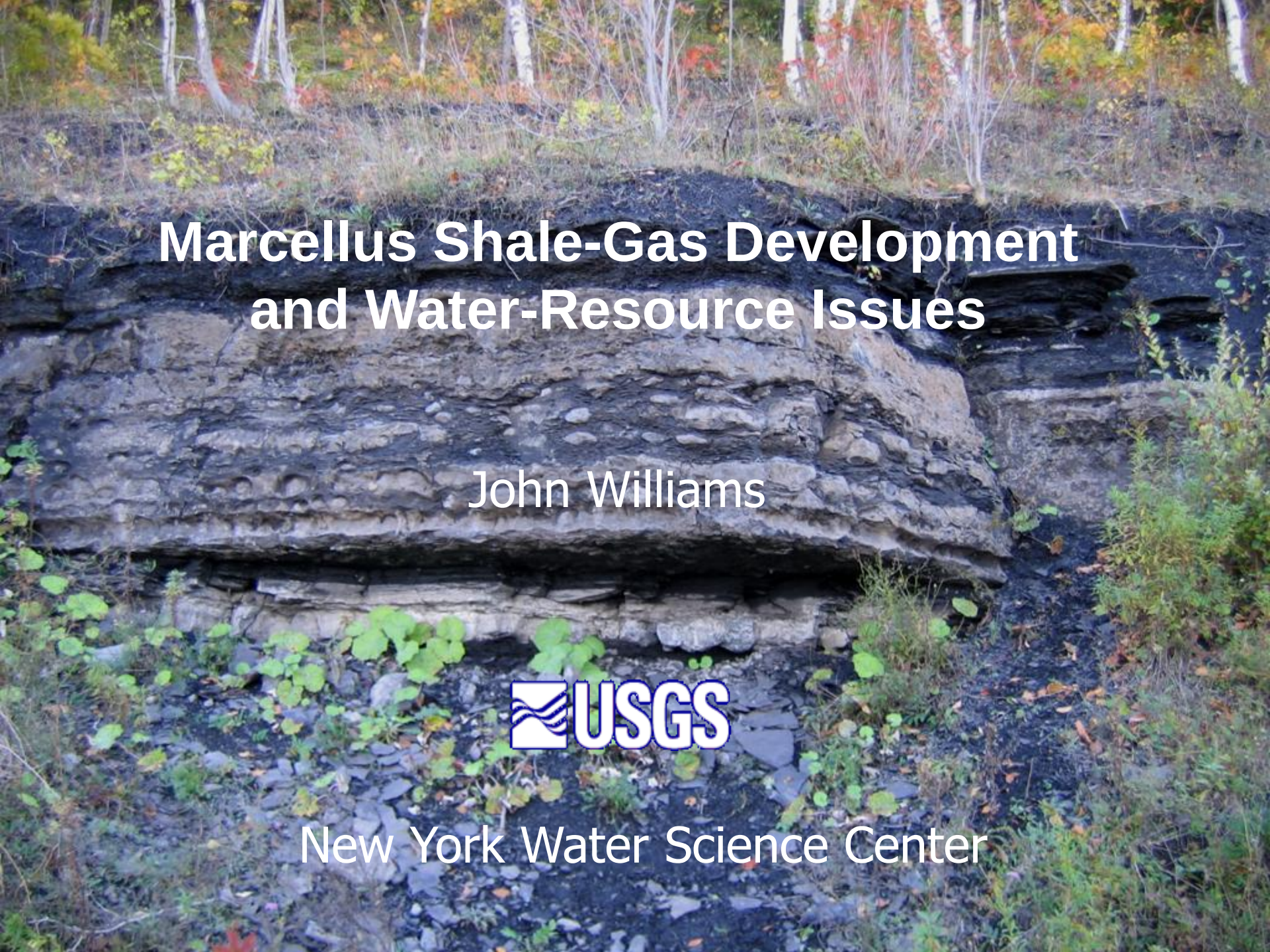


Marcellus Shale-Gas Development and Water-Resource Issues

John Williams

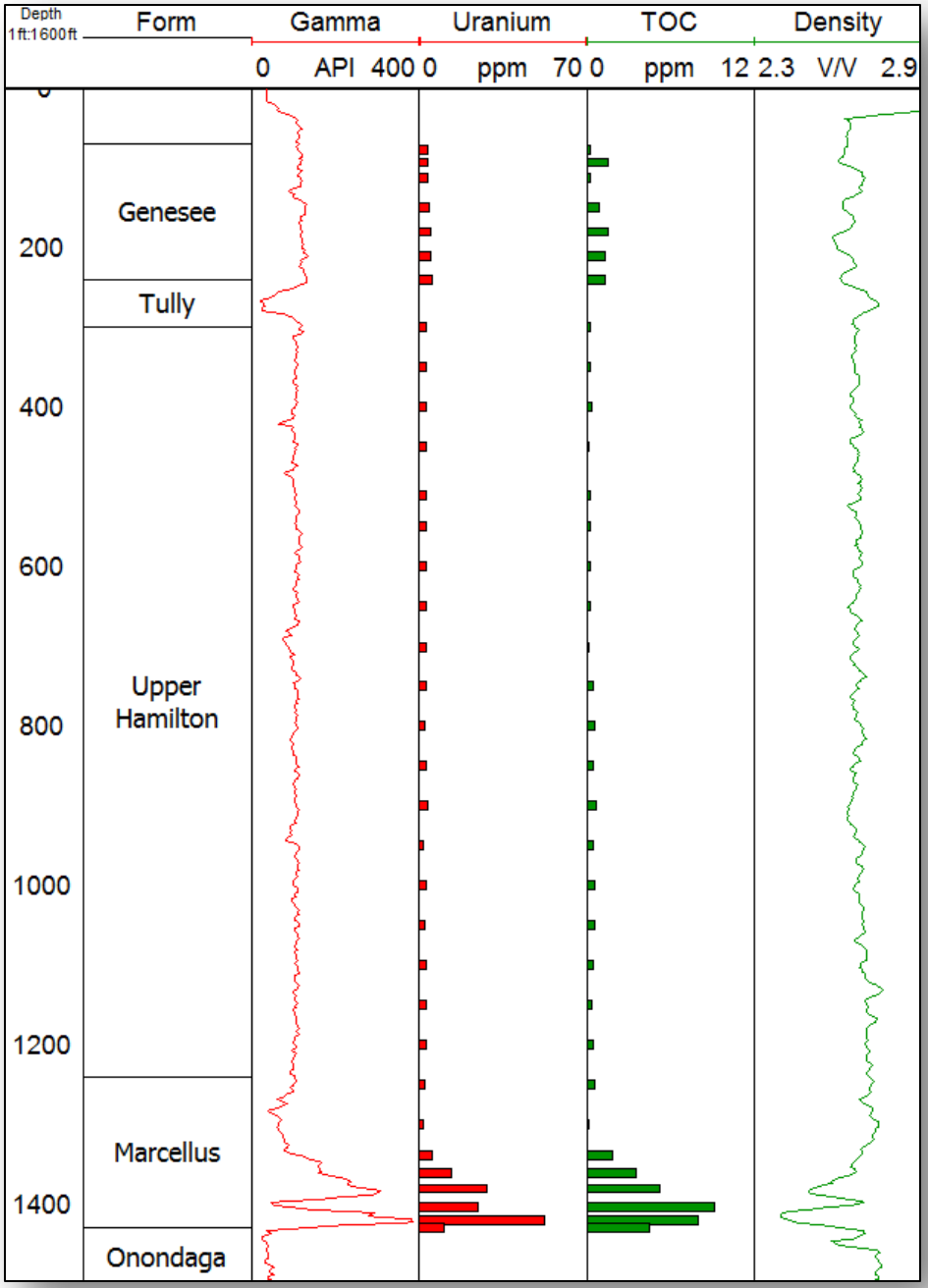
USGS

New York Water Science Center

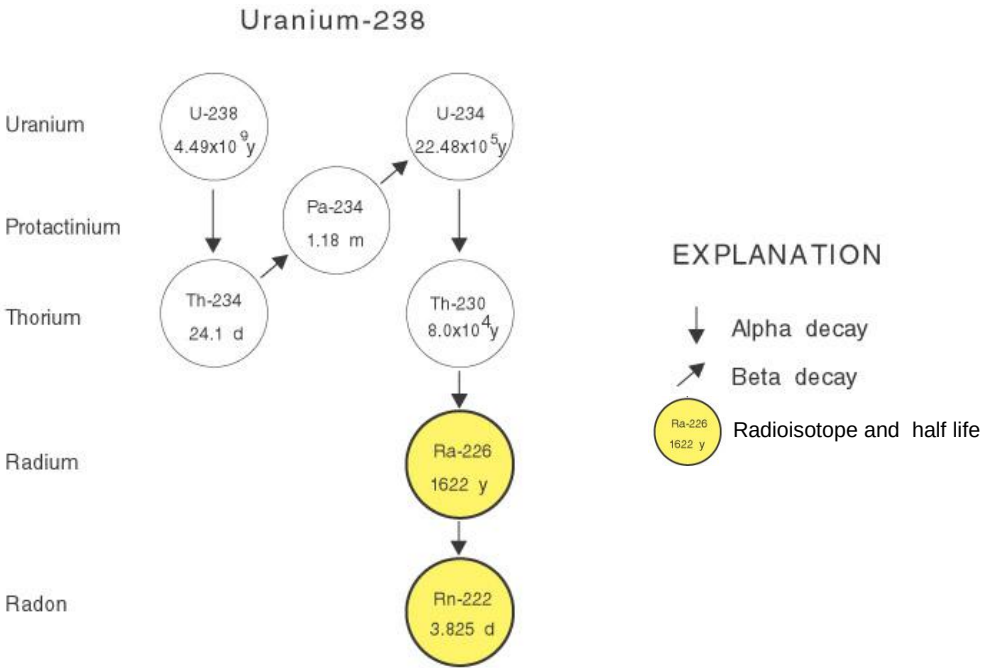
High TOC and elevated radioactivity in basal Marcellus Shale

