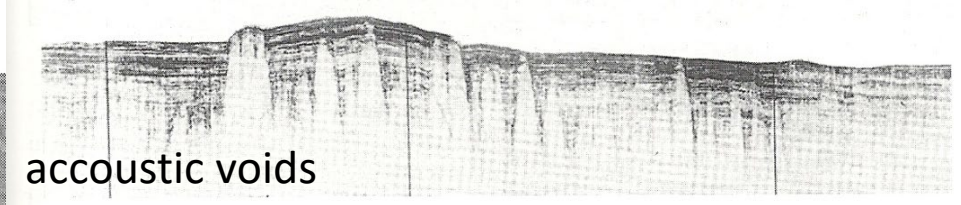
Ian MacDonald (TAMU)

http://oceanlink.island.net/ONews/ONews7/images/mud%20vol%20-%20FBGNMS.jpg

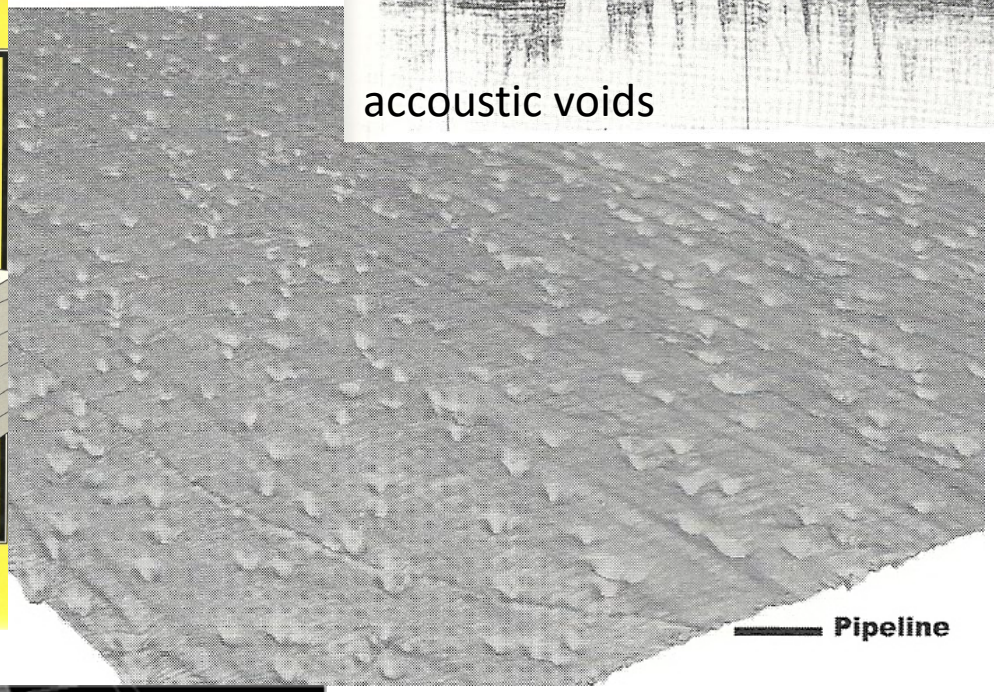


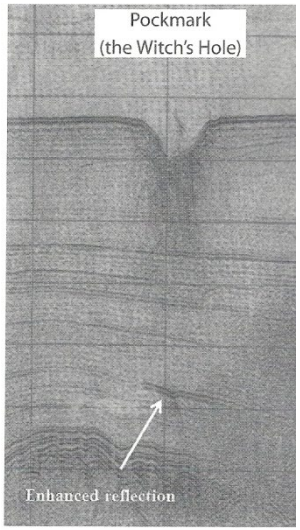
Gas escape UK N. Sea

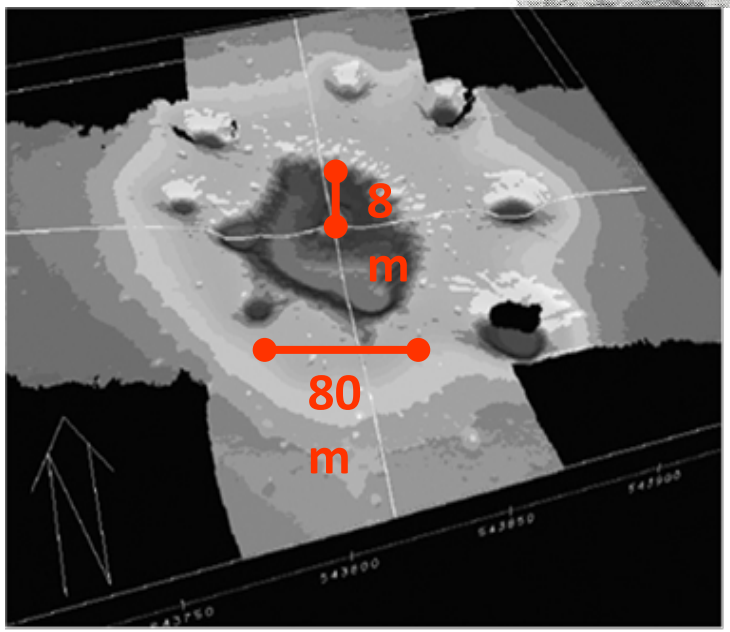


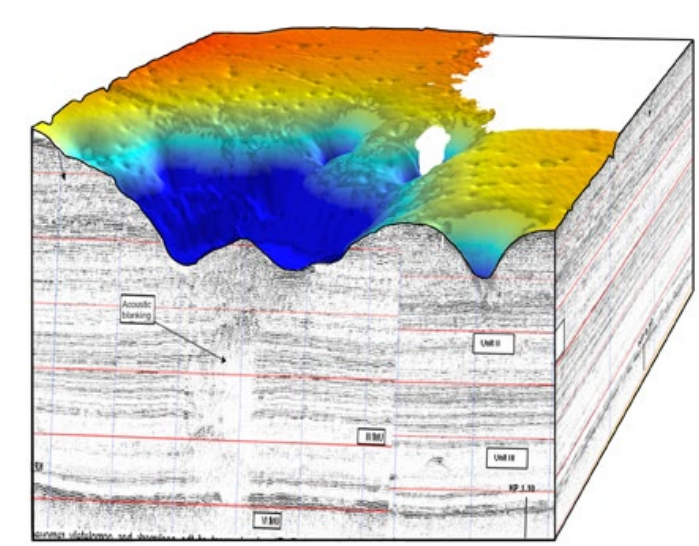


accoustic voids



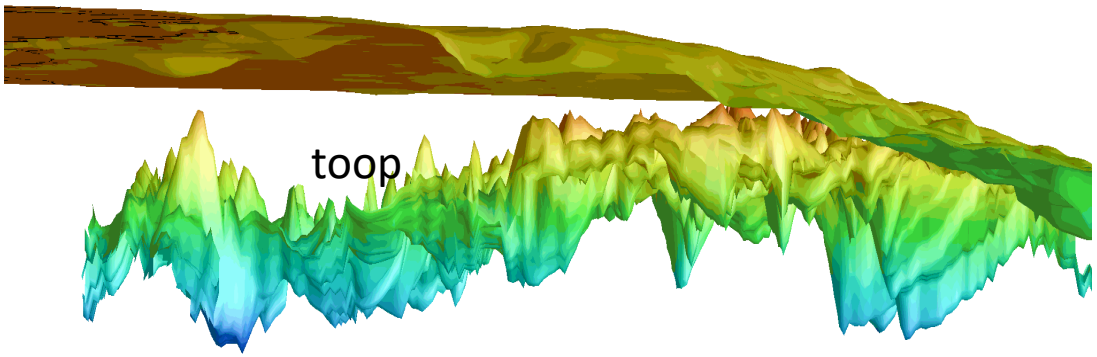






Judd and Hovland, Seabed Fluid Flow (2007)

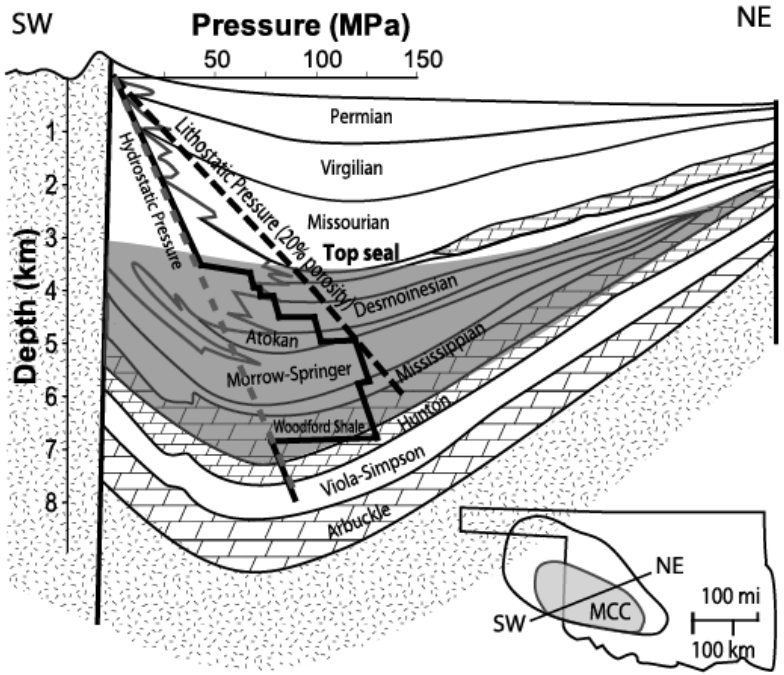
A key is understanding seals



top of overpressure

Why the toop?

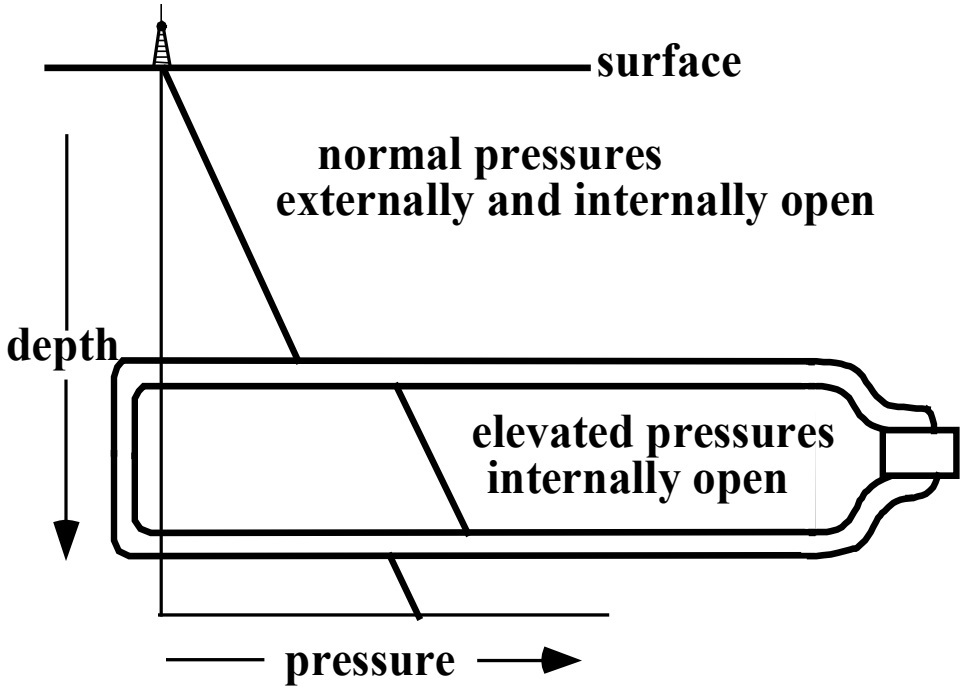
Why are basins Basin Pressure-Compartmented?



