



Groundwater Resource Protection Considerations for Shale Gas Development

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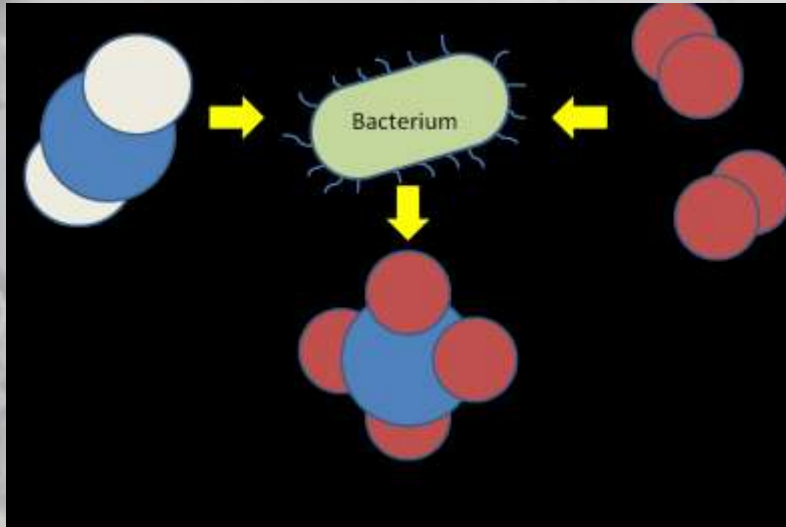
MARCELLUS CENTER

for OUTREACH & RESEARCH (M-COR)

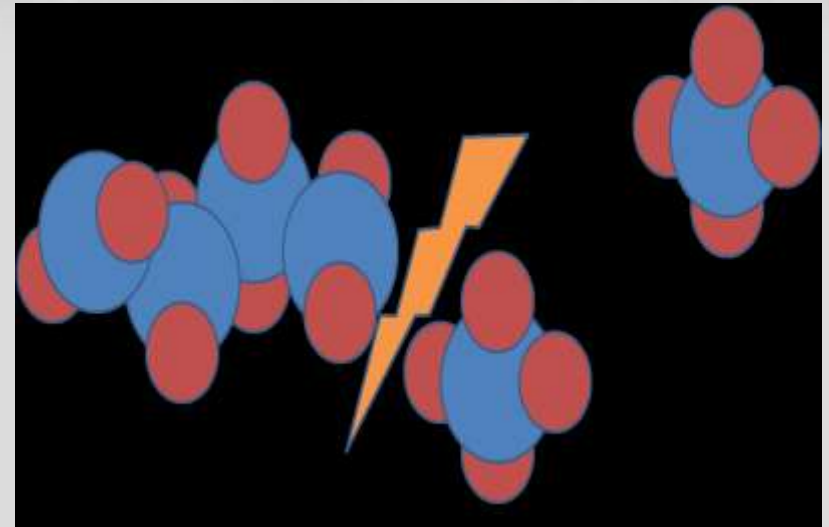
The Nature of the Problem

- Methane detected in shallow groundwater can occur naturally, prior to any natural gas drilling
 - Need to distinguish between pre-existing methane and its source in groundwater (thermogenic vs. biogenic)
- Increased levels of methane have been detected in water wells after gas well drilling in several areas
 - Approximately ten cases of methane migration attributable to Marcellus drilling operations
- Inadequate gas well construction can create pathways for methane to migrate upward into aquifers
 - Regulations developed to ensure adequate casing and seal installed to eliminate methane migration pathways