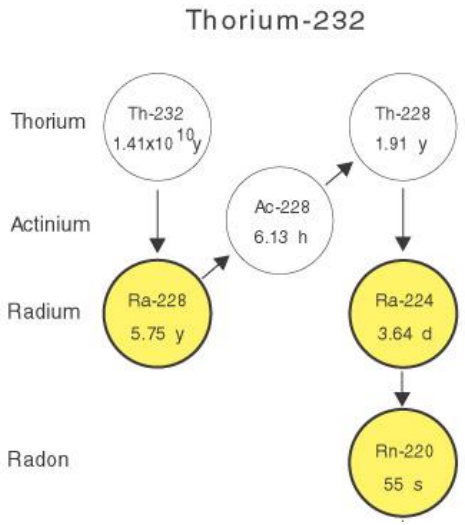
Location of the Core	Uranium Content (ppm)
Allegheny, NY	8.9 – 67.7
Tompkins County, NY	25 – 53
Livingston County, NY	16.6 – 83.7

Levanthal and others (1981)



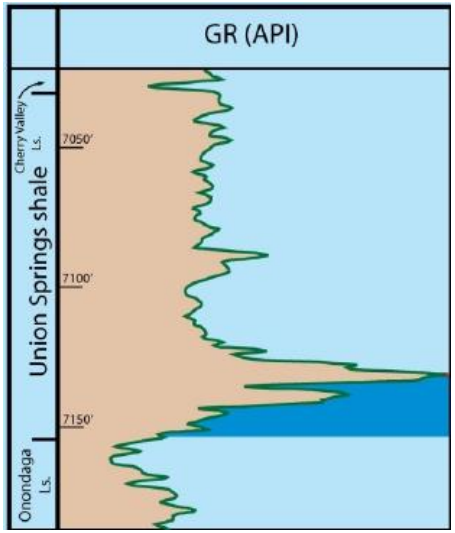
Uranium & Thorium to Radium & Radon Radioactive Decay Series



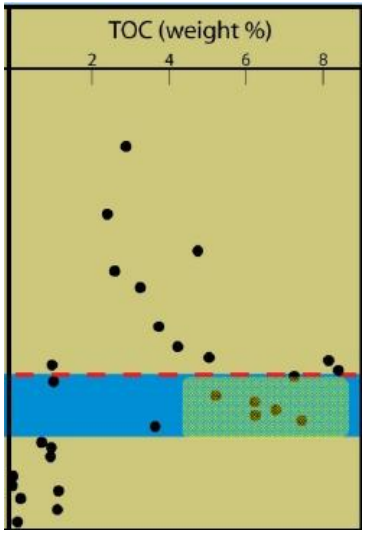


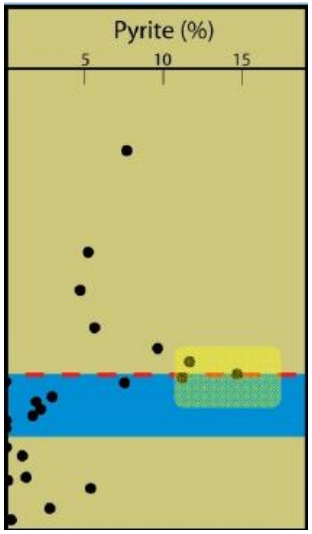
High TOC and abundant pyrite in basal Marcellus Shale

Gamma Log



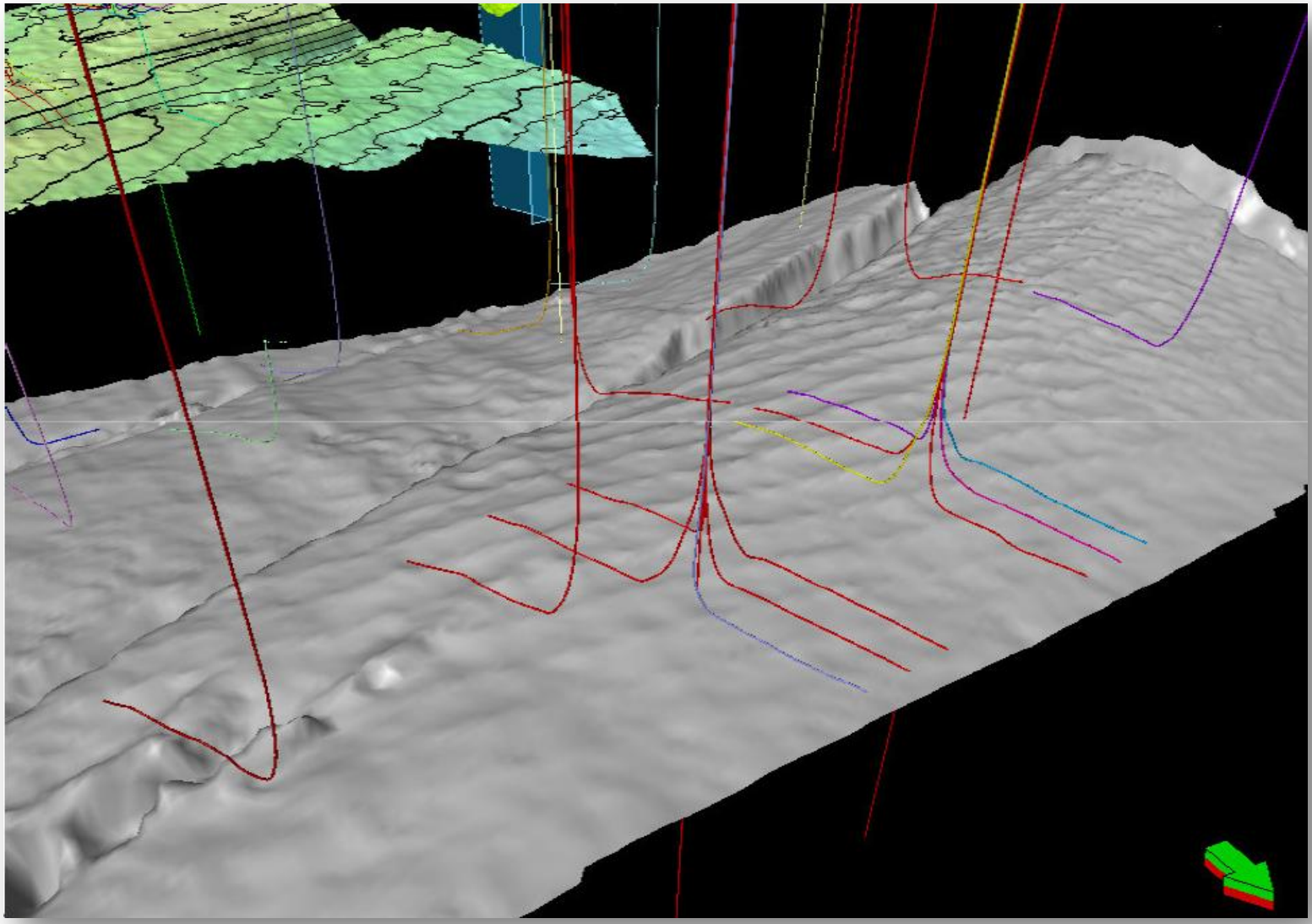
Drill Core Sample Analysis





Lash and Engelder (2009)

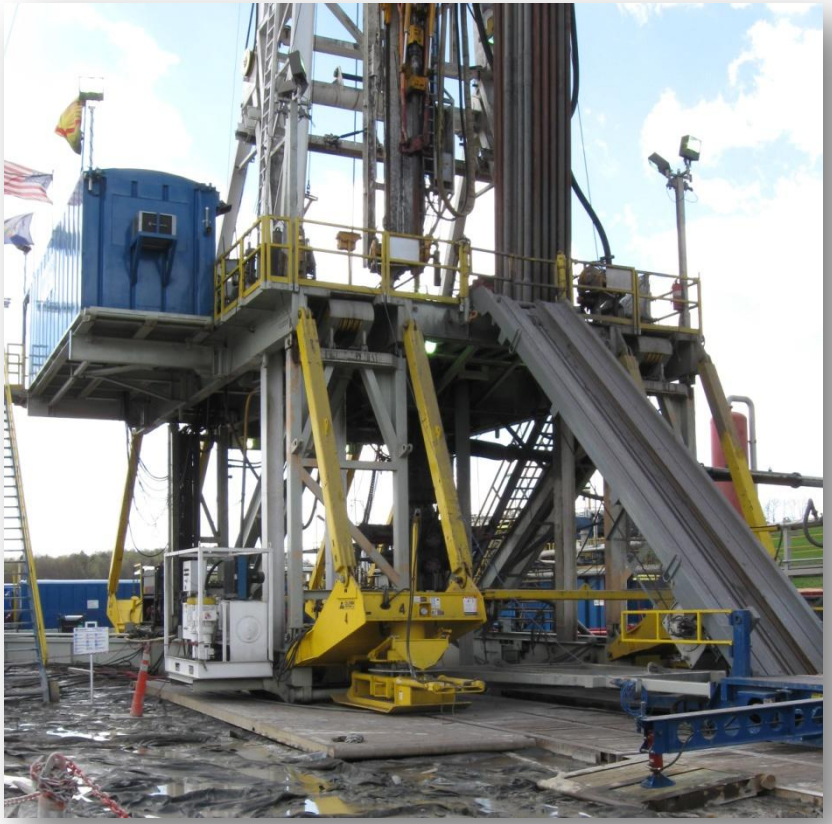
Horizontal wells target basal Marcellus Shale