Al Saieb, Anadarko Basin

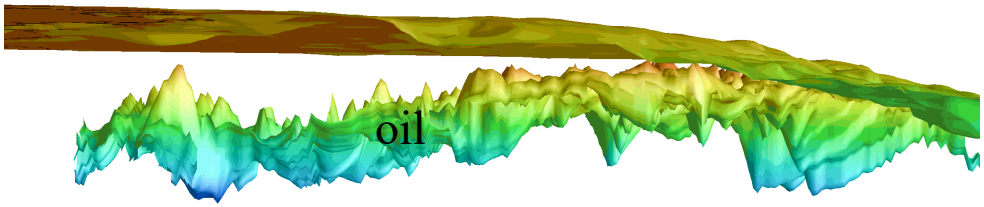
Anadarko = megacompartment complex

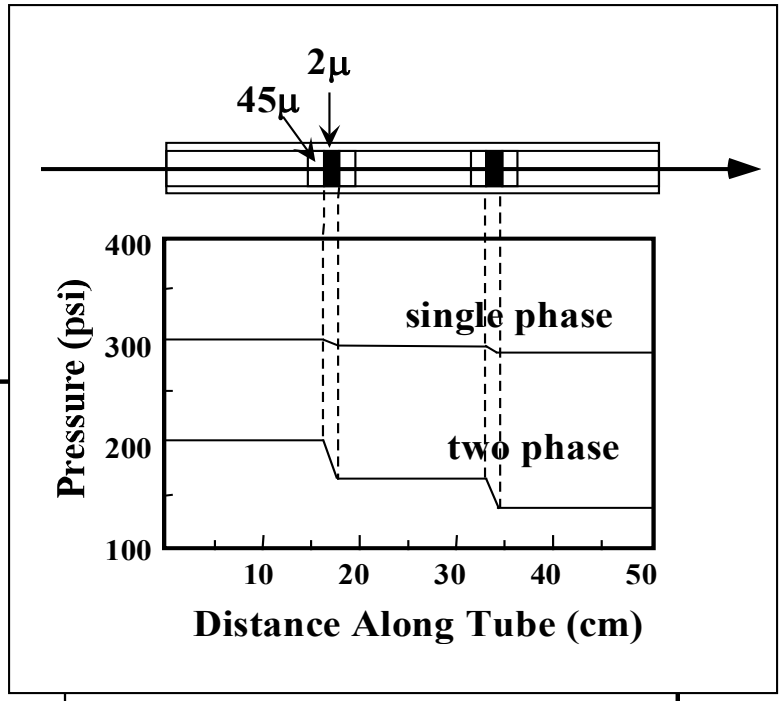
Powley's Buried Beer Bottle Model

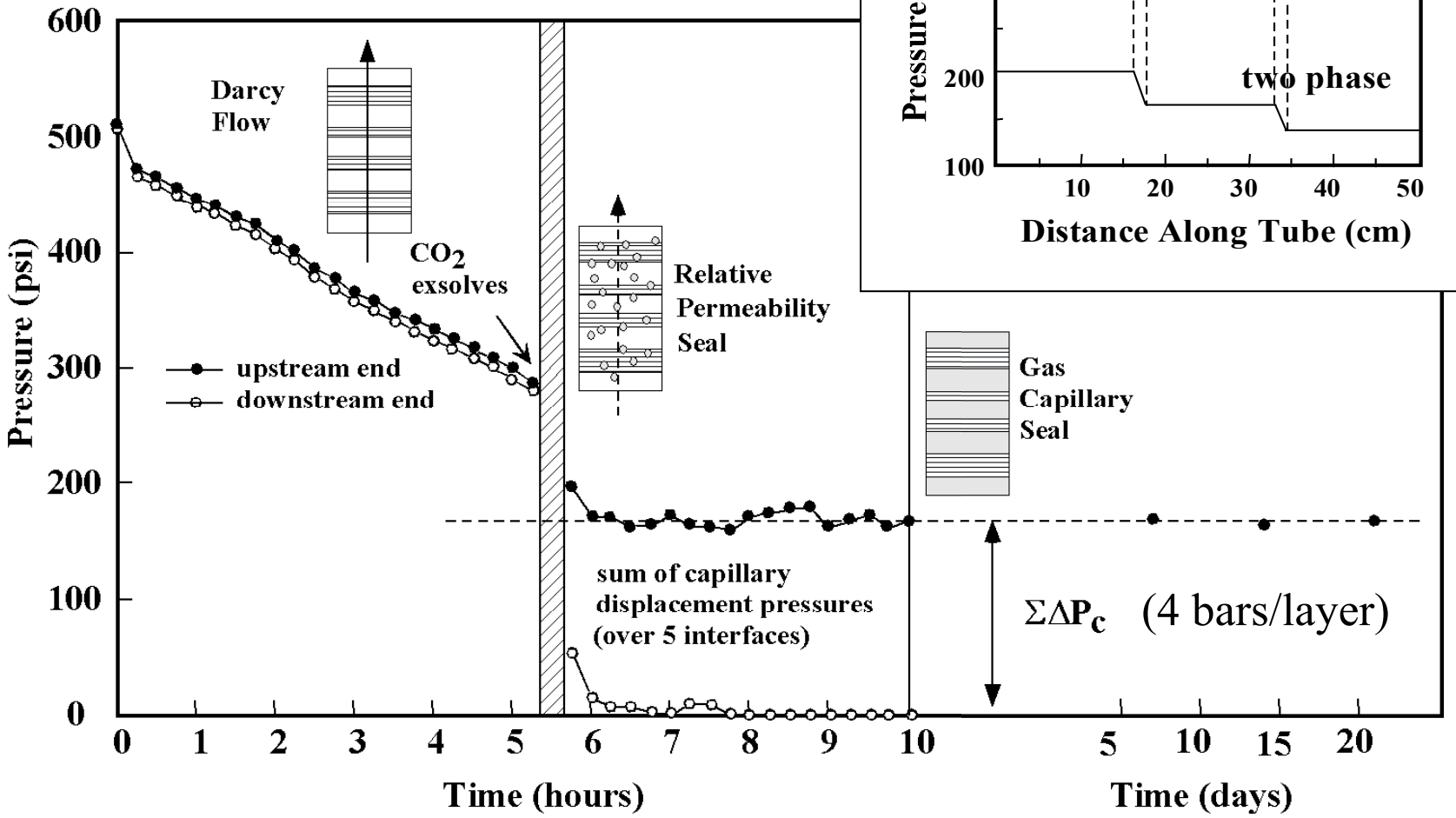


Powley 1987 presentation to Gri

Gas capillary seals



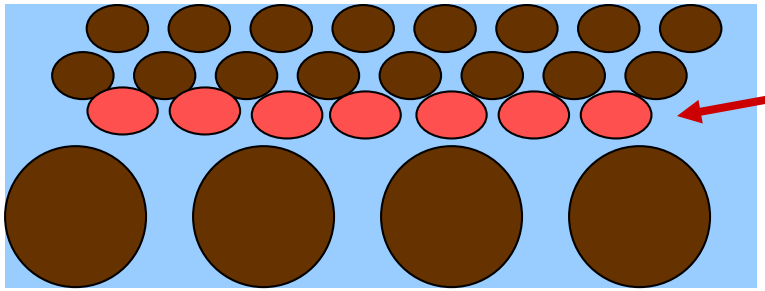




Shosa and Cathles, 2001, 21st Annual Bob F. Perkins Res. Conf., GCSSEPM

Flow blockage is greatly augmented in grain-size layered porous media

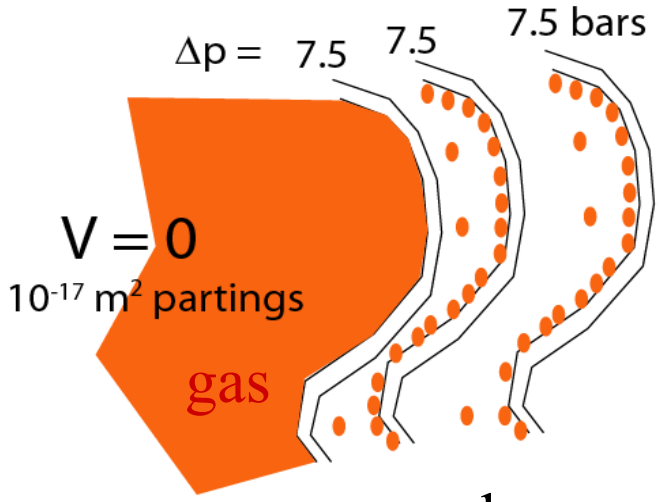
10^{-17} m^2
(10 μ darcy)
parting



ΔP of 7.5 bars needed to push gas bubbles through

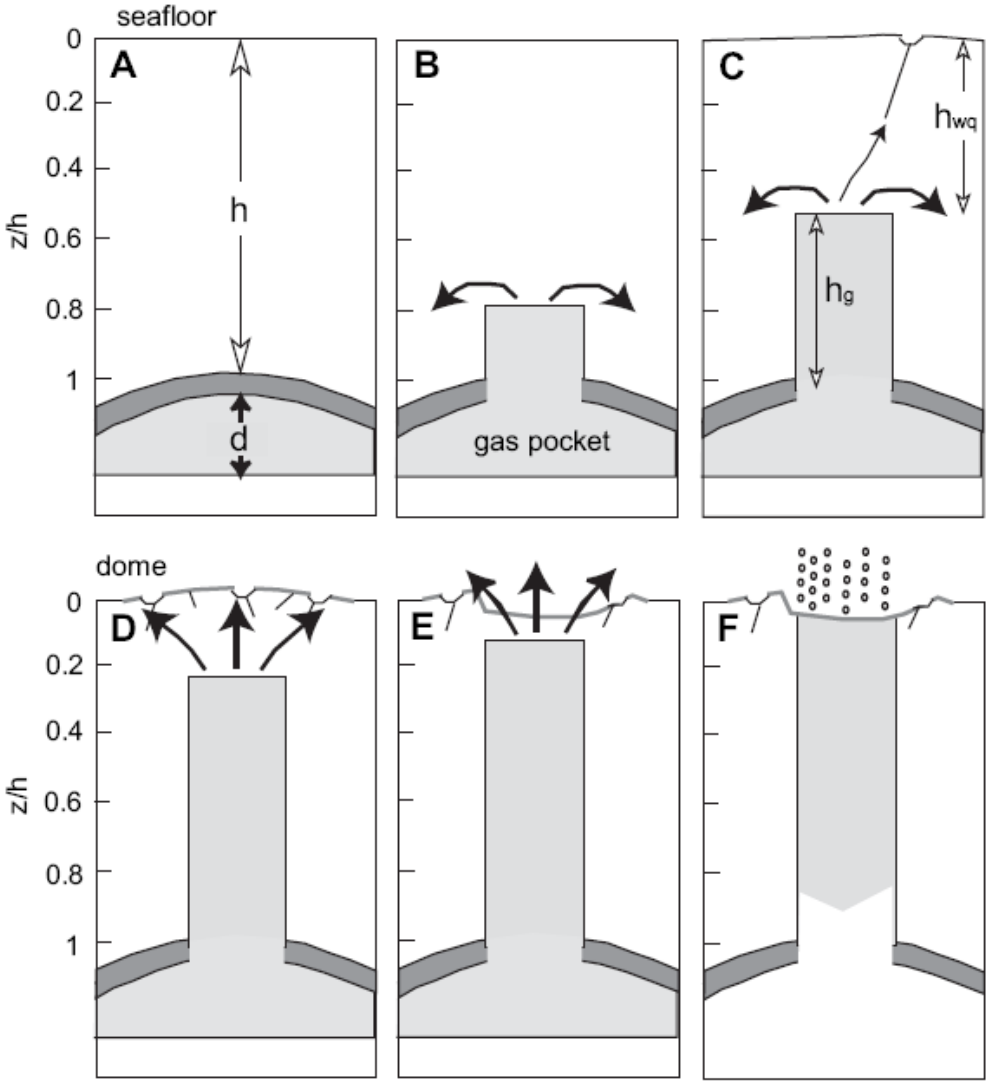
- Gas bubbles block flow of both phases like little toilet plungers