Methane is Not Created Equally



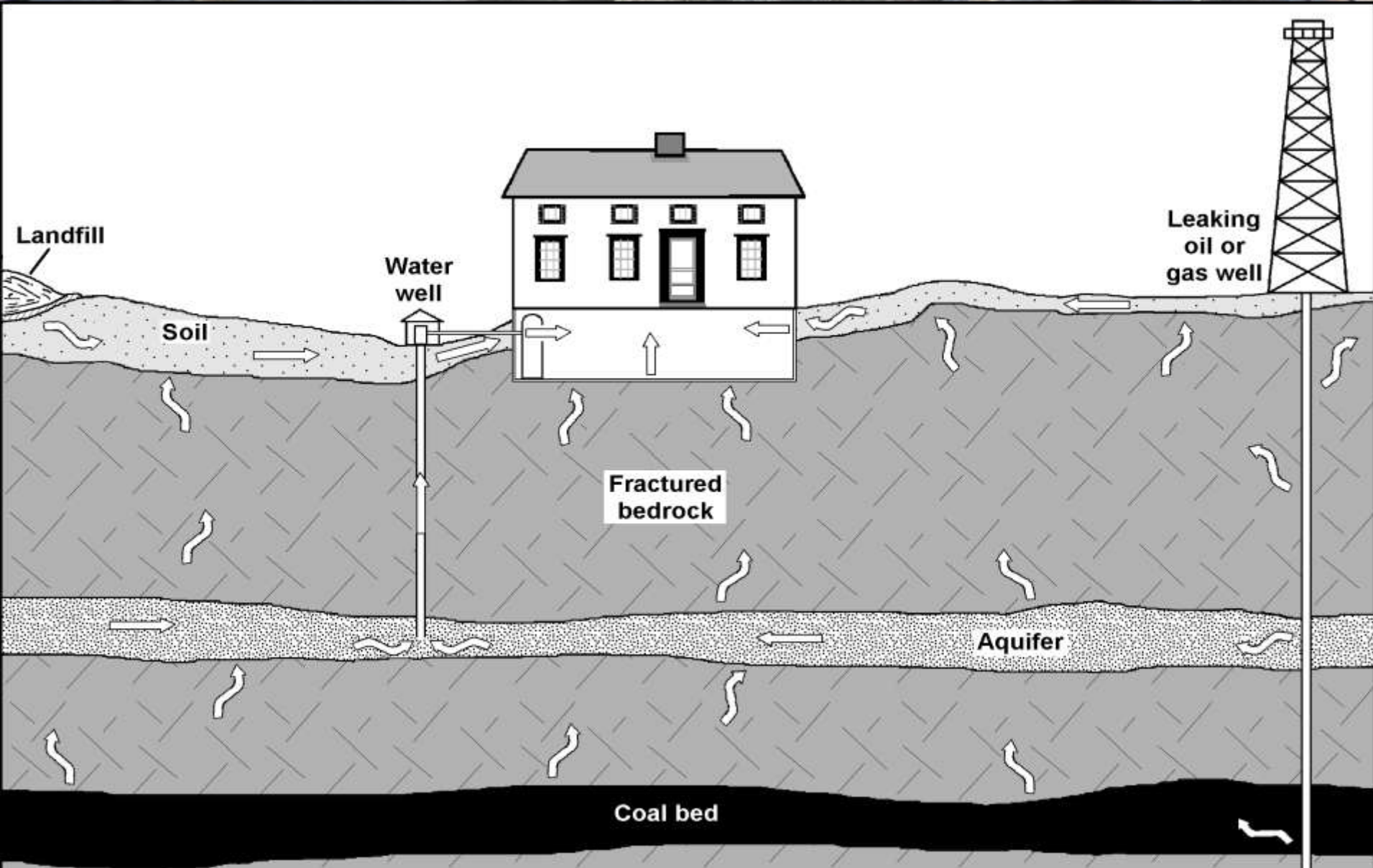
Biogenic methane is formed by methanogens breaking down organic material



Thermogenic methane formed when organic matter in a geological formation is subjected to heat and pressure

Both types of methane have characteristic C and H isotope fractions where lighter isotopes are preferentially selected during transformation processes and heavy isotopes get left behind during the process of methane formation.

Sources of Methane in Groundwater



Graphic from Pittsburgh Area Geologic Society, Gas Migration in W. Pa.

Pennsylvania Regulations

- In February 2011 Pennsylvania Department of Environmental Protection adopted strengthened well construction regulations (Ch. 78) to prevent methane migration:
 - Where gas pressure is $>80\%$ of hydrostatic pressure of casing depth ($0.433 \text{ psi} \times \text{casing depth}$) then intermediate casing shall be installed to prevent gas migration (Ch. 78.73)
 - Casing and cementing plan for each well to:
 - Condition the well to ensure cement bond with formation
 - Use of centralizers on casing
 - Positive cement displacement method using gas block or low flow cement to ensure no annular gas flow
 - Install cement 500 feet above true vertical depth or at least 200 feet above the uppermost perforations in production string, whichever is greater.

24" conductor casing (brown) is installed up to 50 feet deep and cemented (grey) to the surface.