Teff (2011)

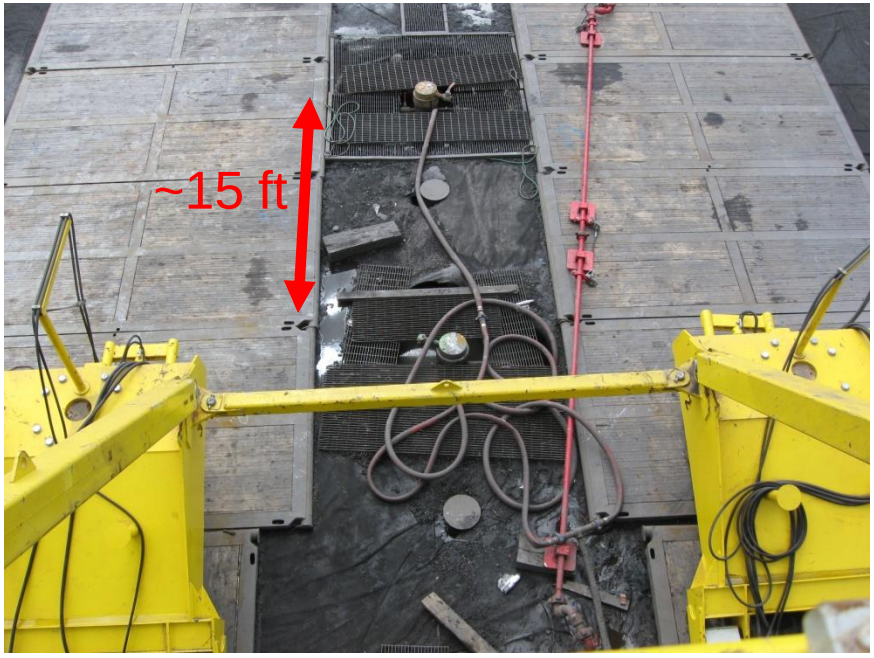
Top-set rig for drilling vertical surface-cased interval

Directional rig for drilling horizontal leg

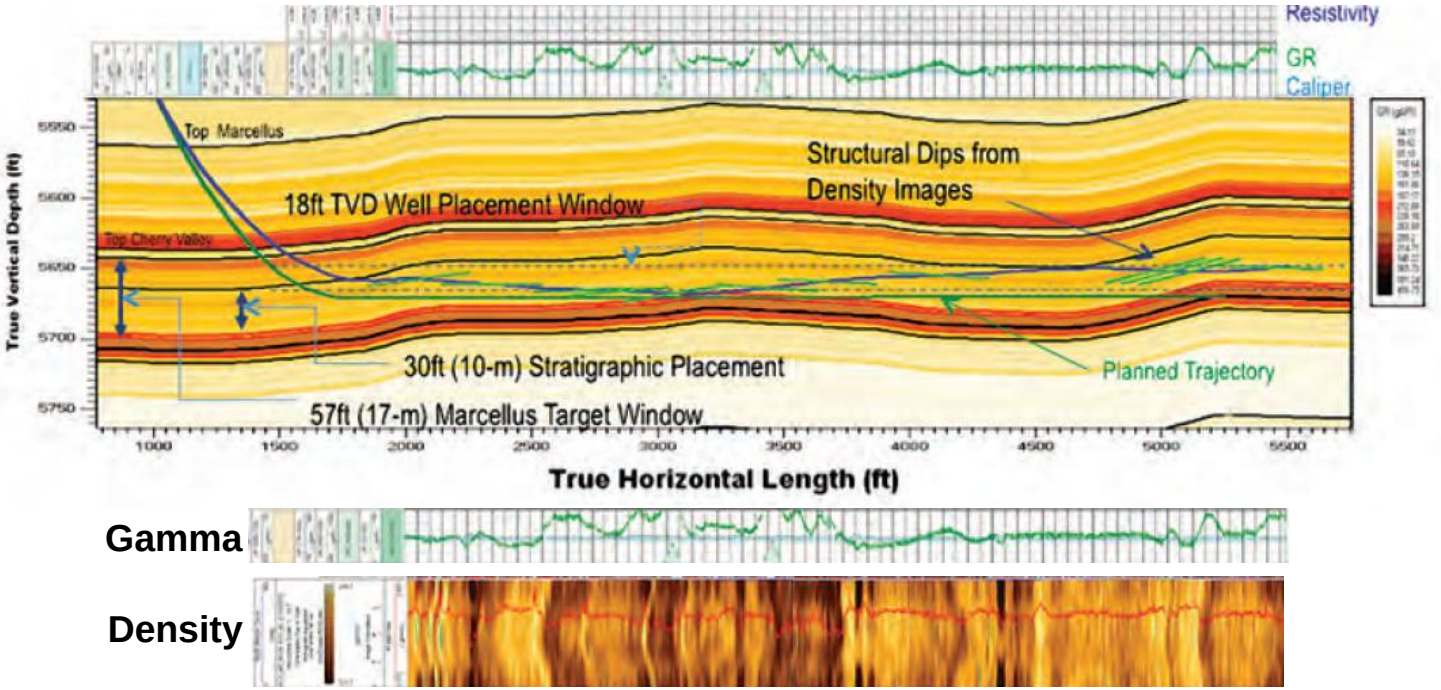


Walking legs on directional drilling rig

Wellheads of first two of six horizontal wells



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

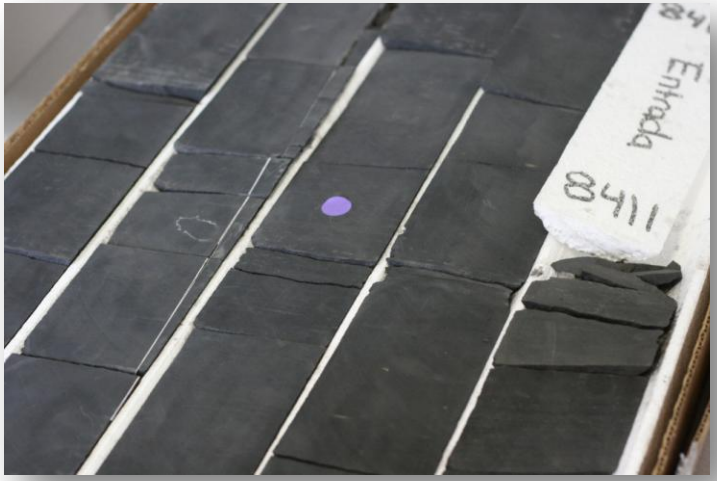


Logging-while-drilling used to steer lateral within target beds

Schlumberger (2010)

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

Flowback

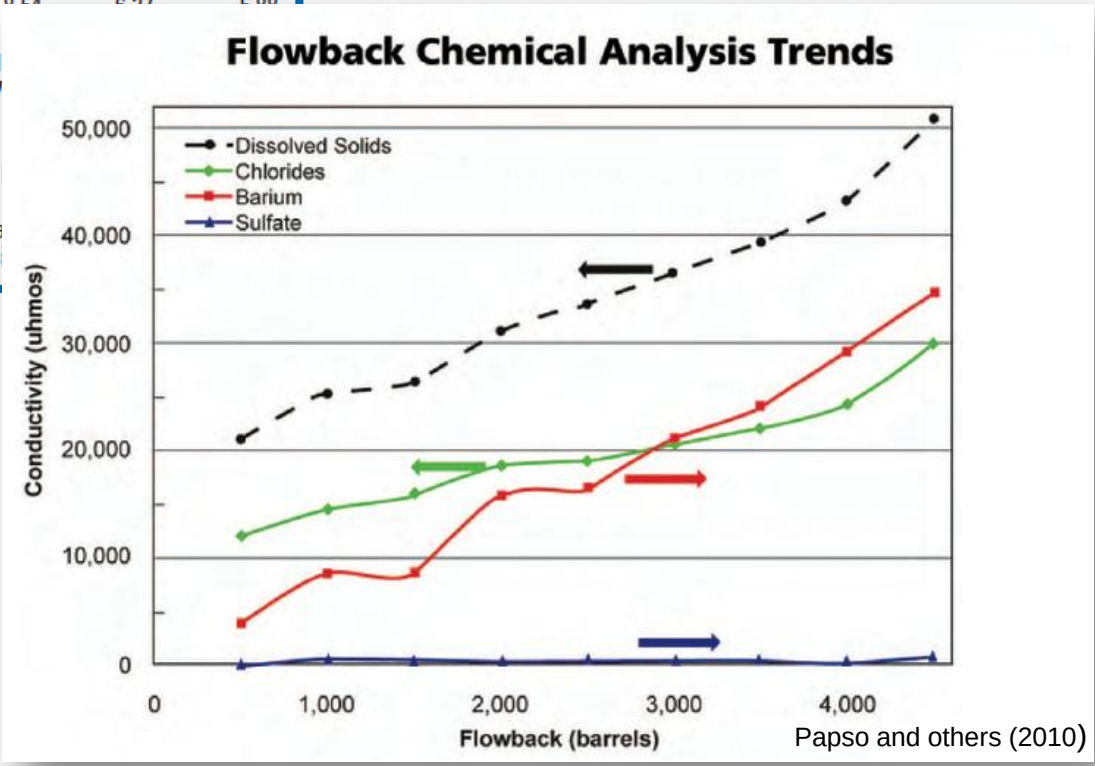
Contains elevated TDS, chlorides, barium, and radioisotopes whose concentrations increase during the flowback period approaching formation brine