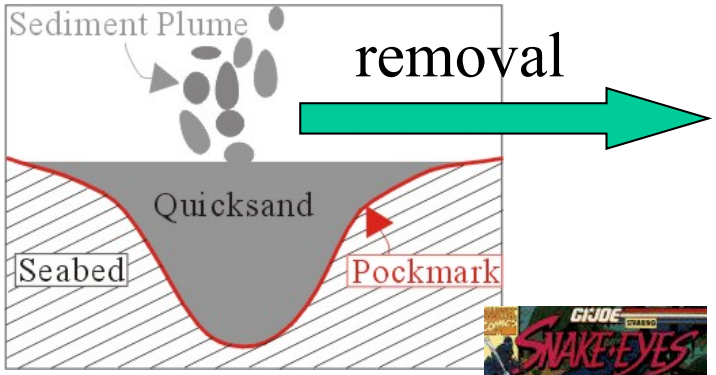
- Many layers make seal that can trap gas



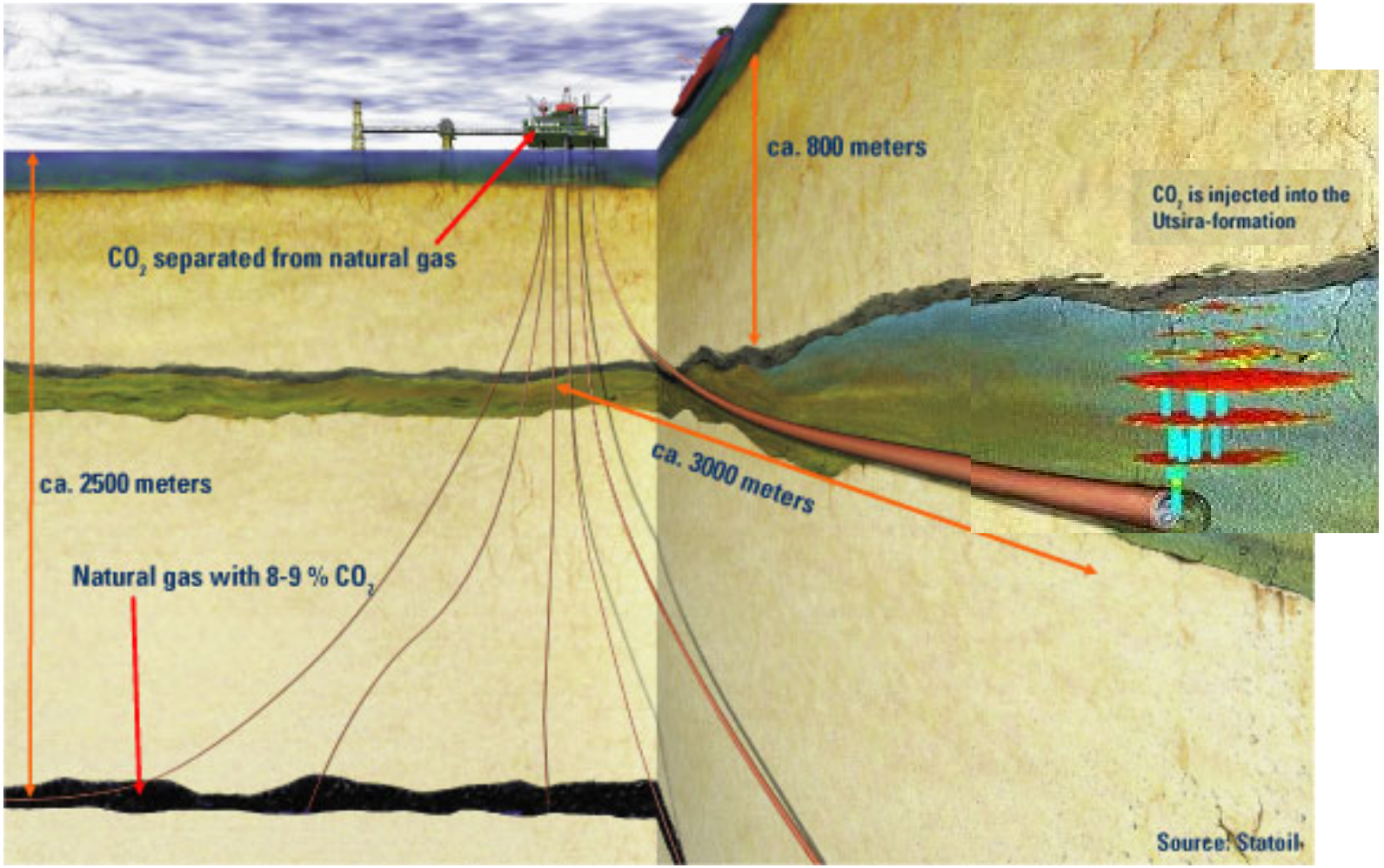
seal

Pockmark Formation:





StatoilHydro's Sleipner carbon capture and storage project



Radial spread limited by capillary forces

blog.norway.com/tag/sleipner-gas-field/

Outline

- Geology & Technology
- Gas
- Worries
- Puzzles
- Community

All kinds of worries…

- Water
  - Consumption
  - Contamination
  - Treatment
- Community Impacts
  - Earthquakes
  - Infrastructure Degradation (e.g. roads)
  - Traffic
  - Transient population increases
  - Landscape deteoration
  - Habitat segmentation
  - Forced integration
- Global Warming
  - Gas could be twice as bad as coal