20" casing is installed through the 24" casing and continuing up to 500 feet deep. This casing is cemented to surface to isolate and protect near-surface groundwater.

13 3/8" casing is installed through the 20" casing and continuing up to 1000 feet deep. This casing is also cemented to the surface to protect the groundwater aquifer from the gas well.

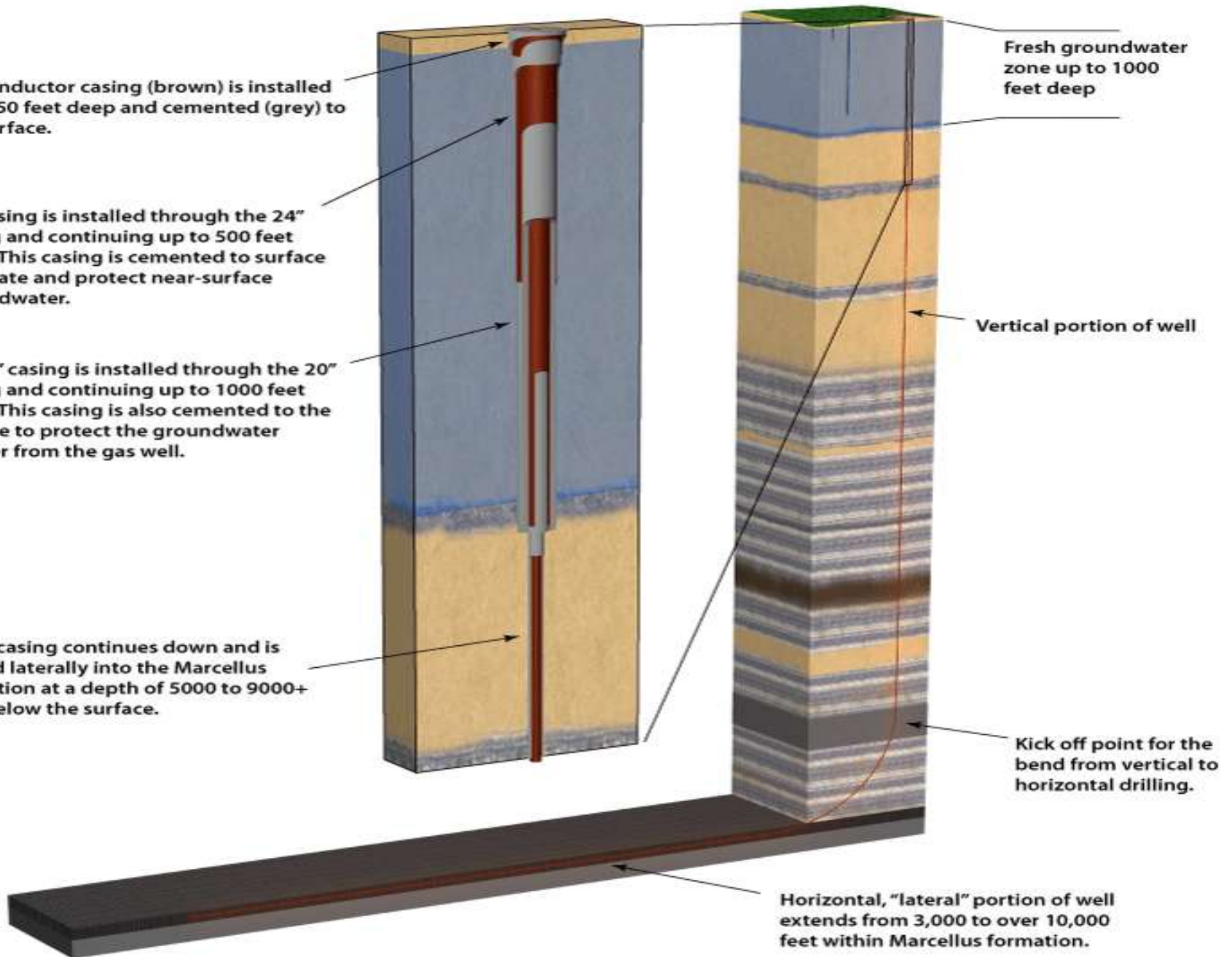
5 1/2" casing continues down and is turned laterally into the Marcellus formation at a depth of 5000 to 9000+ feet below the surface.