TABLE 1. Flowback water analysis (Case 1)

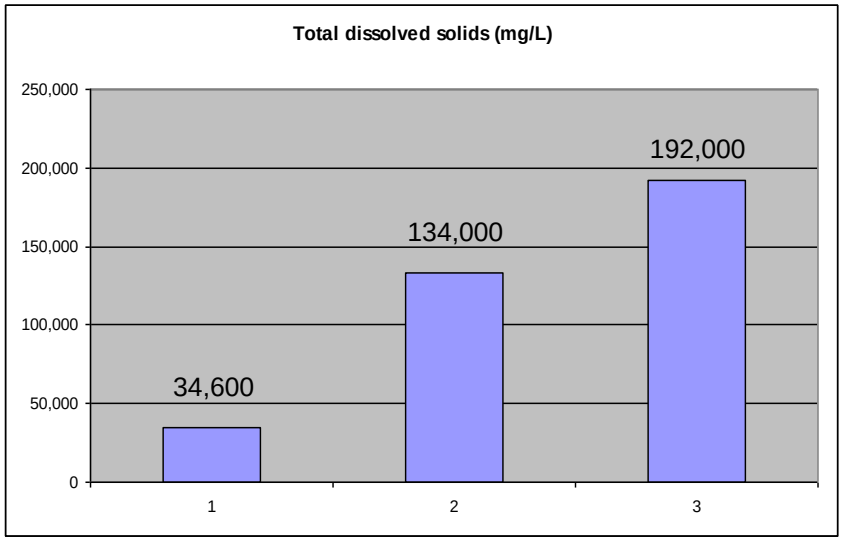
Flowback, bbl	500	2,500	6,000	11,000	15,000
Anions					
P alkalinity, mg/L as $CaCO_3$	0	0	0	0	0
M alkalinity, mg/L as $CaCO_3$	580	560	360	260	160
Chloride, mg/L as Cl^-	2,000	5,800	16,400	53,000	104,000
Sulfate, mg/L as $SO4^{2-}$	1,115	910	588	57	24
Cations					
Sodium, mg/L as Na^{1+}	714	1,470	2,671	9,062	12,830
Potassium, mg/L as K^{1+}	27	40	105	381	544
Calcium, mg/L as Ca^{2+}	240	536	1,960	6,840	9,720
Magnesium, mg/L as Mg^{2+}	44	73	171	341	805
Total hardness, mg/L as $CaCO_3$	780	1,640	5,600	18,500	27,600
Barium, mg/L as Ba^{2+}	0.4	0.5	2.1	7.3	70.2
Strontium, mg/L as Sr^{2+}	16.5	48.4	211	995	1,837
Ferrous iron, mg/L as Fe	1.8	0.8	0.4	0.6	3.3
Total iron, mg/L as Fe	42	27	38	157	78
Miscellaneous					
pH	7.25	8.31			
Total suspended solids, mg/L	90	20			
Specific gravity, g/ml	1.001	1.016	1		
Conductivity, µΩ	7,160	16,800	37		
Δ ATP (microbiological content), relative light units	5	6			
Microbiological content	Low	Low			
Langelier saturation index (LSI)	1.02	2.37			
Langelier potential scaling	Scaling	Scaling	Sca		
Calcium sulfate scaling potential	Positive	Positive	Pos		

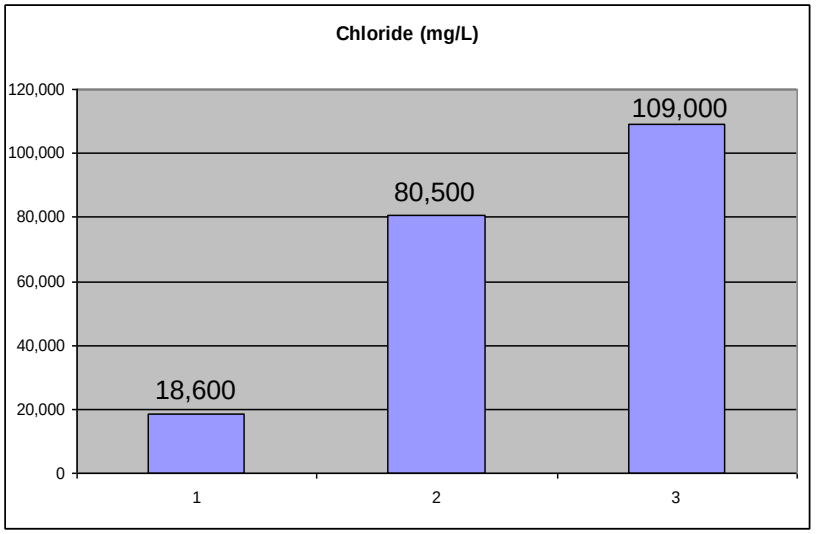
WORLD OIL **JULY 2010**

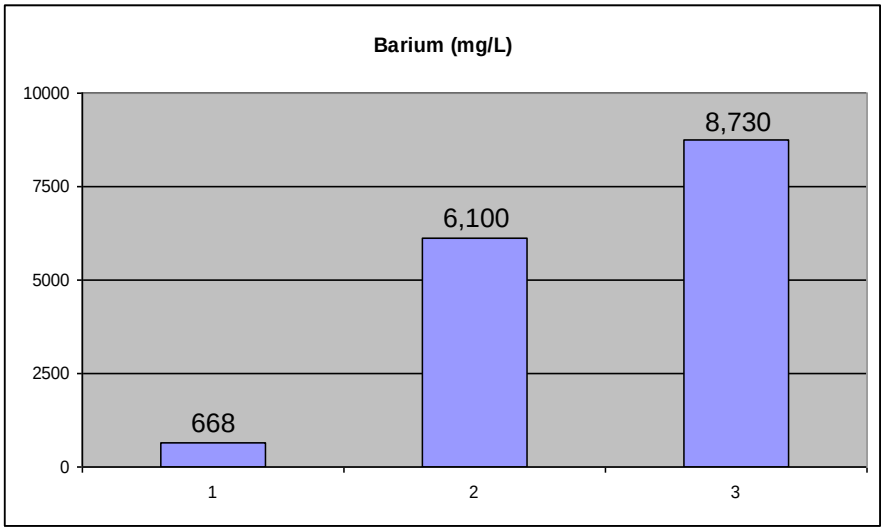
Blauch (2010)

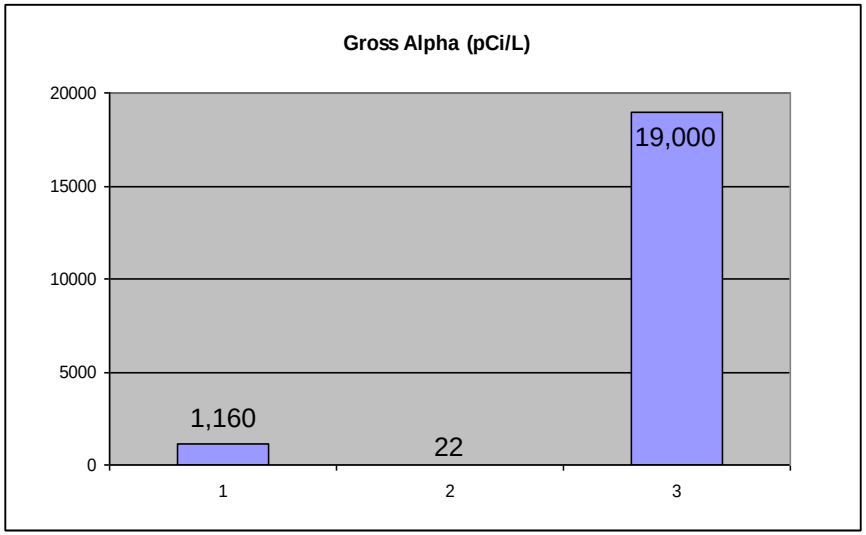


Papso and others (2010)