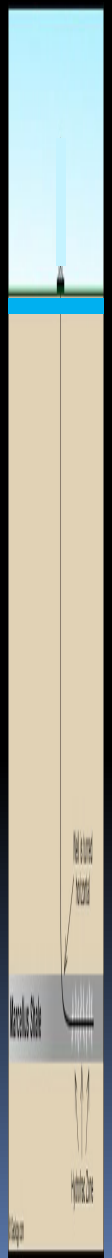
Fracking not an issue

Long way below aquifers

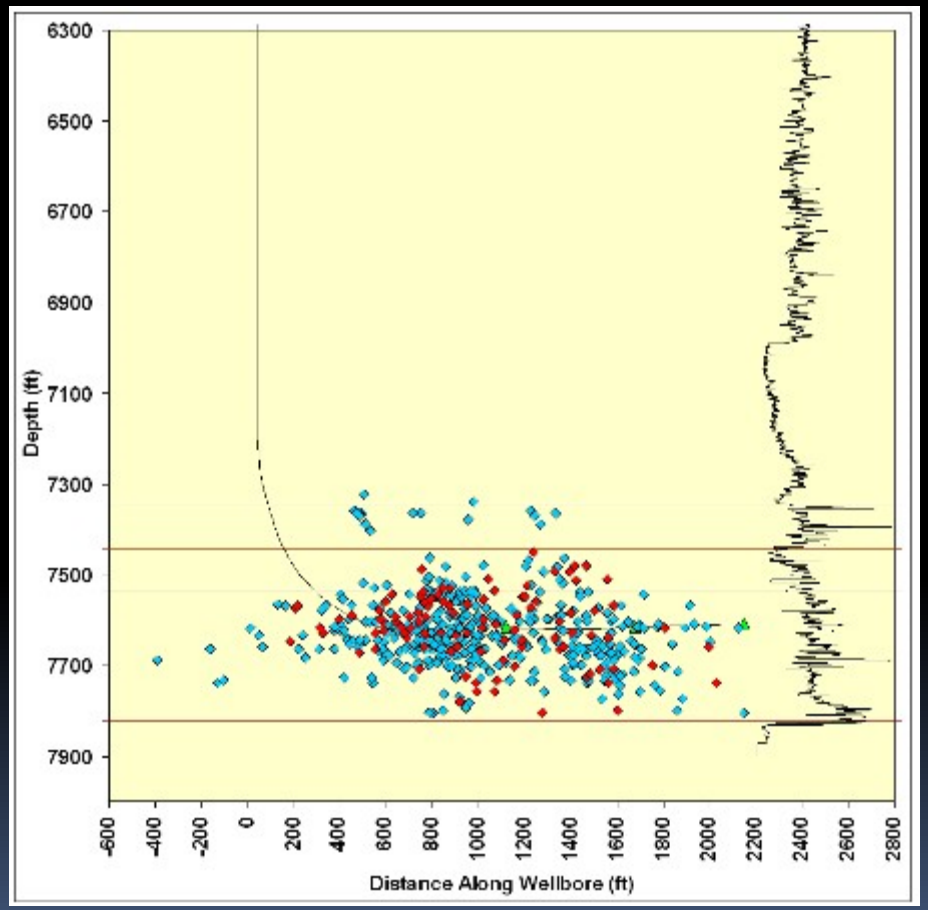
aquifers

Naturally nasty stuff

Pressure diffuse out like heat; duration of fracking is short



Can be monitored



… also large aquifer dilution factor

LDB

Hydrofracking

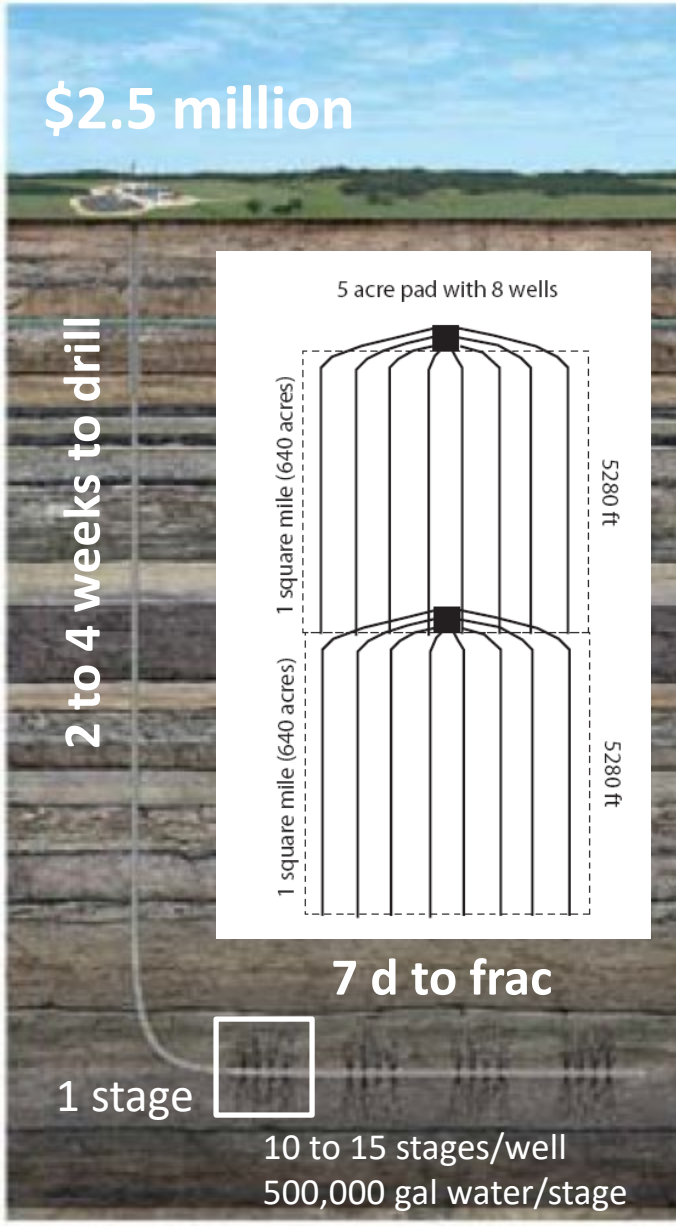
- 1 horizontal well can tap 80 acres
- 8 wells per ~5 acre pad
- $5x10^6$ gal/well; **$40x10^6$ gal/pad**
- water return ~20% =**$8x10^6$ gal/pad**
- 1 pad per square mile

Scale

Tompkins County (pop 100,153)

- 25,000 houses
- 421 mi^2 could be drilled
- if 50% developed over 10 years with 1 pad/mi^2
  - 21 pads/yr
  - 210 wells /yr
  - 2,500 jobs (10 p/well) ~4% TC workforce
  - **10^9 gallons of water /yr**
  - **$0.2x10^9$ gallons salty return** water/yr
  - **500,000 truck trips /yr** (2400 tt/well) , = 1,300 tt/d = 4% increase in traffic but large trucks will damage roads
  - 25,000 houses (@ 0.6 tpd x 2 = 31,000 tpd)

trips per day



10^9 gallons of water /yr not that scary
=5 cfs (& recycling reduces)

Tompkins Co Needs 5 cfs for 21 pads/yr

Local rivers could easily supply

	cfs
Fall C	140
Salmon C	1,000
Senaca	4,100
Susquehanna	29,000

Similar to current usage

Bolton Point Power Plant = 4 cfs

City of Ithaca = 6 cfs

Cornell University = 2 cfs

Chemicals Used in Hydrofracking

- Friction Reducer – polyacrylamide
  - commonly used in contact lenses, children's toys, paper making, and water management operations
- Biocide – glutaraldehyde
  - a disinfectant commonly used in swimming pools, farming, and in soaps and hand sanitation
- Scale Inhibitor – ethylene glycol
  - commonly used in water well and municipal water system maintenance, automotive antifreeze, household cleaners, and other de-icing agents
- Oxygen scavenger – ammonium bisulfate
  - commonly used in cosmetics, food and beverage processing, food packaging, and pharmaceutical products
- Diluted acids – hydrochloric acid
  - commonly used in swimming pools and dozens of other household applications

Radioactivity- U increases with TOC

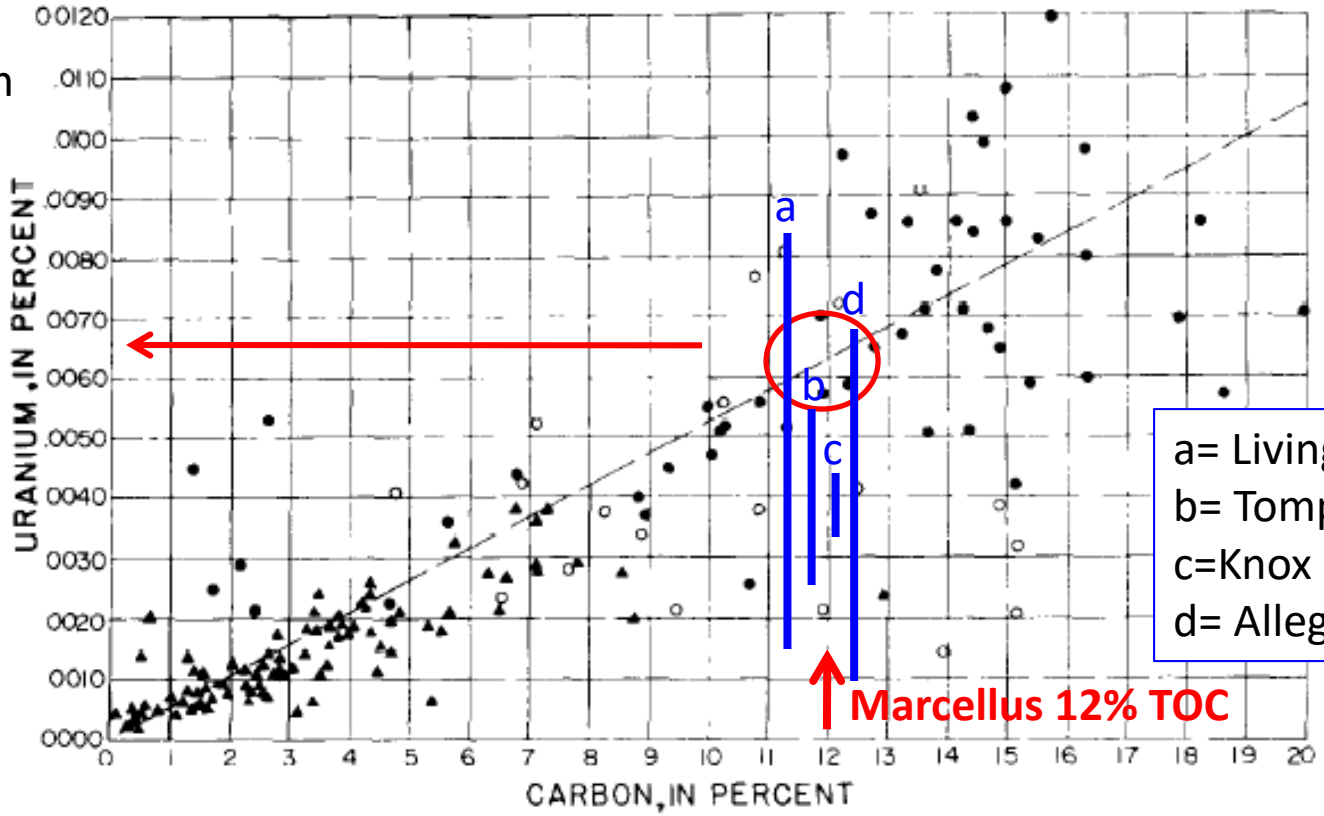
Harper Pennsylv Geol 38(1) 2008 p5:
Radioactivity = organic richness = gas

- K, Th, U adsorbed on clays (Wignall and Meyers (1988)
- Th/U~4 (Faure, 1977)
- U can be authigenic (Wignall and Meyers (1988)

100 ppm

65 ppm U

10 ppm



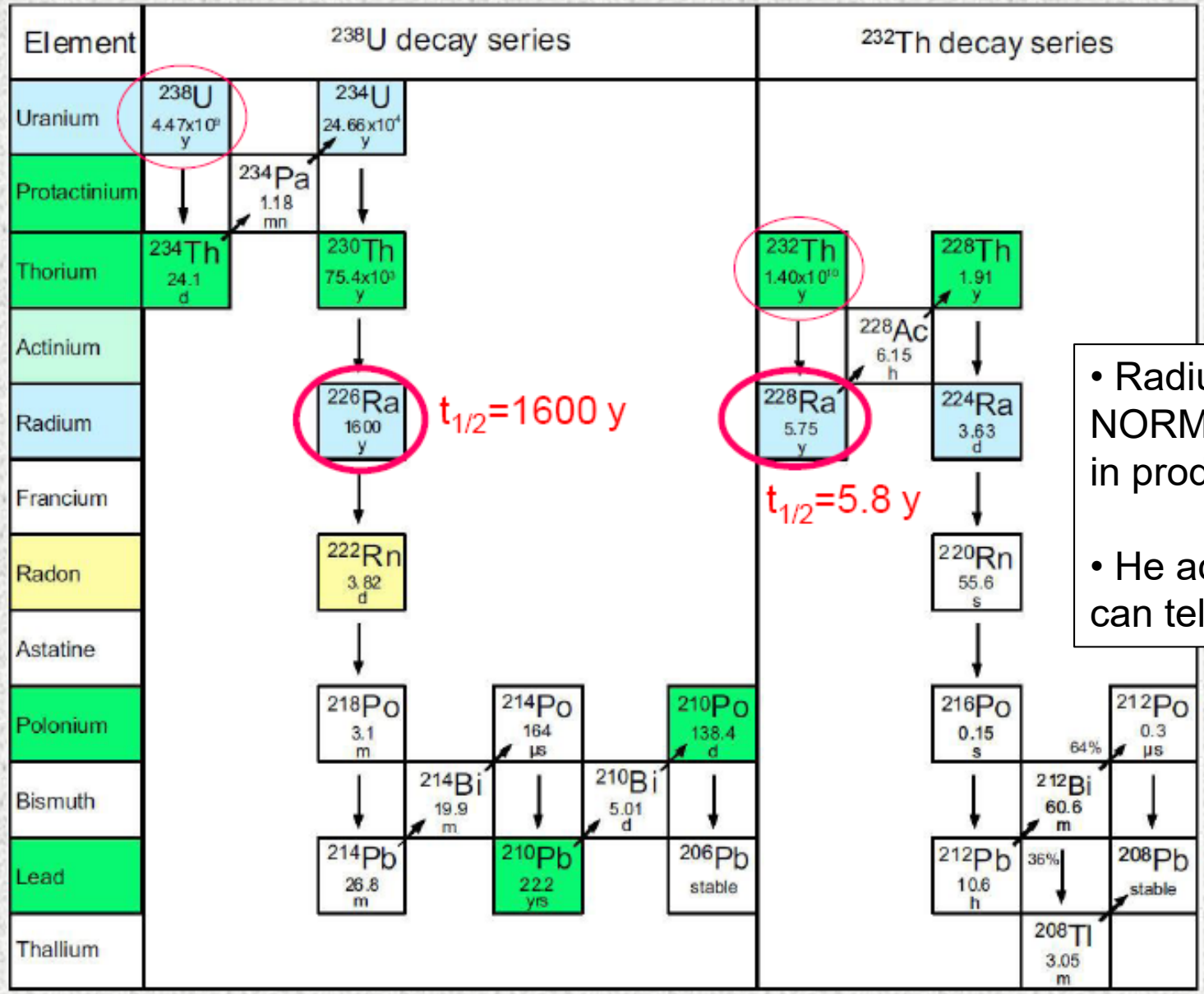
Resnikoff 2010

a= Livingston Co NY
b= Tompkins Co NY
c=Knox Co OH
d= Allegheny NY

Fig. 1. Organic carbon vs uranium in Appalachian Devonian shale samples. Solid circles and line of correlation represent data from SWANSON (1960); triangles show data from LEVENTHAL and GOLDHABER (1978), and LEVENTHAL (1979), open circles show data from this study.