Fresh groundwater zone up to 1000 feet deep

Vertical portion of well

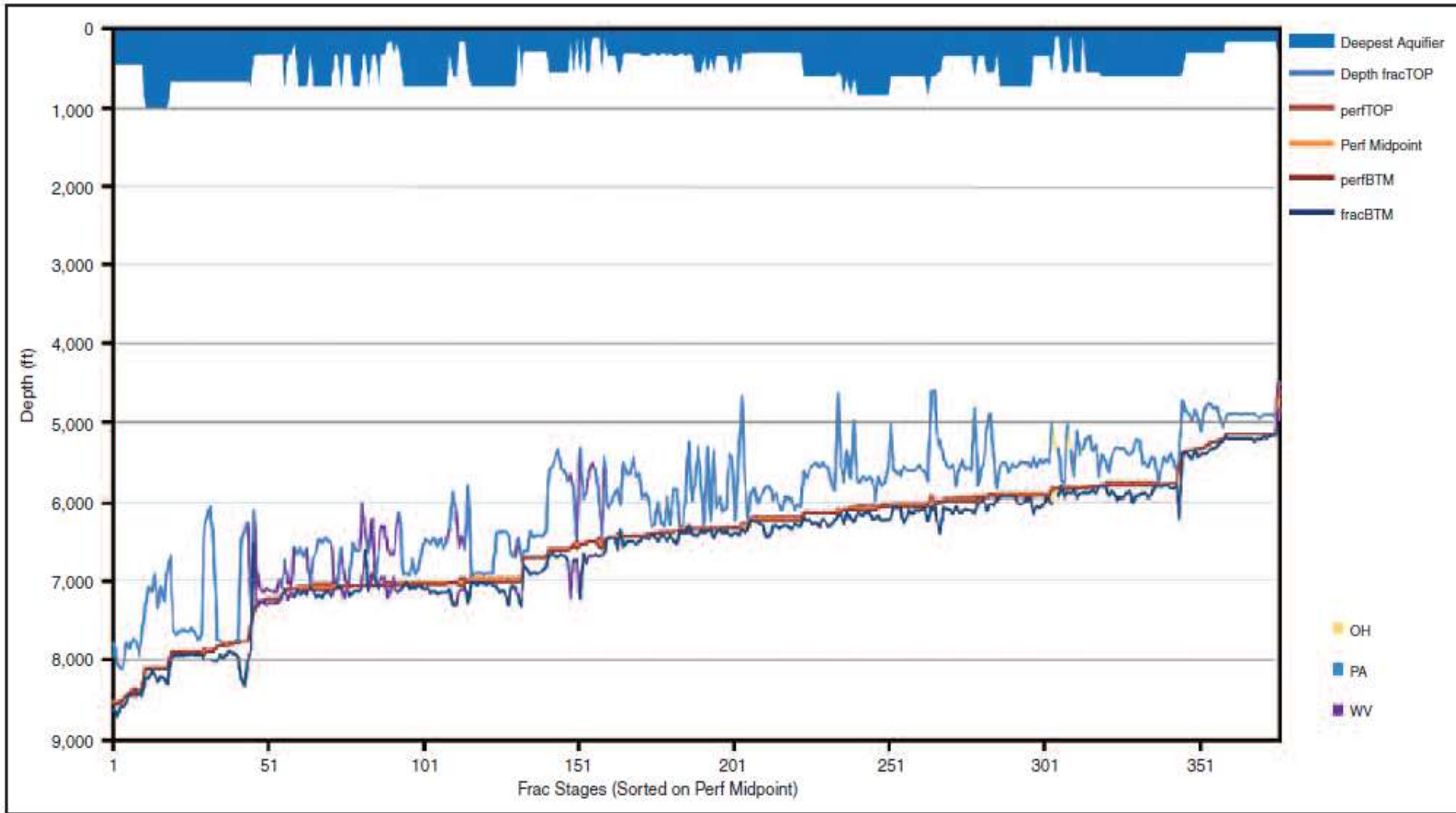
Kick off point for the bend from vertical to horizontal drilling.

Horizontal, "lateral" portion of well extends from 3,000 to over 10,000 feet within Marcellus formation.