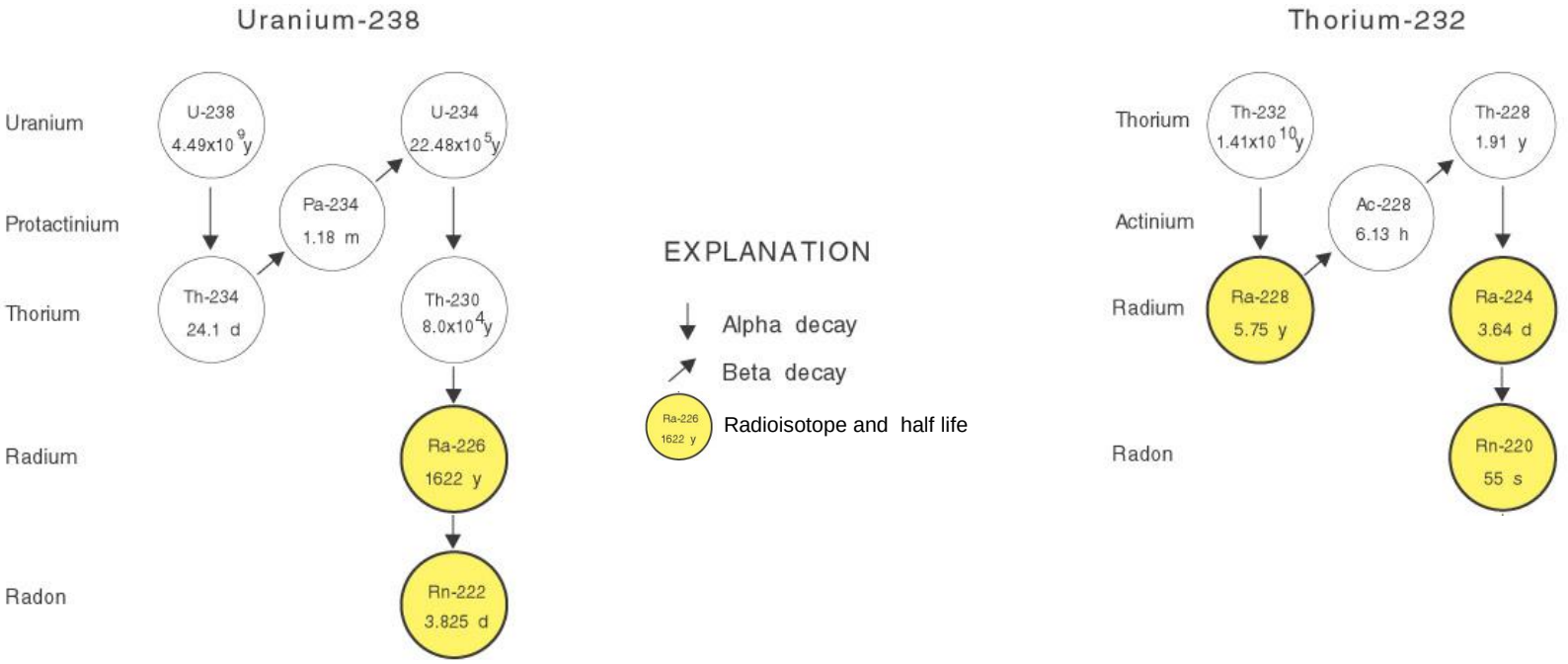






Water quality of flowback (1.5 million gallons) from Marcellus shale well after completion of hydraulic fracturing (Samples were taken at 1, 2, and 3 third intervals of the 2-week flowback period, PADEP)

Uranium & Thorium to Radium & Radon Radioactive Decay Series



Brine from a Marcellus Shale-Gas Well

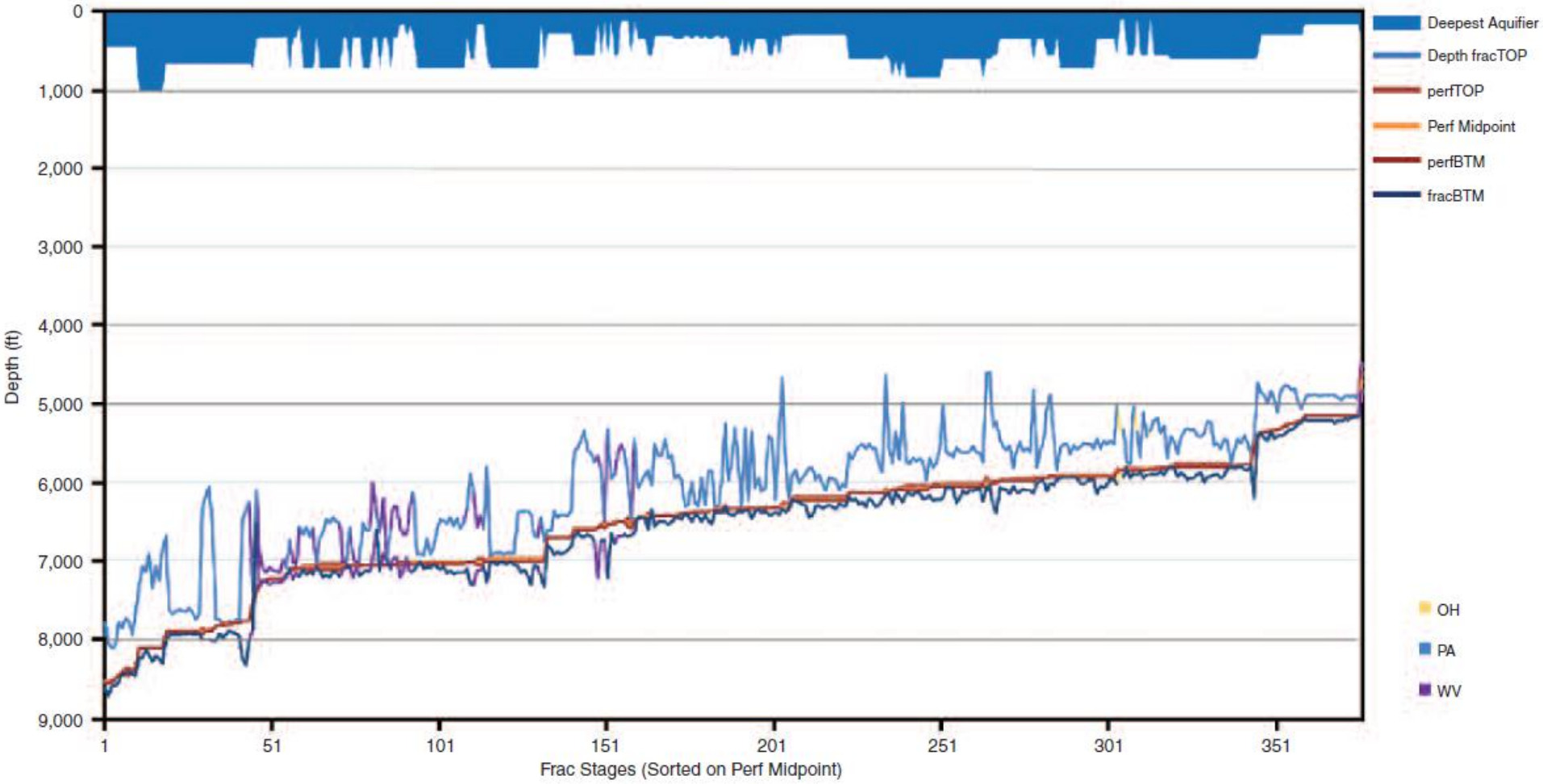
Gross Alpha	20,800 pCi/L
Gross Beta	2,390 pCi/L
Radium 226	10,200 pCi/L
Radium 228	1,250 pCi/L
Thorium 228	47.5 pCi/L
Thorium 232	0.0 pCi/L
Uranium 234	0.5 pCi/L

Municipal wastewater treatment plants not designed to handle flowback chemistry

Reuse of frac water, onsite treatment for solids / blend with 70 % freshwater

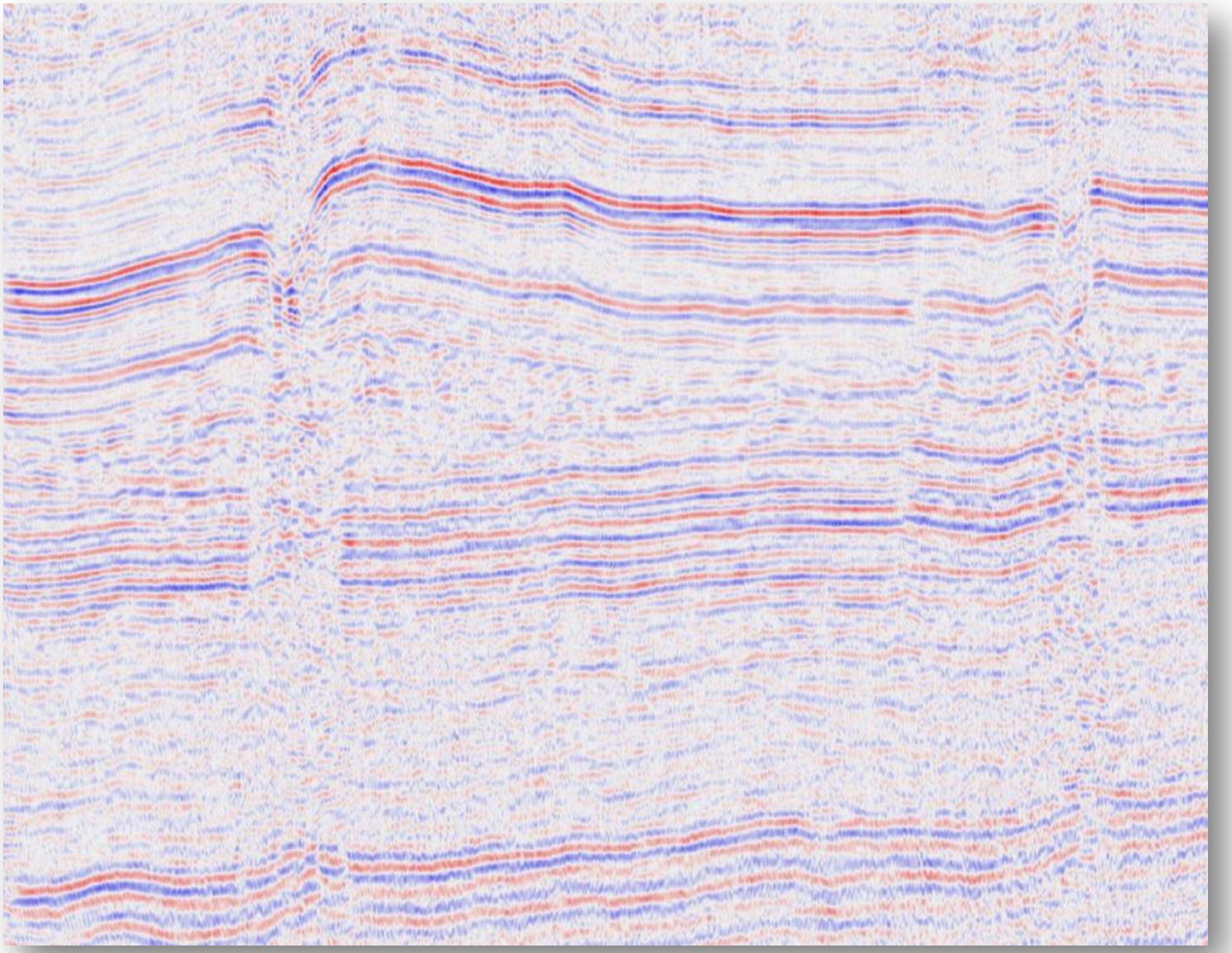
Microseismic Mapped Frac Tops and Bottoms