Leventhal JS (1981) … organic matter and … U..of Appalachian Devonian black shales, GCA 45 p883-889

Uranium equilibrium decay series through Radium (1st water soluble product)



Th/U Ratios:

Sandstone: ~4

Black Shale: ~0.2

- Radium is a NORM of concern in produced fluids
- He accumulation can tell of porosity

Kramer(2010)

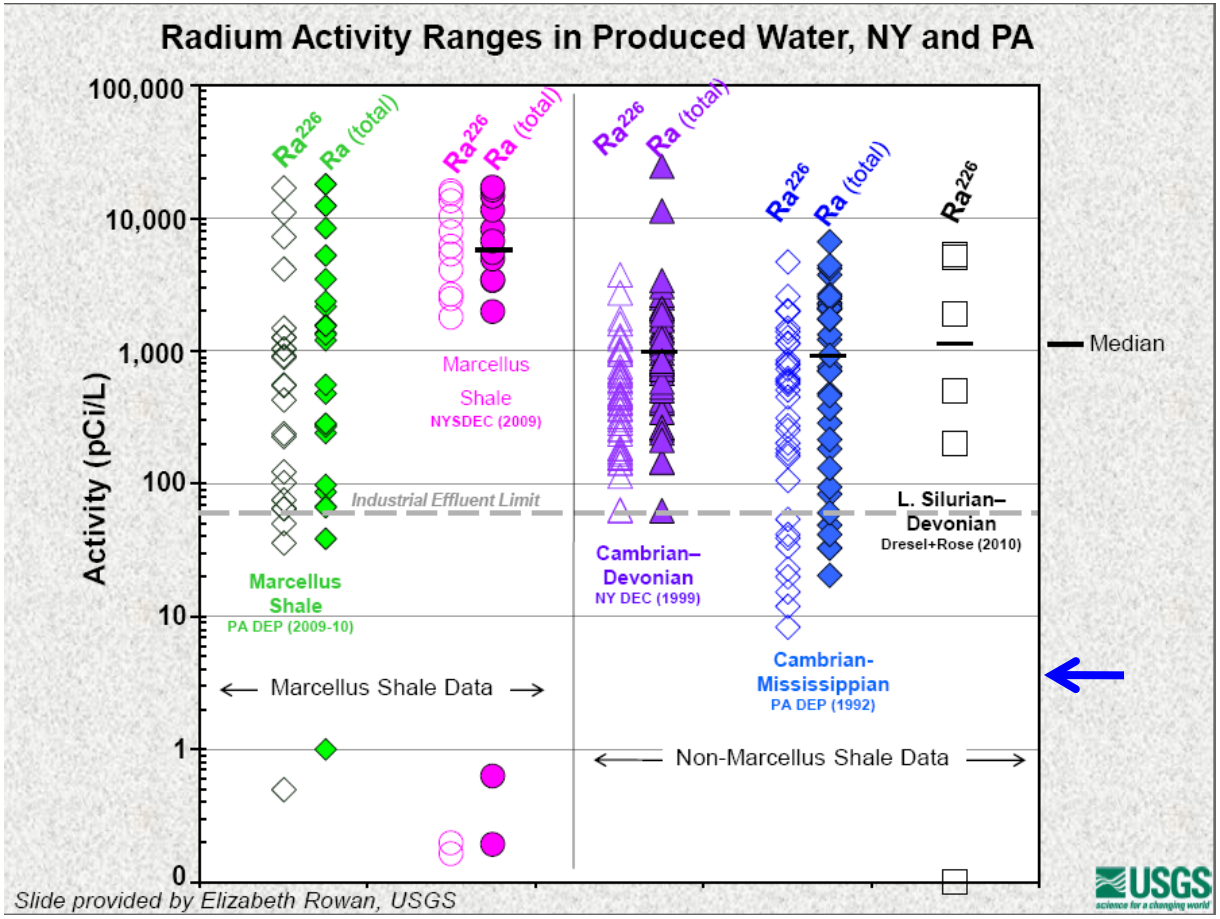
Slide provided by Elizabeth Rowan, USGS

Modified from Schmidt and Kirk, 2010

USGS science for a changing world

Fracking chemicals less serious than minerals dissolved

Radium is an issue that must be managed



- Managed at existing wells
- Can be detected and precipitated at well head
- Can be removed in drinking water treatment facilities

5 pCi/L = USEPA drinking water standard

Environmental Levels of Radium in Water of Central New York, Thomas F. Kraemer U.S. Geological Survey, Reston, VA, Finger Lakes Research Conference, December 4, 2010

Return water can be treated

Niagra Falls Wastewater Treatment

Not same as drinking water treatment

- Screen for large solids
- Remove grit is settling ponds
- flocculate with $FeCl_3$ and polymer -> thickeners , belt dewater, disposal
- Flow through carbon beds
- Treat with peroxide and Na hyperchlorite
- dispose Niagra River
- capacity 136 ML/d = 55 cfs

- 21 pads generate 1 cfs return water
- Niagra plant could treat 1100 pads per year

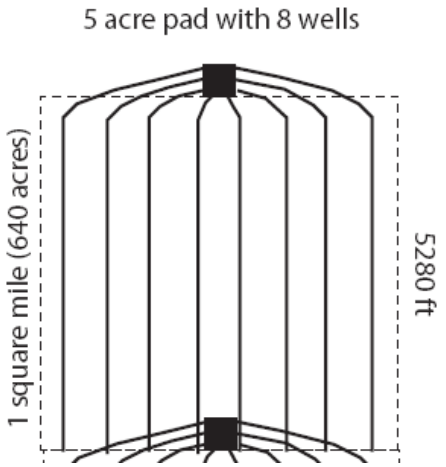
Niagara Falls Wastewater Treatment Plant High Rate Treatment, Canada

Gallery 1

http://nfwb.org/customer/faq.php

http://www.water.mottmac.com/waterprojects/?mode=type&id=327912

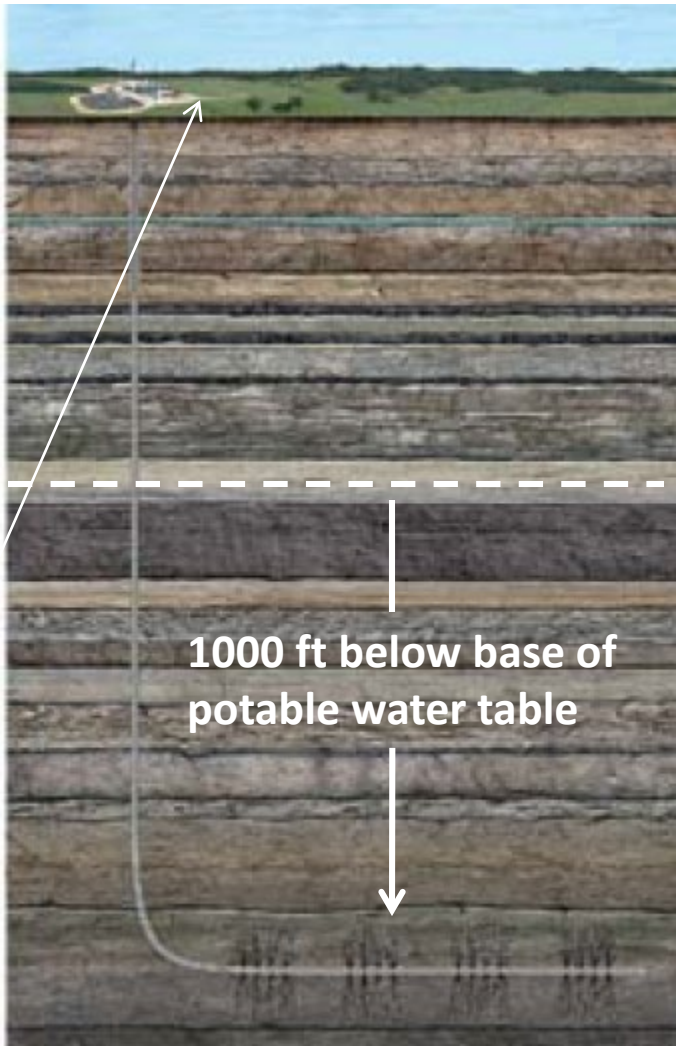
Risk is shallow drilling and water handling, which is manageable



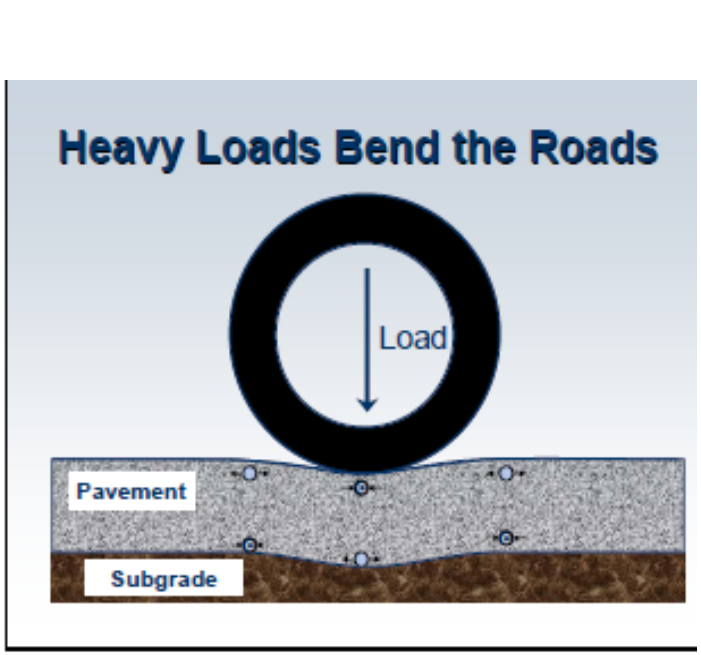
Risk of encountering a gas pocket before casing in place minimized by drilling >8 wells from one pad