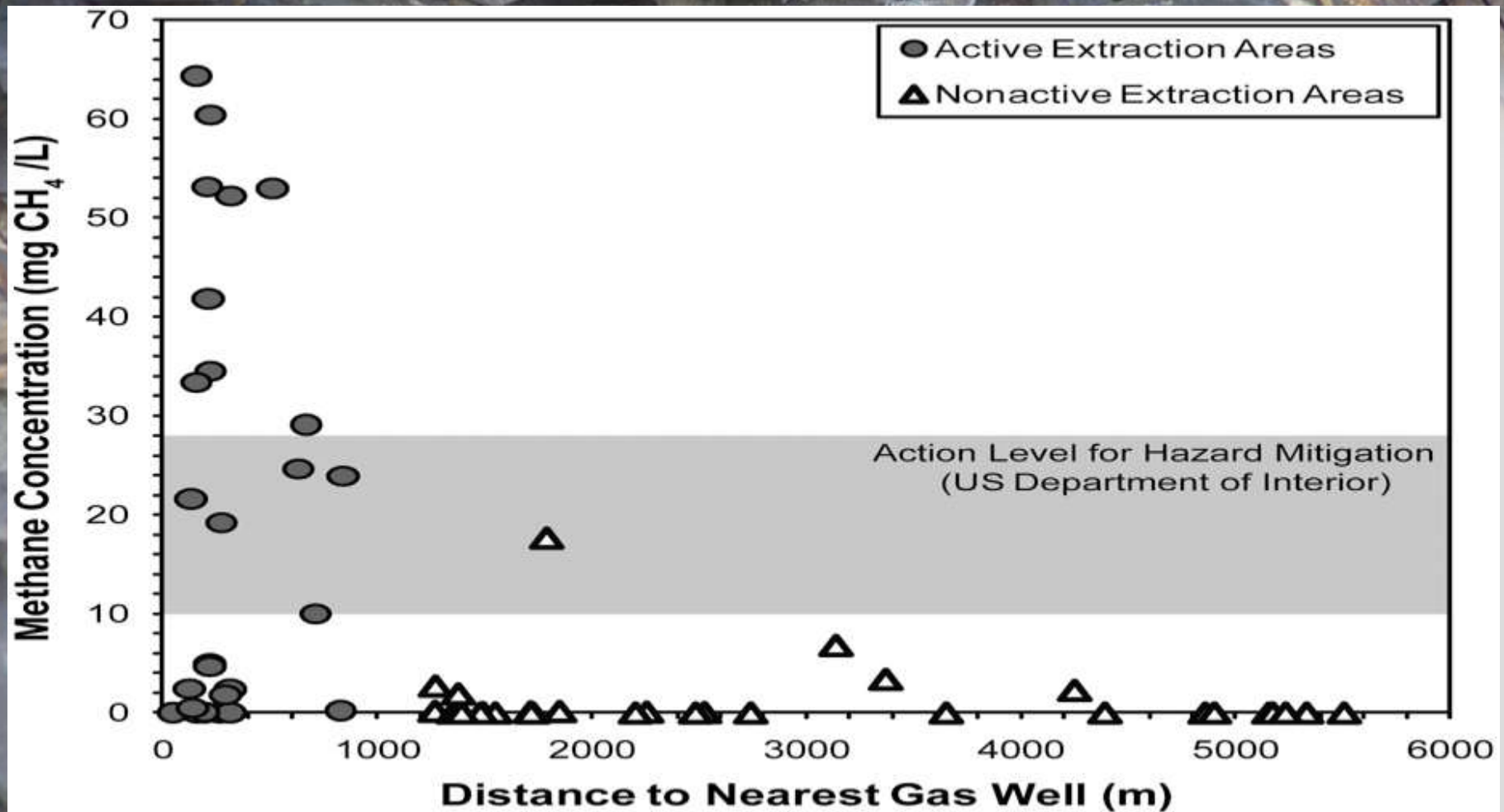
Hydraulic Fracture Vertical Growth

Marcellus Shale Mapped Fracture Treatments (TVD)



Graphic from Fisher, 2010, Data Confirm Safety Of Well Fracturing, American Oil and Gas Reporter.