Marcellus Shale



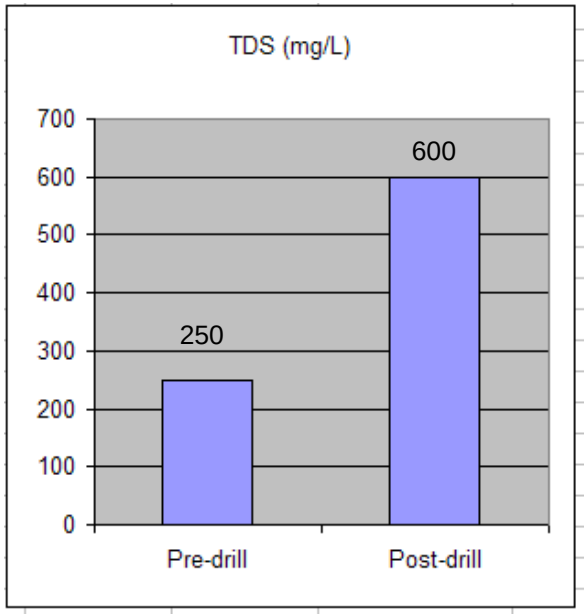
Halliburton (2010)

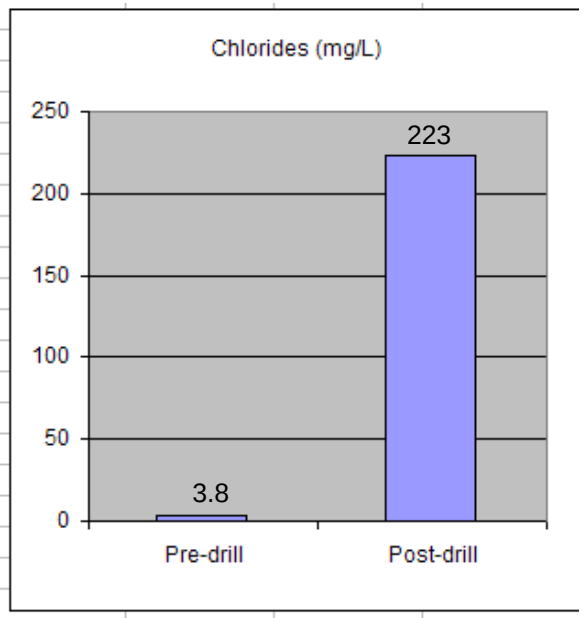
Structure (folds and faults)

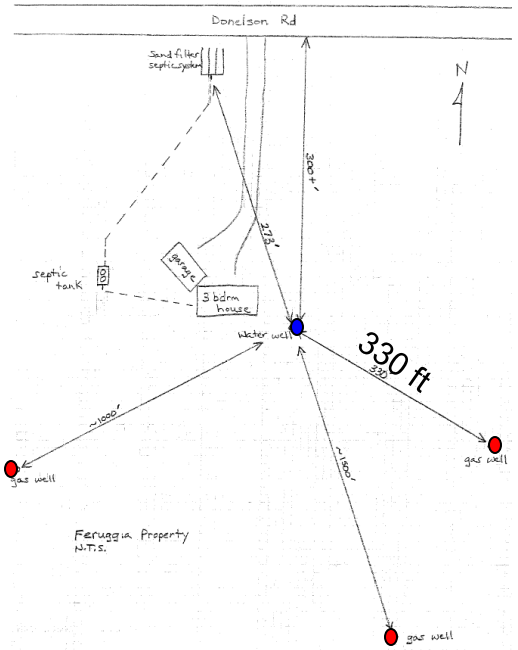


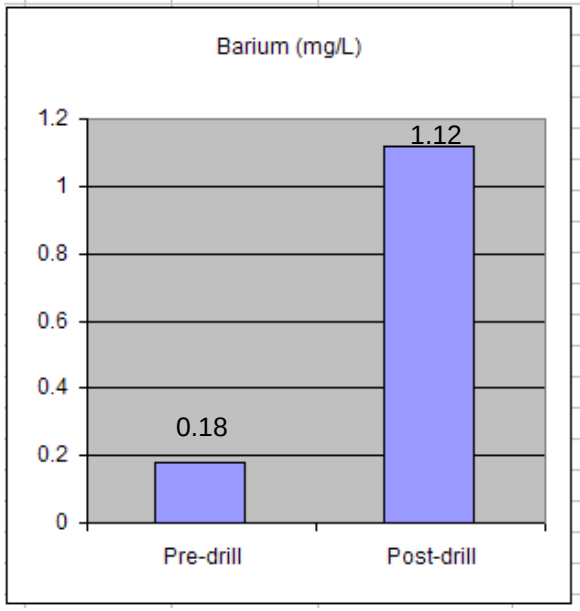
Seismic survey

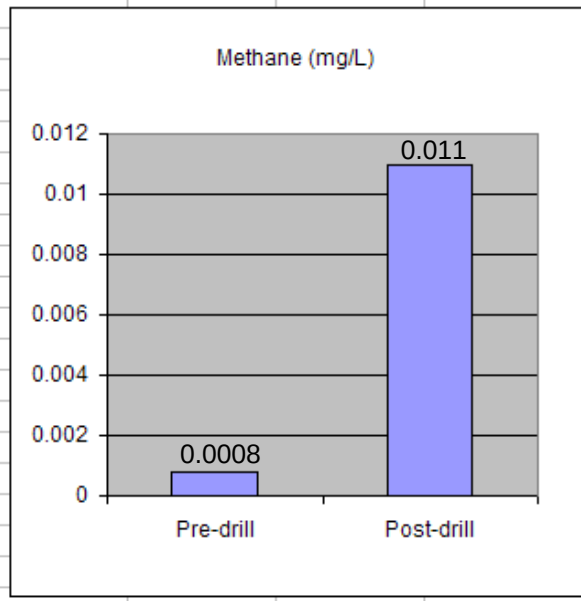
Smith and Leone (2010)