Water handling and disposal is a risk that can be managed by regulation

Short duration or pressure injection and distance below potable water minimizes risk to ground water supply



Roads will be damaged




Before Drilling


After Drilling

Propane fracking eliminates water problems, cuts trucks by 5x, and does not impair resource

- no water injected
- no capillary seals
- no contaminants returned (Ra, metals)
- recycle 80% propane
- propane uniform chemistry→gelation chemistry simple (P-ester, Fe+++ SO4 linker, MnO breaker)
- no flaring at startup
- Fewer trucks (30 vs 947)
- Fewer frac jobs (all fracture good)
- Lower cost because more effective

Technological innovation can address issues

Robert Lestz, Gasfrac Energy Services Inc
Cornell Lectures March 1 and 2, 2010

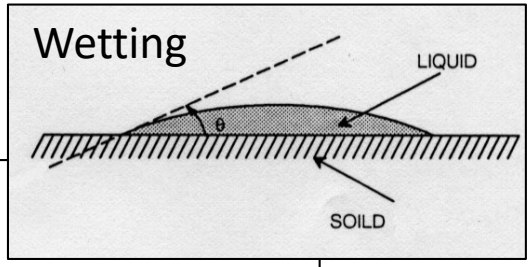
Outline

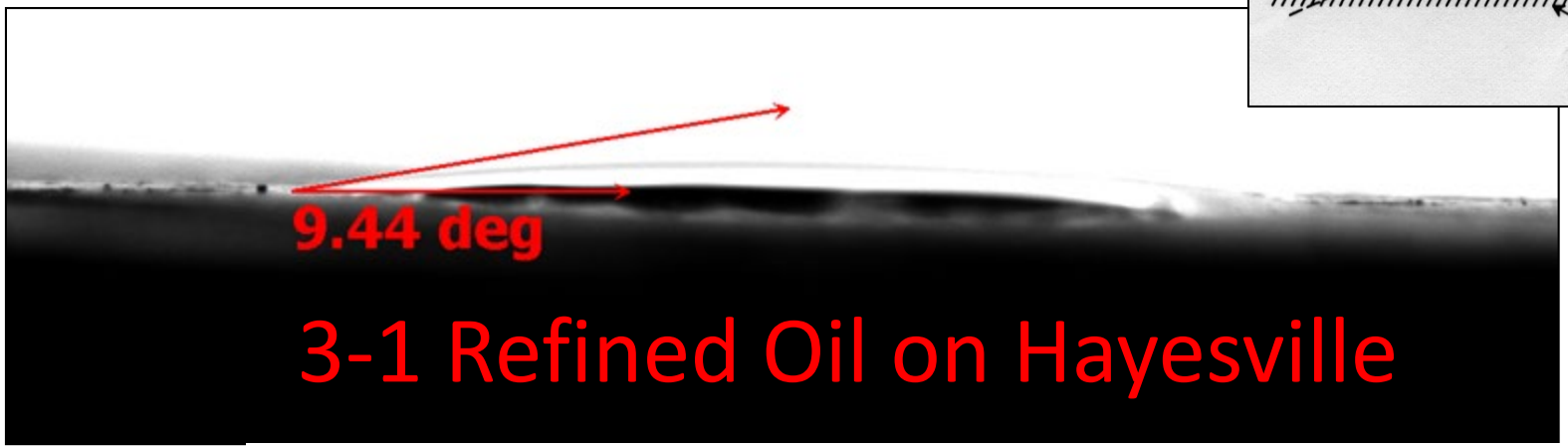
- Geology & Technology
- Gas
- Worries
- Puzzles
- Community

…strange observations

- Gas shale is a dry sponge
  - Only ~20% of treatment water returns
  - but shale is both oil and water wet
- Treatment water is fresh, returns as 200 kppm brine
  - No halite in shale

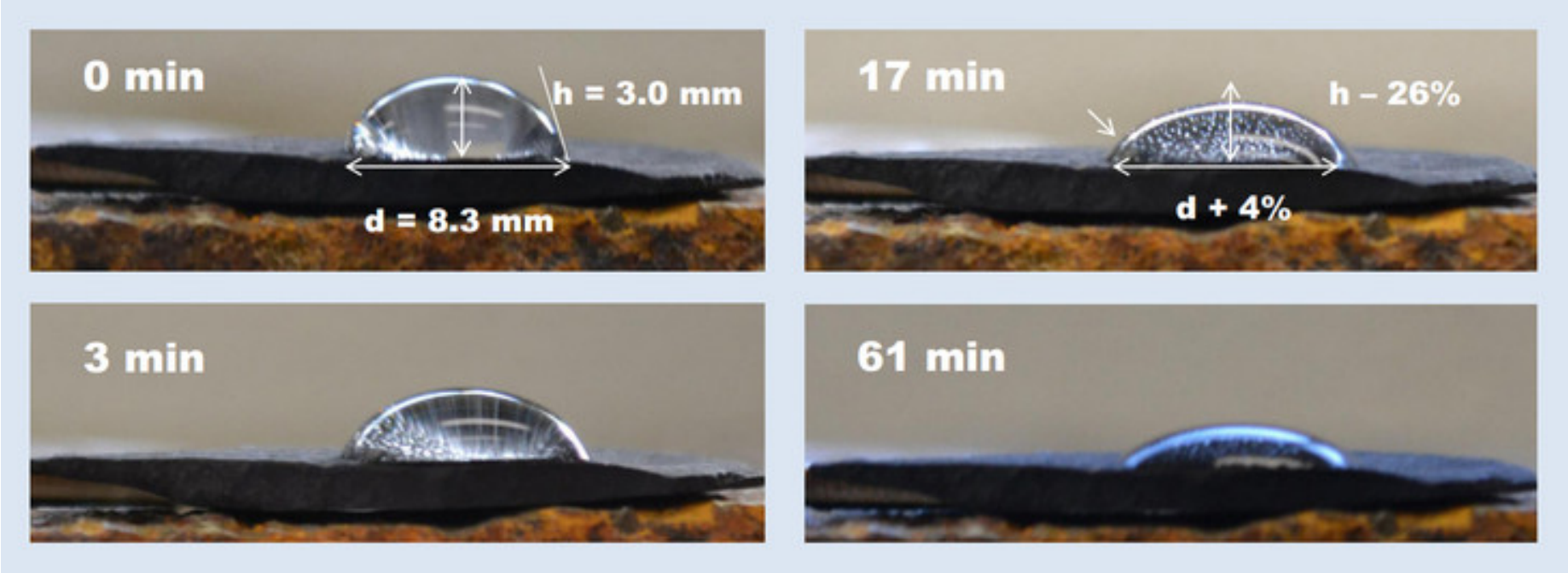
Organic shales are strongly oil wet





Imbibition associated with gas expulsion

- Water imbibed
- Gas expelled
- More water wet (saltier) with time

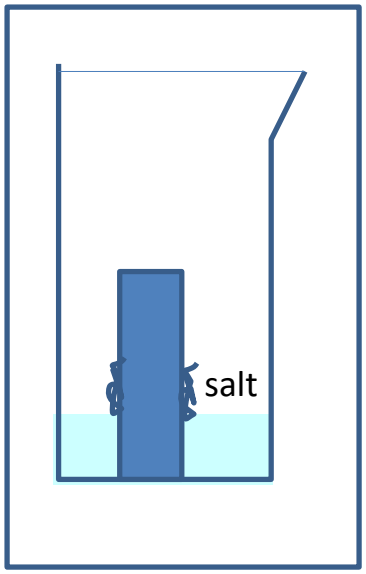


Union springs member of Marcellus

Classic example of diffusion osmosis

- Osmotic forces push water in
- Salts diffuse out
- Gas expelled

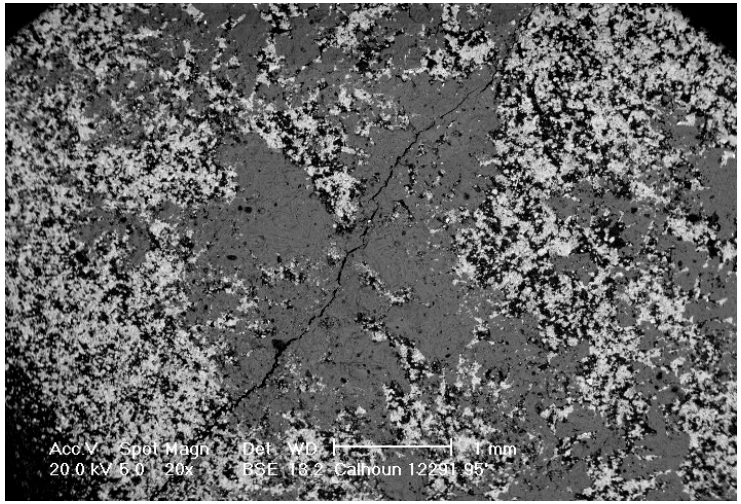
Ions from core, but no halite…



Salt on core of beaker experiments

Salt on cores stored after washing off OBM

salt adsorbed on clay surfaces



Outline

- Geology & Technology
- Gas
- Worries
- Puzzles
- Community

… or the lack thereof

Horseheads, NY

Ithaca, NY

If not natural gas, then what?

Nuclear

Fukushima Daiichi

Coal

Mountaintop Mining

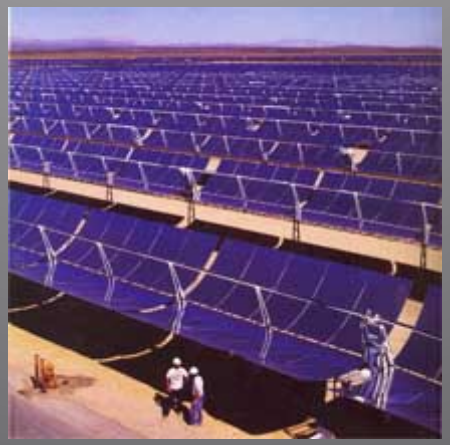
Oil

Deepwater Horizon

Renewables?