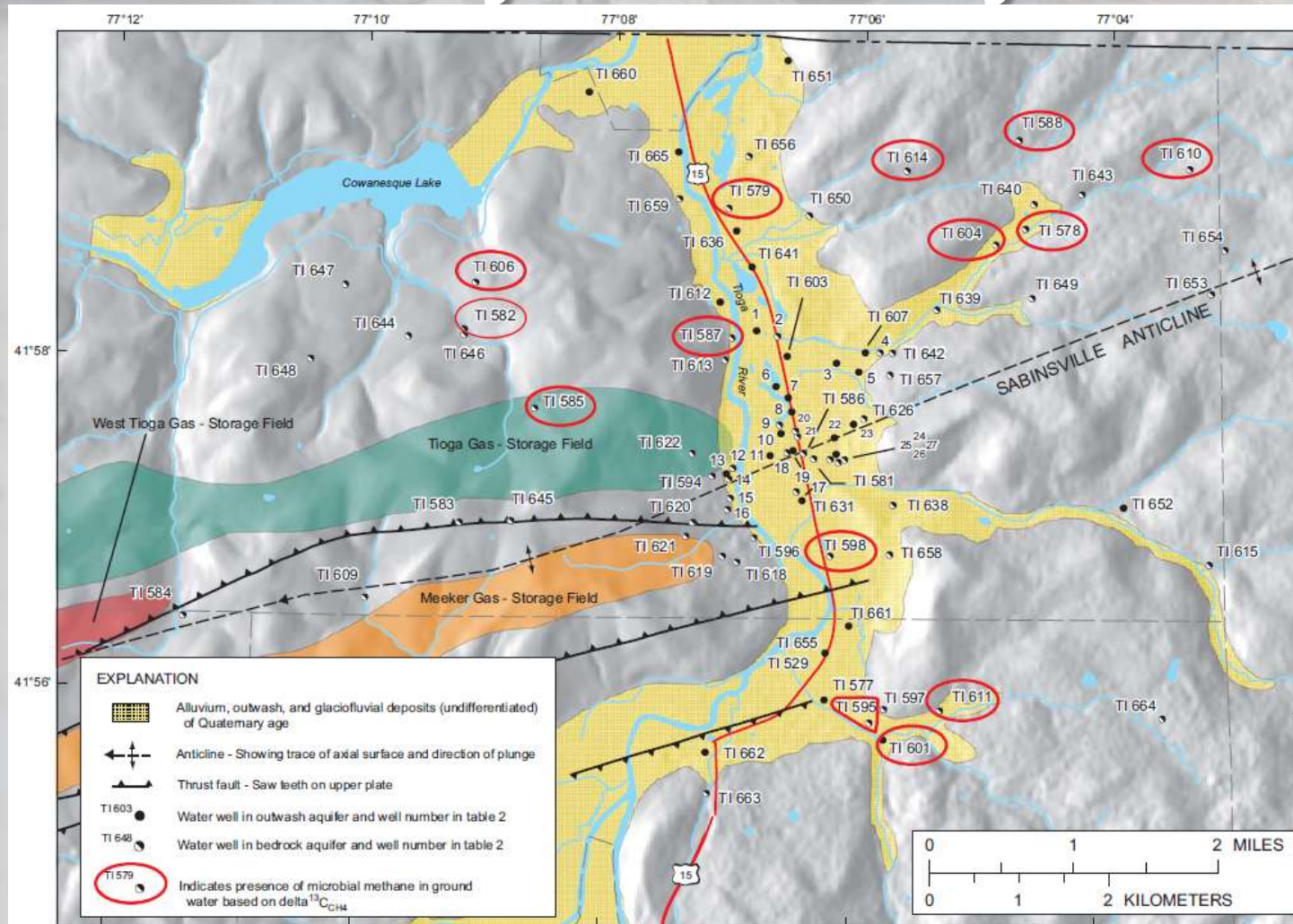
Methane in Groundwater



Many of these water wells with increased methane were near Marcellus wells with known methane migration problems. As a result the gas wells were either abandoned or remediated to seal off leaking zones, consequently reducing methane levels in groundwater.

Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing, Osborne et al, 2011

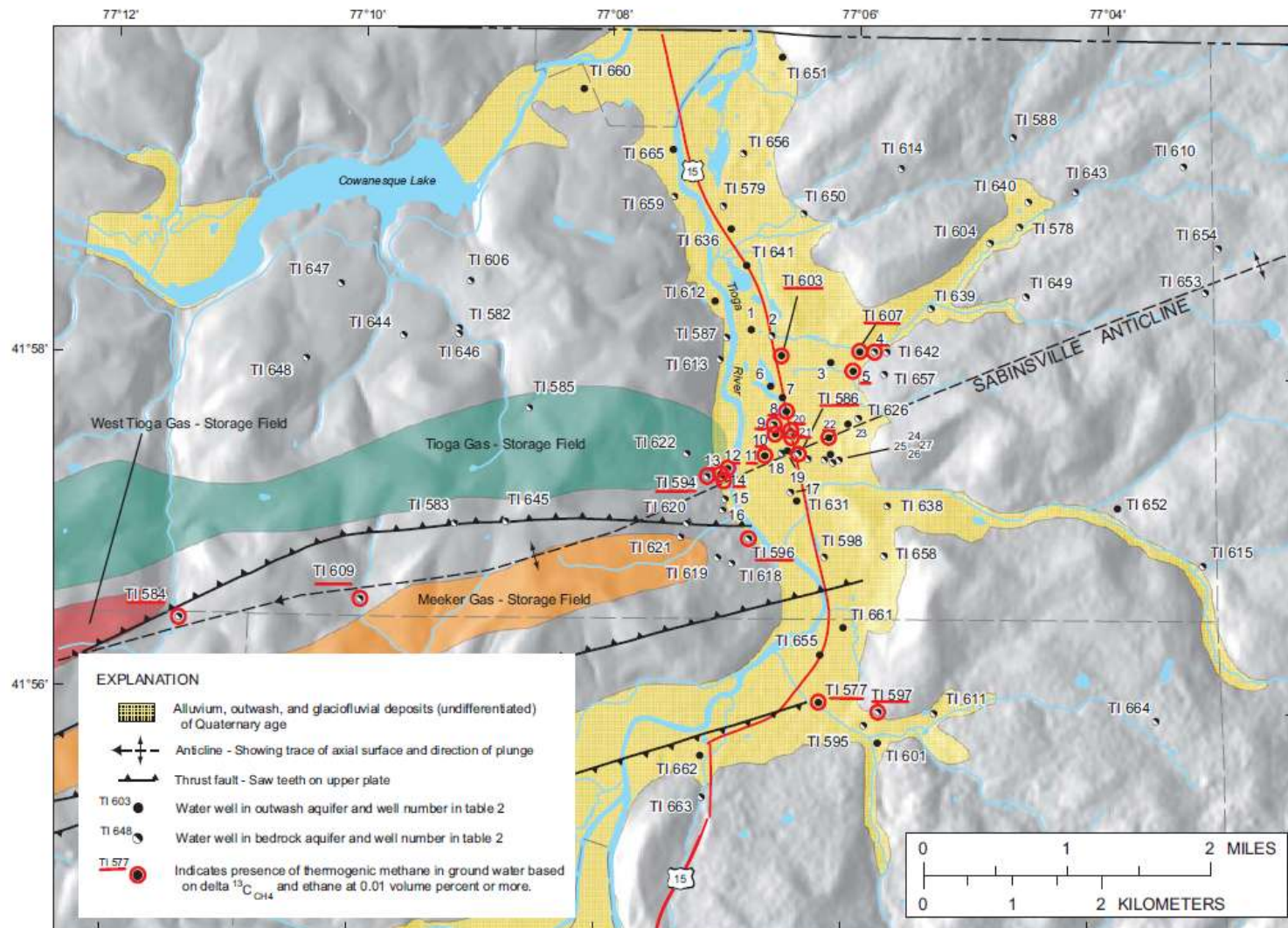
Microbial Methane Detections in a Stray Gas Study Area



Surficial deposits from Commonwealth of Pennsylvania, 1989
 Streams from U.S. Geological Survey, 2000
 Township boundary and U.S. Routes from Commonwealth of Pennsylvania, 2006
 Shaded relief prepared from U.S. Geological Survey National Elevation Dataset, 2004