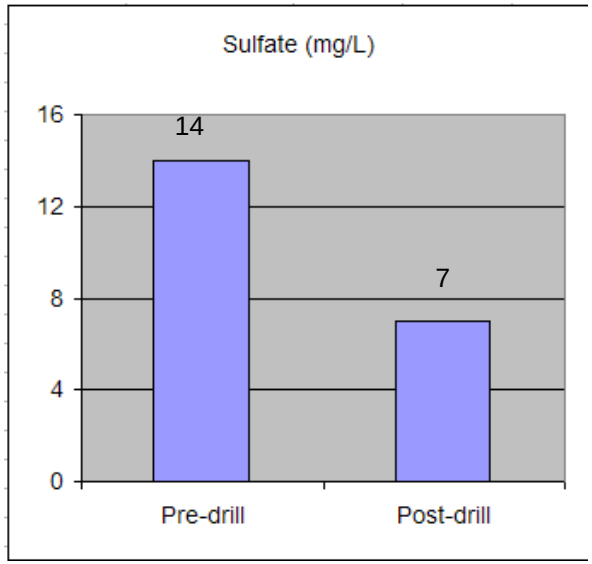








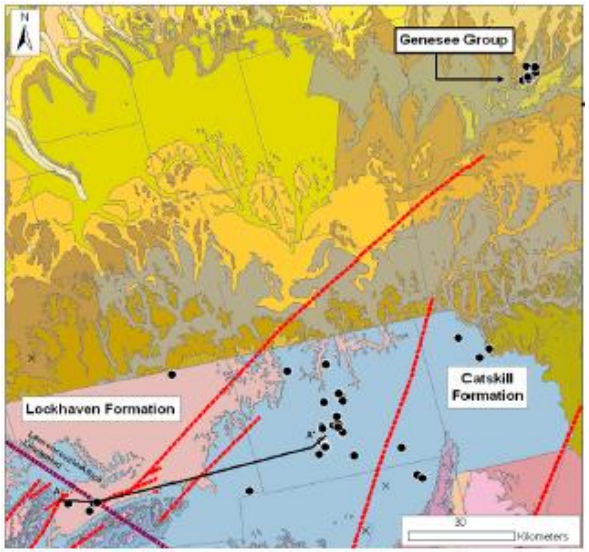




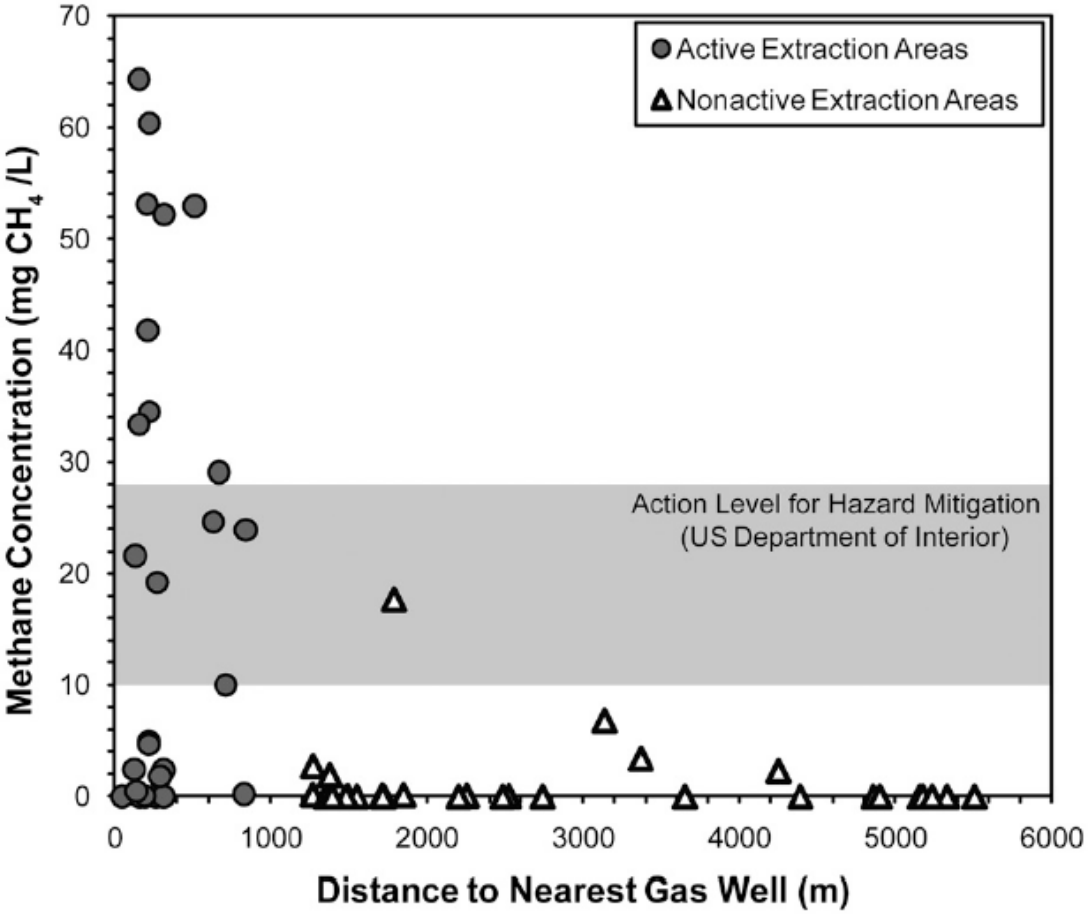
Water quality of water well impacted by Medina gas drilling

Methane in Water Wells

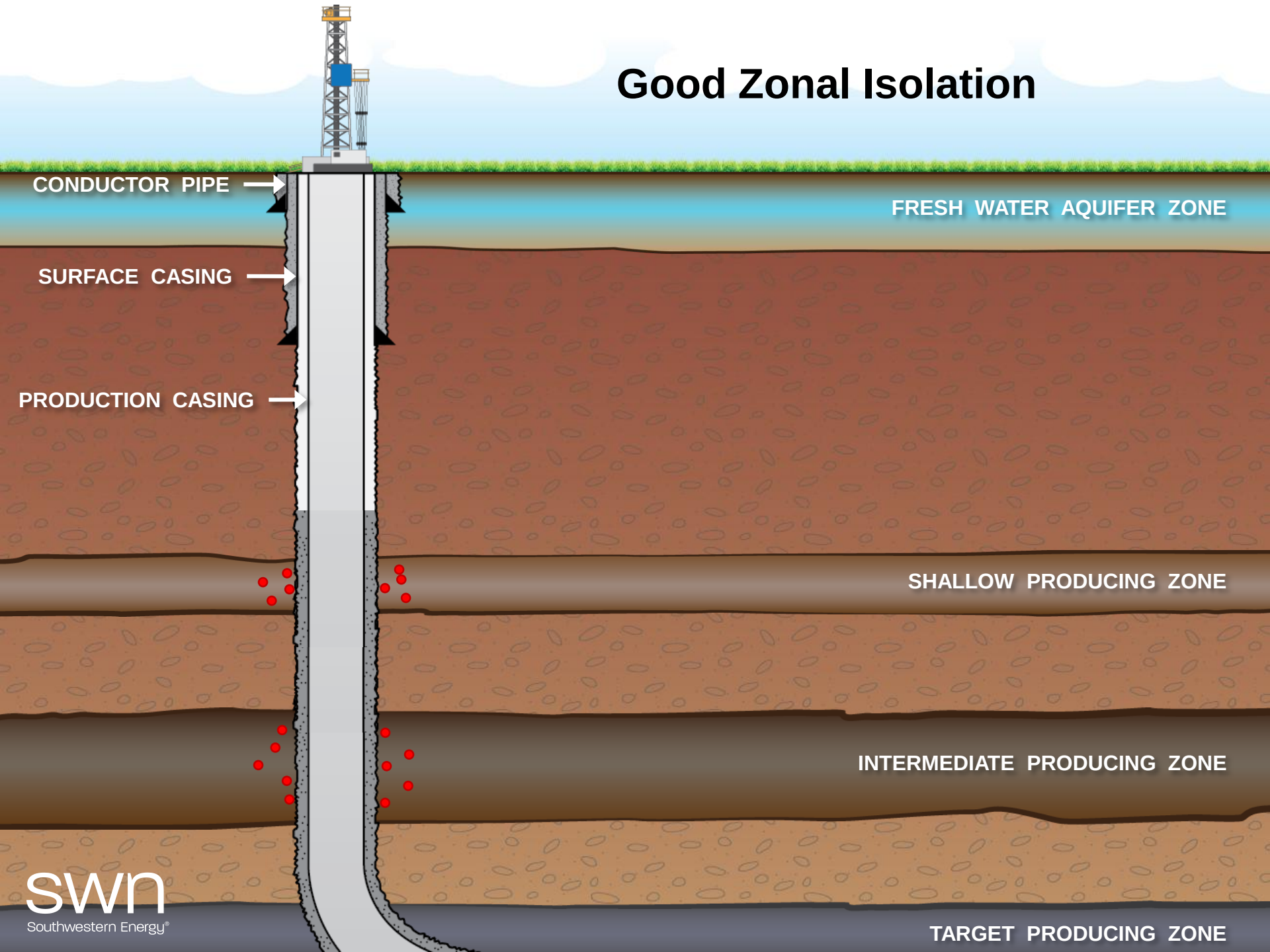
Marcellus/Utica Gas-Play Area



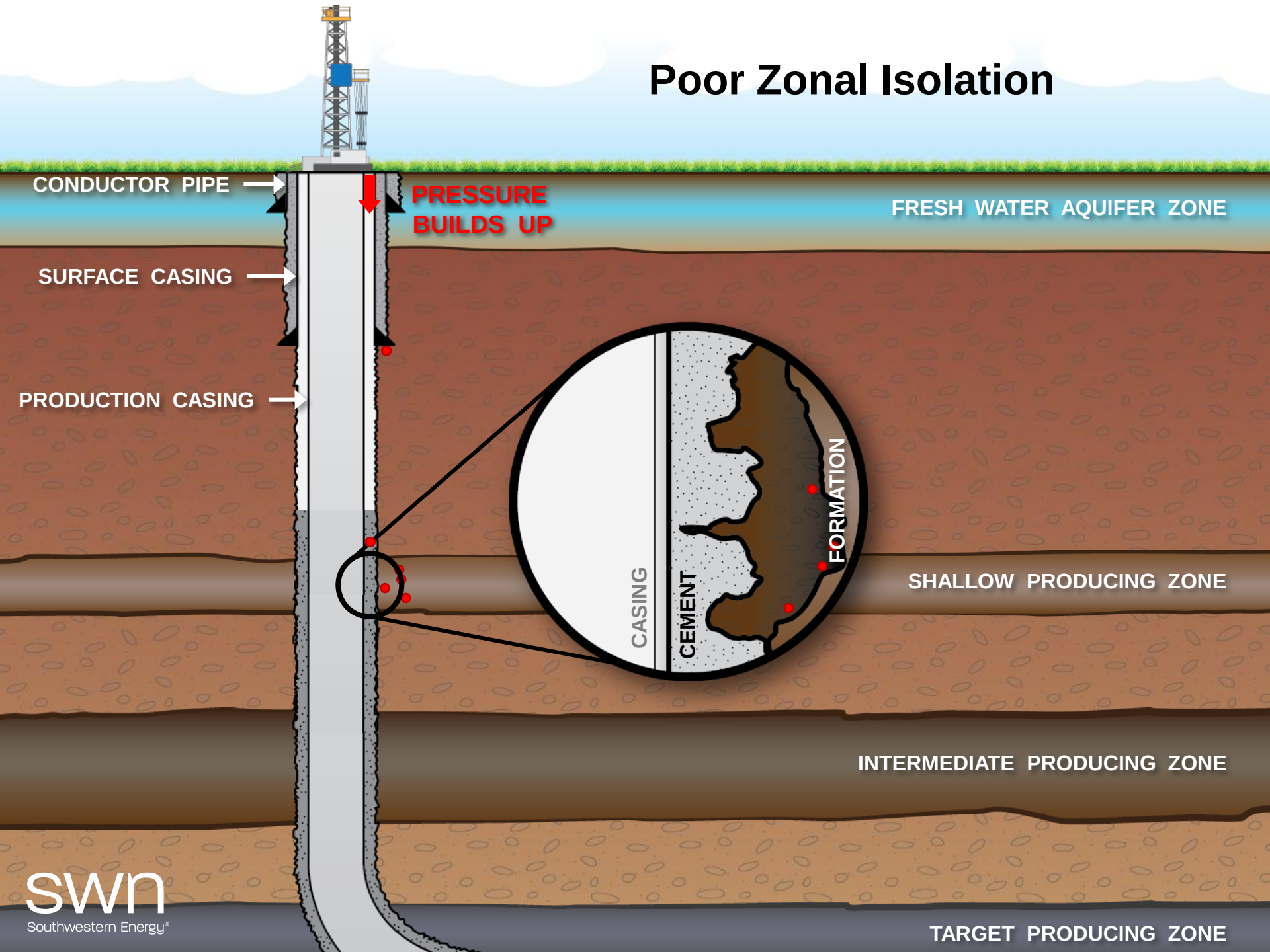
Sampling sites



Osborn and others (2011)