Wind

Solar



Biofuels

?Economics

?Environmental Impacts

LDB

In NY the worries won…

- Water
  - Consumption
  - Contamination
  - Treatment
- Community Impacts
  - Earthquakes
  - Infrastructure Degradation (e.g. roads)
  - Traffic
  - Transient population increases
  - Landscape deteoration
  - Habitat segmentation
  - Forced integration
- Global Warming
  - Gas could be twice as bad as coal

In Pa they did not

Local community response

Supplemental Generic Environmental Impact Statement

- Massive community input to SGEIS
- TCCPI Tompkins County Climate Protection Initiative
- Drilling committees organized in all local communities (Ithaca, Lansing, Caroling, Dryden)
- All ways to block development explored (zoning, banning, regulating, delaying)

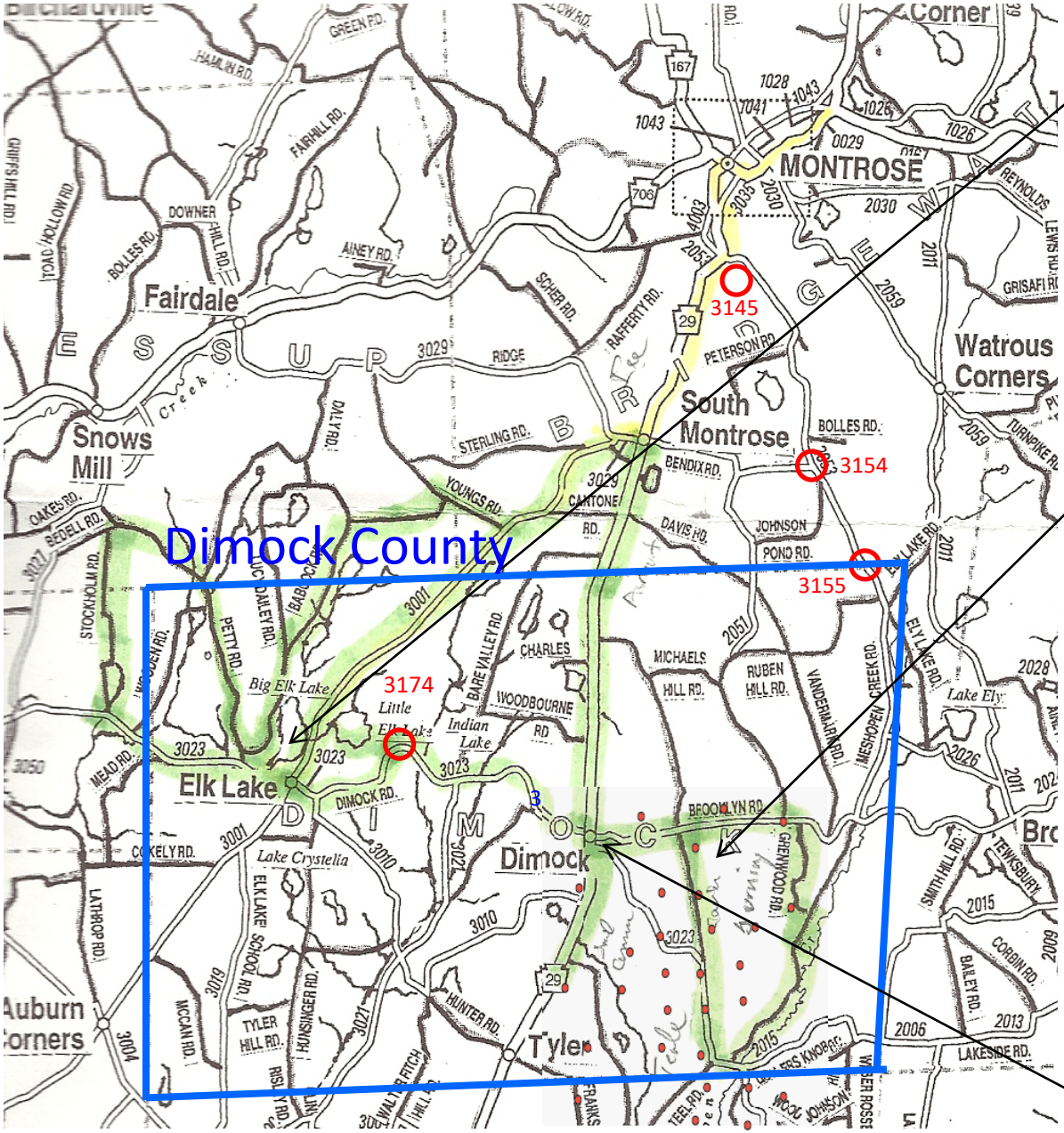
Cornell

- A center of opposition, not engagement

What does Pa look like?

A beautiful area

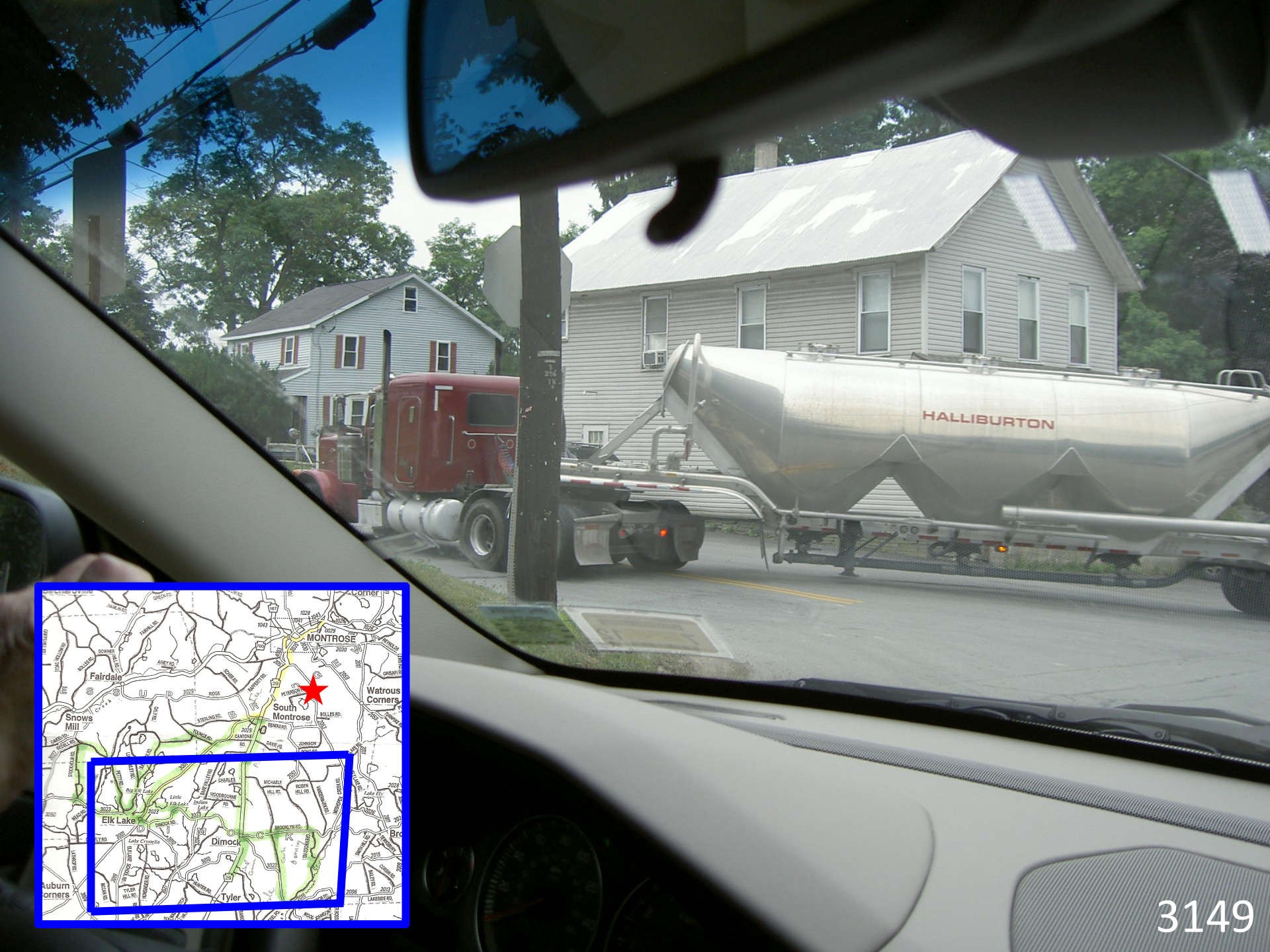
0 2 miles 4 6



lehighvalleyclanculariusintrospective.blogspo...

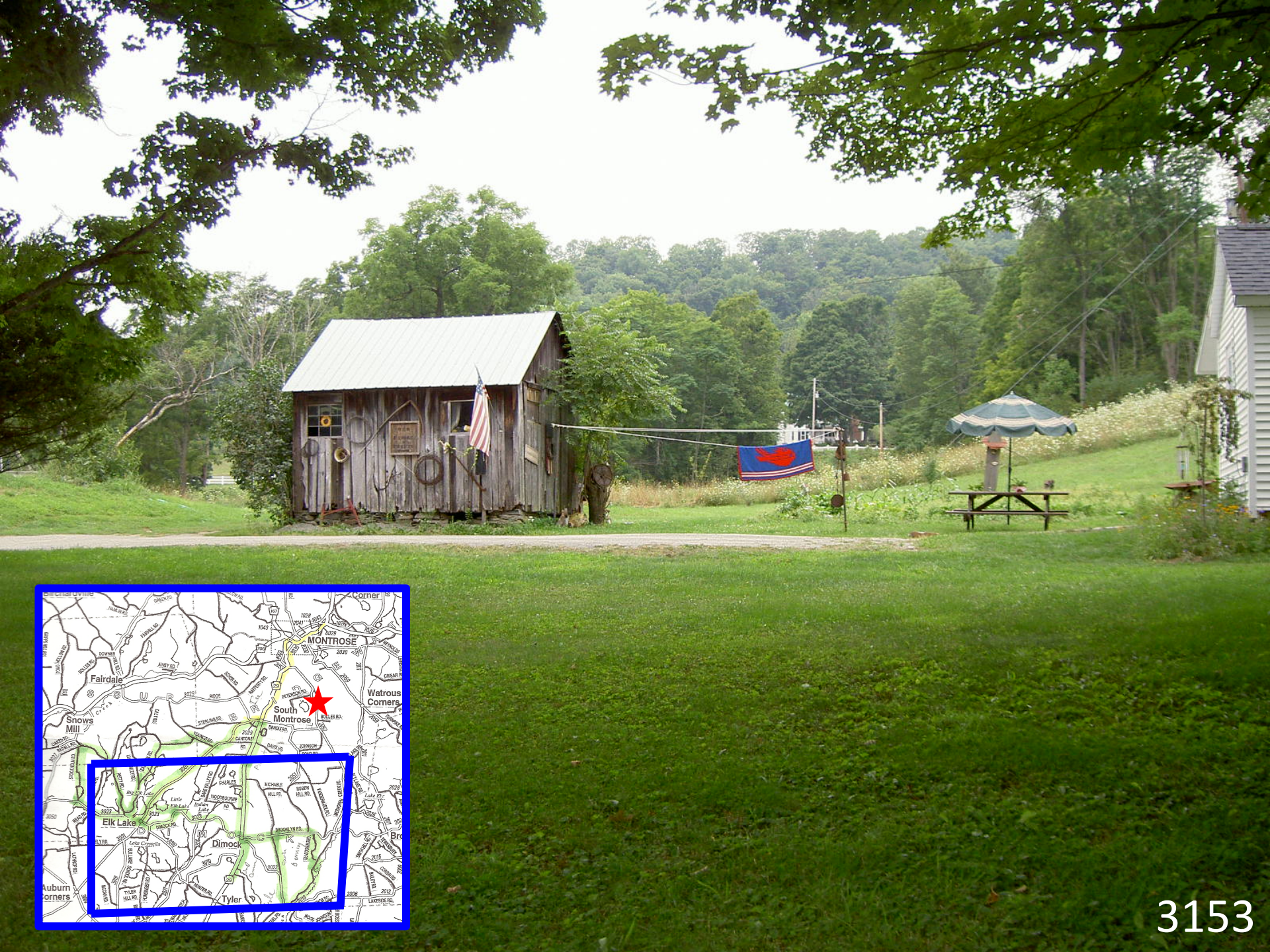
● = 30 Dimock/Carter Rd gas wells (by google earth in 5.3 mi² area 113 acres/pad) from Consent Order DEP -Cabot 4/11/09