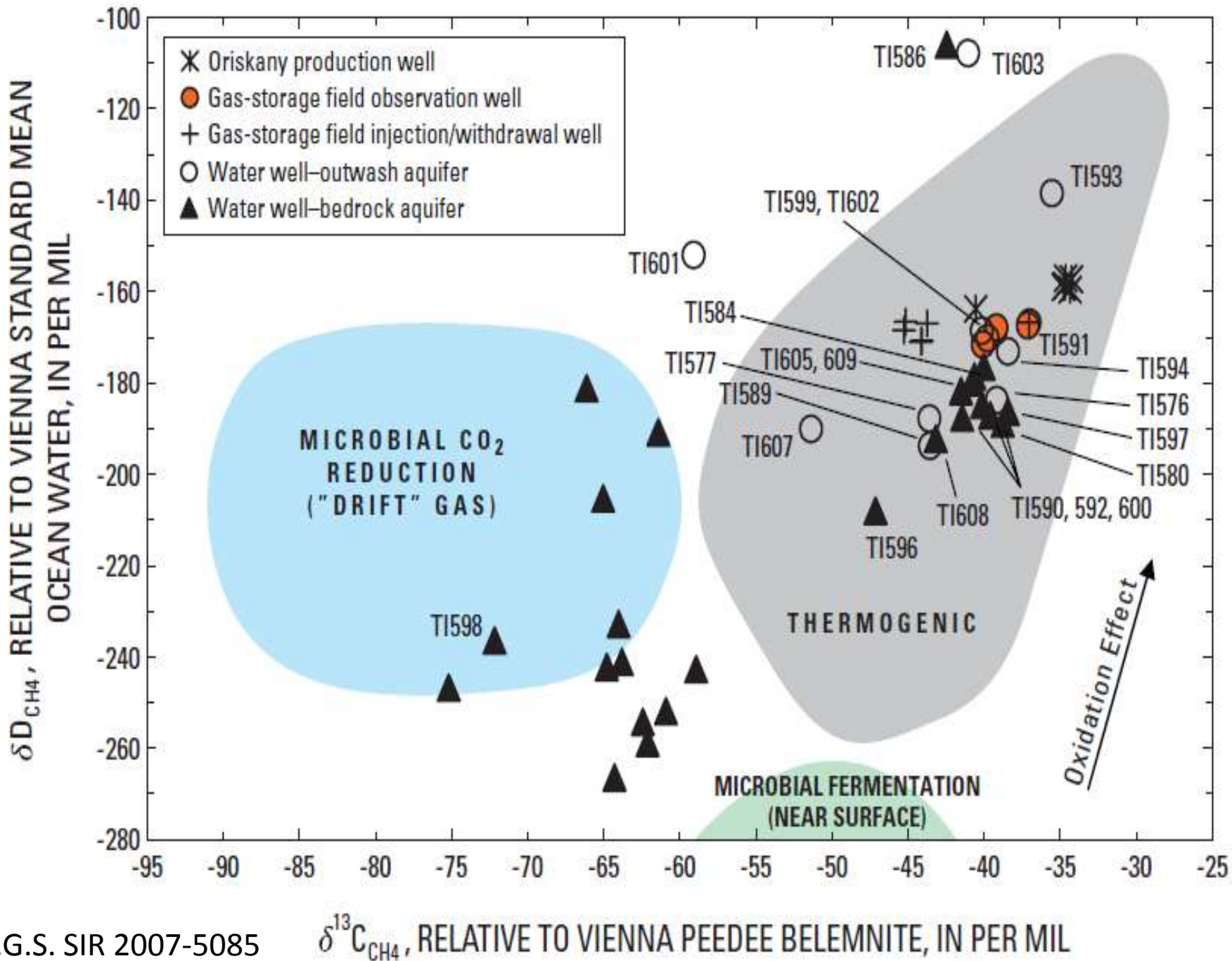
Base from U.S. Department of Commerce digital data, 1993.
 1:100,000 Albers Equal-Area Conic projection: Standard Parallels 29°30' N and 45°30' N,
 Central Meridian 77°45' W, Latitude of Origin 23°00' N

Thermogenic Methane Detections... Geology Matters!



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Methane Migration Mitigation Measures

- Geologic characterization of shallow geology to determine depth of aquifer and shallower gas-bearing sandstones to verify where to set casing
- Installation of intermediate casing string to seal off shallow gas where present at elevated pressure
- Geophysical borehole log surveys used to characterize gas-bearing zones and cement seal integrity
- Widespread pre-drilling groundwater sampling on private wells to verify baseline groundwater quality
- Characterizing methane found in water wells
 - Isotopic characterization of methane in water wells vs. in gas wells
 - Comparing ratio of methane and C2+ hydrocarbons
- Where stray gas has been problematic wells have been either abandoned or remediated
- Emplacing sealant in problem zones via “squeeze jobs” has been effective in sealing off shallow methane thus reducing concentrations in groundwater.