Good Zonal Isolation
CONDUCTOR PIPE
SURFACE CASING
PRODUCTION CASING
FRESH WATER AQUIFER ZONE
SHALLOW PRODUCING ZONE
INTERMEDIATE PRODUCING ZONE
TARGET PRODUCING ZONE
swn
Southwestern Energy®

Poor Zonal Isolation



swn
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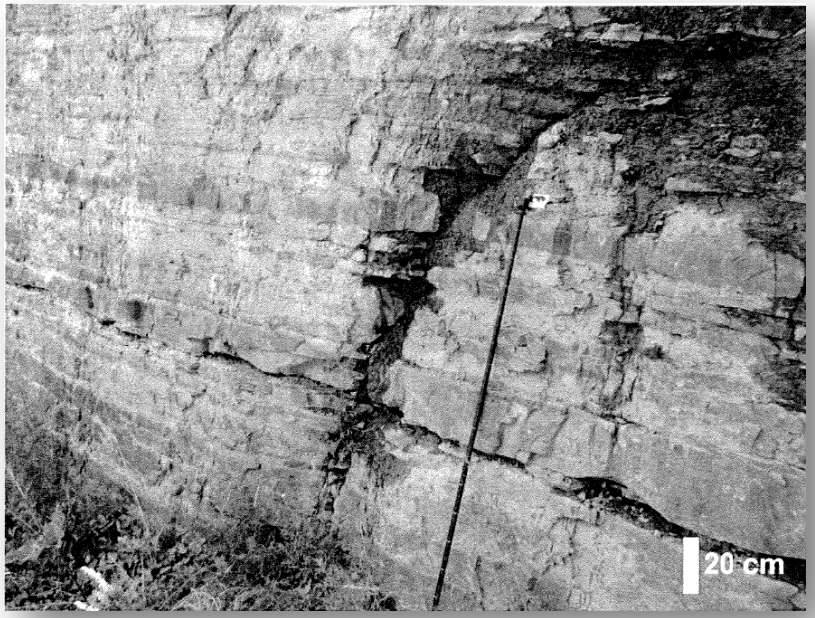
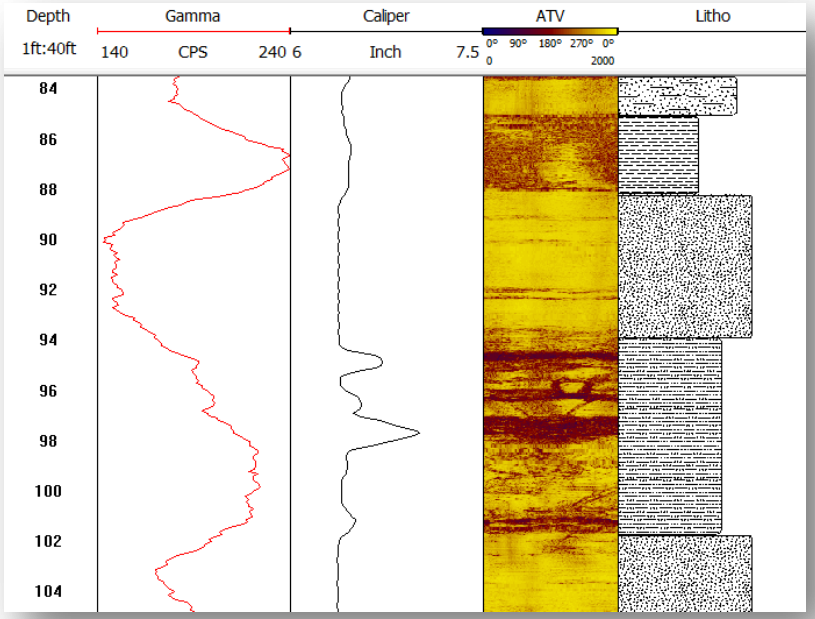
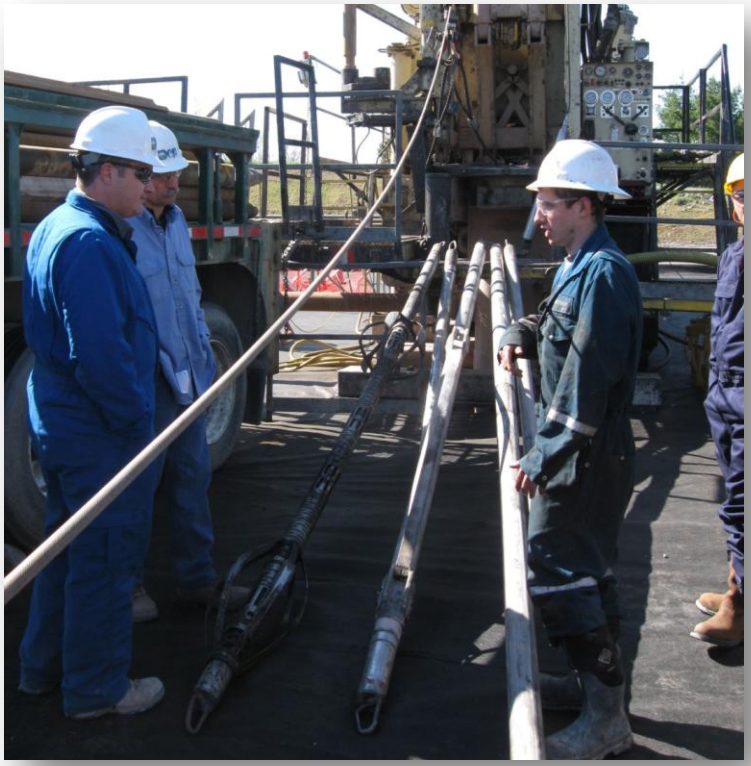
Fractured Zones in Upper Devonian Bedrock



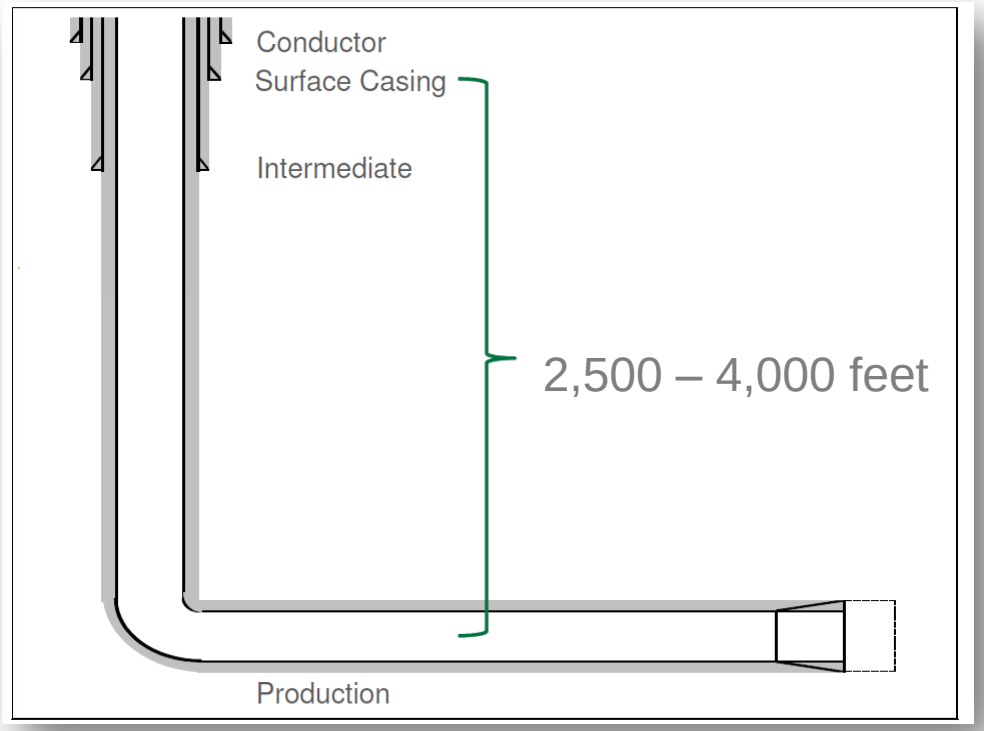


Pathways for methane and brine migration

Protection of Freshwater Aquifer



Characterization of deep freshwater and shallow gas and saltwater



Engineered zonal isolation by casing, cement, packers, and venting

Geophysical Logs and Base of Freshwater Aquifer