NOTICE
WARNING
WARNING
Cabot Oil & Gas
CONSUMPTIVE WATER USE
MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners


HALLIBURTON
MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners


MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners
3150

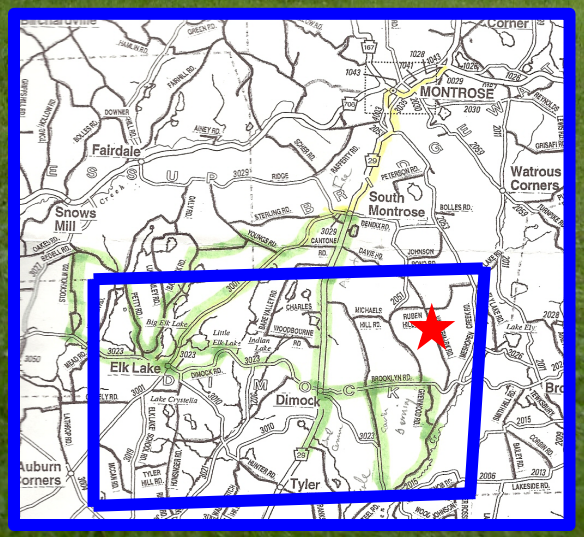

NOTICE!
ACCESS to this location IS RESTRICTED to AUTHORIZED PERSONNEL ONLY!
Visitors and Contractors Please Sign In With The Well Site Supervisor Before Proceeding
WARNING
WARNING
MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners


MONTROSE
Fairdale
South Montrose
Watrous Corners
Snows Mill
Elk Lake
Dimock
Tyler
Auburn Corners

3153


MESHOPPEN CR RD
T508
SPEED
LIMIT
35
MONTROSE
Fairdale
Snows
Mill
South
Watrous
Corners
Elk Lake
Dimock
Tyler
3154


MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
3157

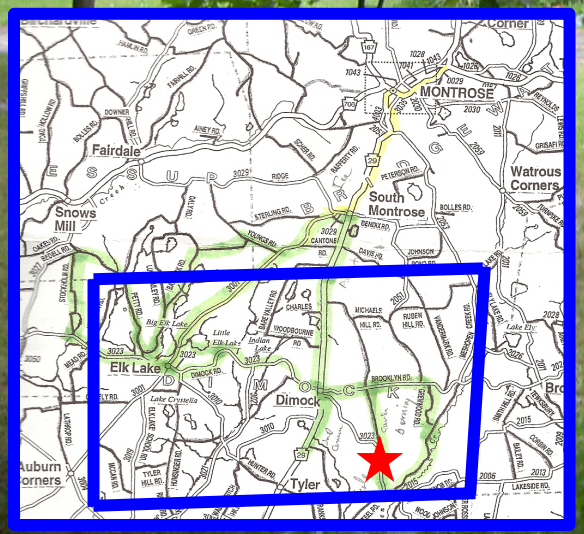

MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler

3159


MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners
3160

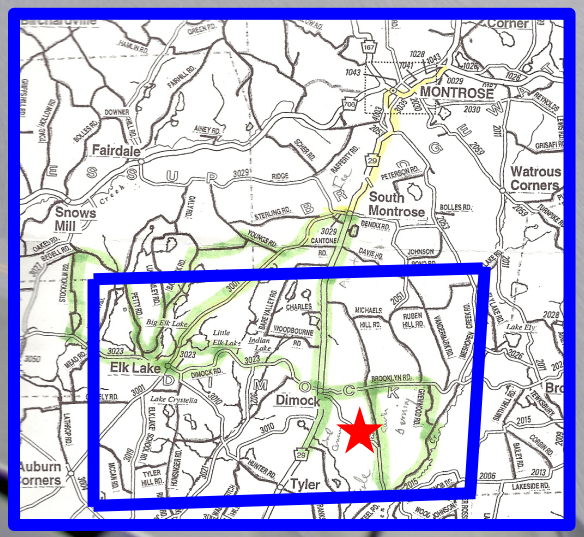
Only no fracking sign we saw (Carter Road)

3163

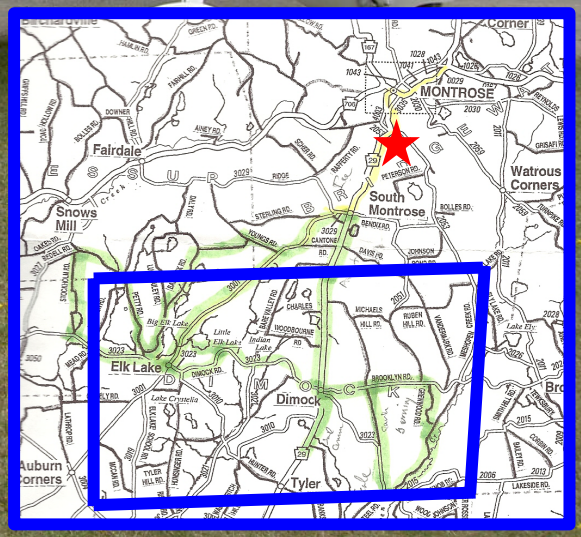

MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners

3164


CARTER
STOP
SPEED LIMIT 40
MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners


MONTROSE
Fairdale
Snows Mill
South Montrose
Watrous Corners
Elk Lake
Dimock
Tyler
Auburn Corners

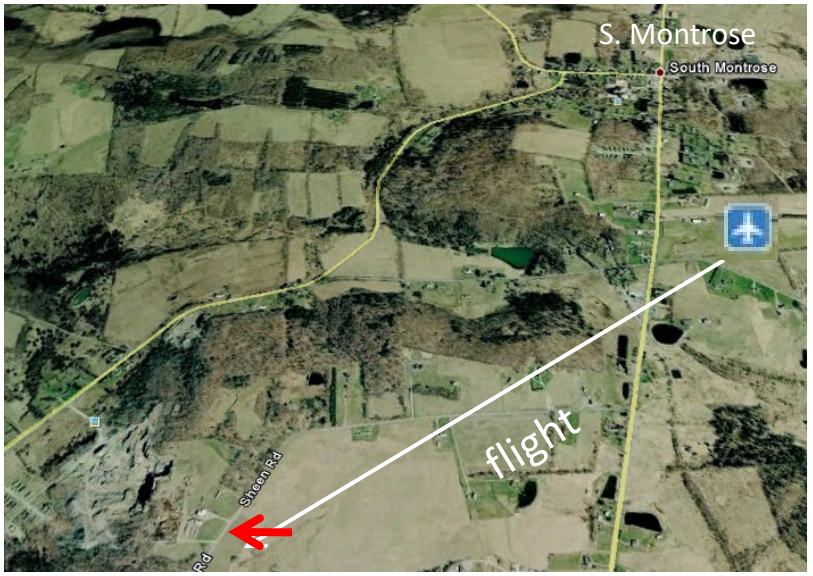
The intention of the flight was to see what the area affected by drilling looked like from the air. We flew over all the drilling operations in the area covered in the insert map, and the pictures presented here are, I believe, a fair representation of what the area looks like from the air.



Joe McCann
Captian USAir (Retired)
Flight August 10, 2010

Picture number
3145

… immediately after take off



Drill pad

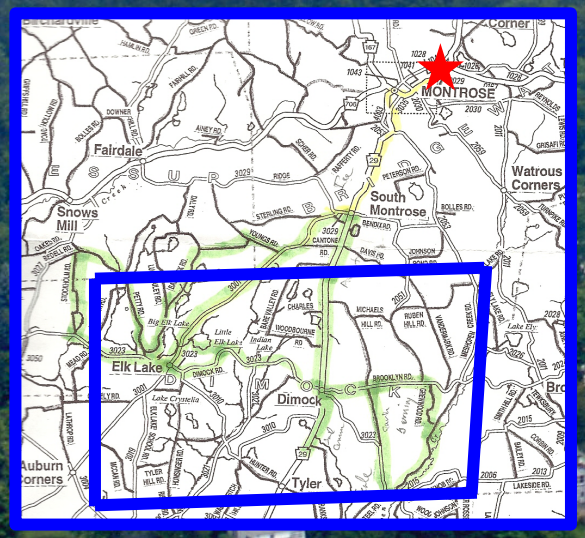
Marcellus gas

Quarry

Pennsylvania Blue Slate


3102

Montrose



3129


Drill pad


Drill Rig
3135


Drill pad
pipeline
3093


Drill pad
3108


Drill pad
Drill pad
Drill pad
3089


Quarry
Drill pad
pipeline
3094

3096


Quarry
3123

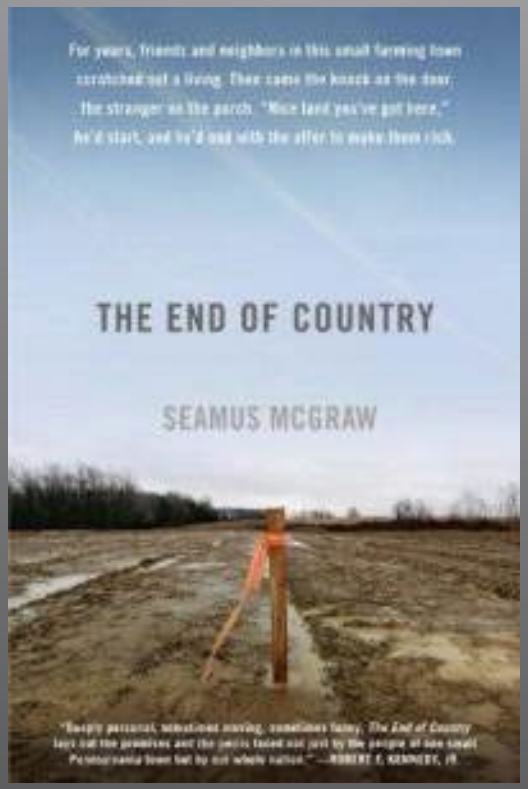

Quarry
3092

Conclusions

- Marcellus is a high value resource
- Managed properly it will be minimally intrusive
  - no permanent increase in population (schools, housed, roads,…)
  - value needed in poor rural areas
  - not new (Quarries)
  - opportunities: better roads, trails along pipelines
- Development risk: shallow drilling & water handling
- Shallow drilling risk (e.g., for water wells): remains whether develop Marcellus or not
- Good for climate (gas is better than coal, fund electrical infrastructure)

Recommended Reading

Seamus Mcgraw
The End of Country



LDB