

Using Geochemistry Data to Identify Groundwater Quality Issues in Shale Gas Production Areas

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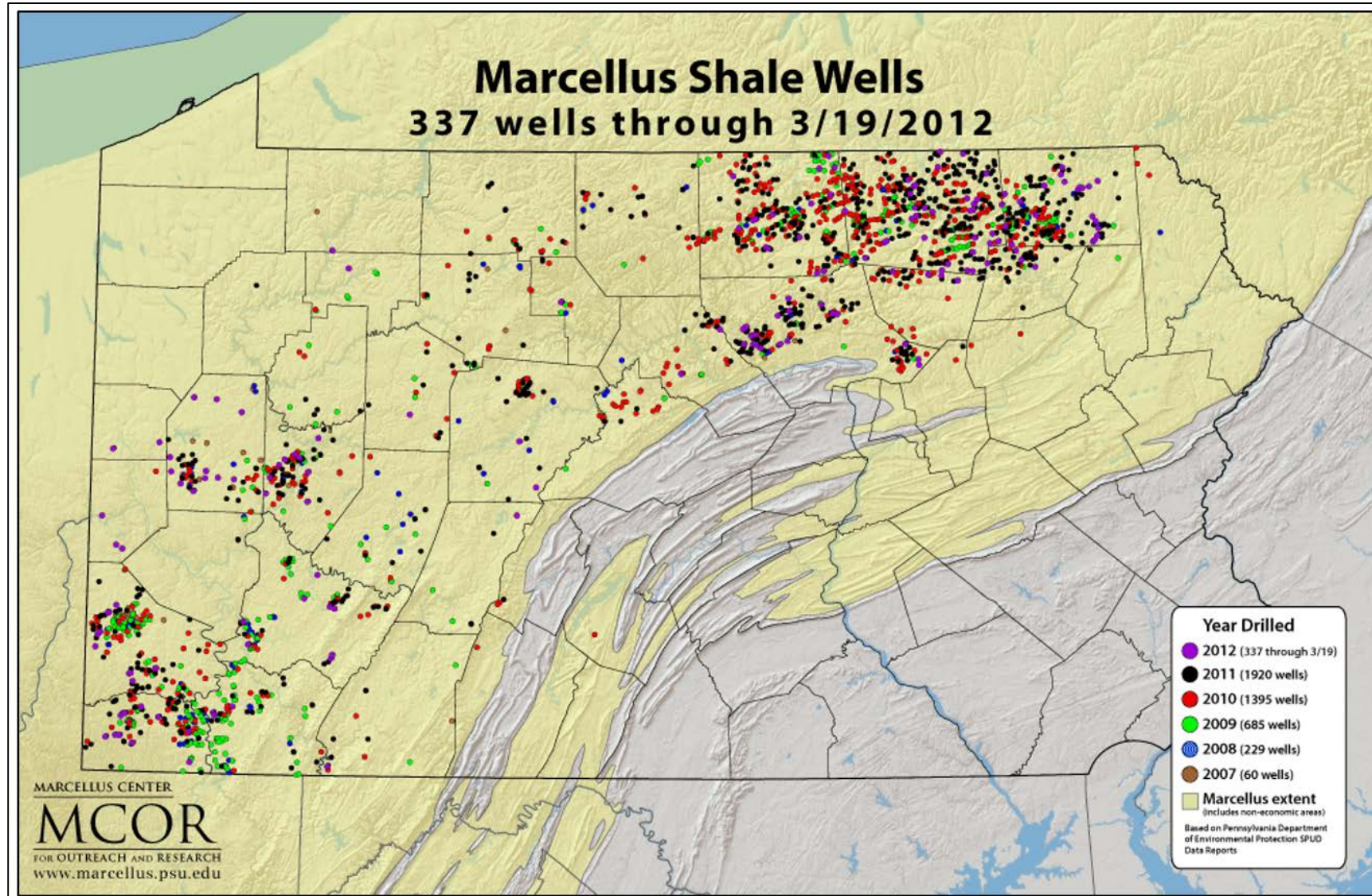
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Extensive development of shale gas exploration & production in the Marcellus Shale since 2007



Potential environmental impacts of shale gas development to be discussed in this talk

- Anomalous CH₄ in groundwater: invading into the shallow groundwater recently caused by human activities (e.g., shale gas development); in contrast to long-standing naturally-occurring CH₄
- Metal elements ? e.g., barium (Ba), arsenic (As), lead (Pb)
- Other organic compounds

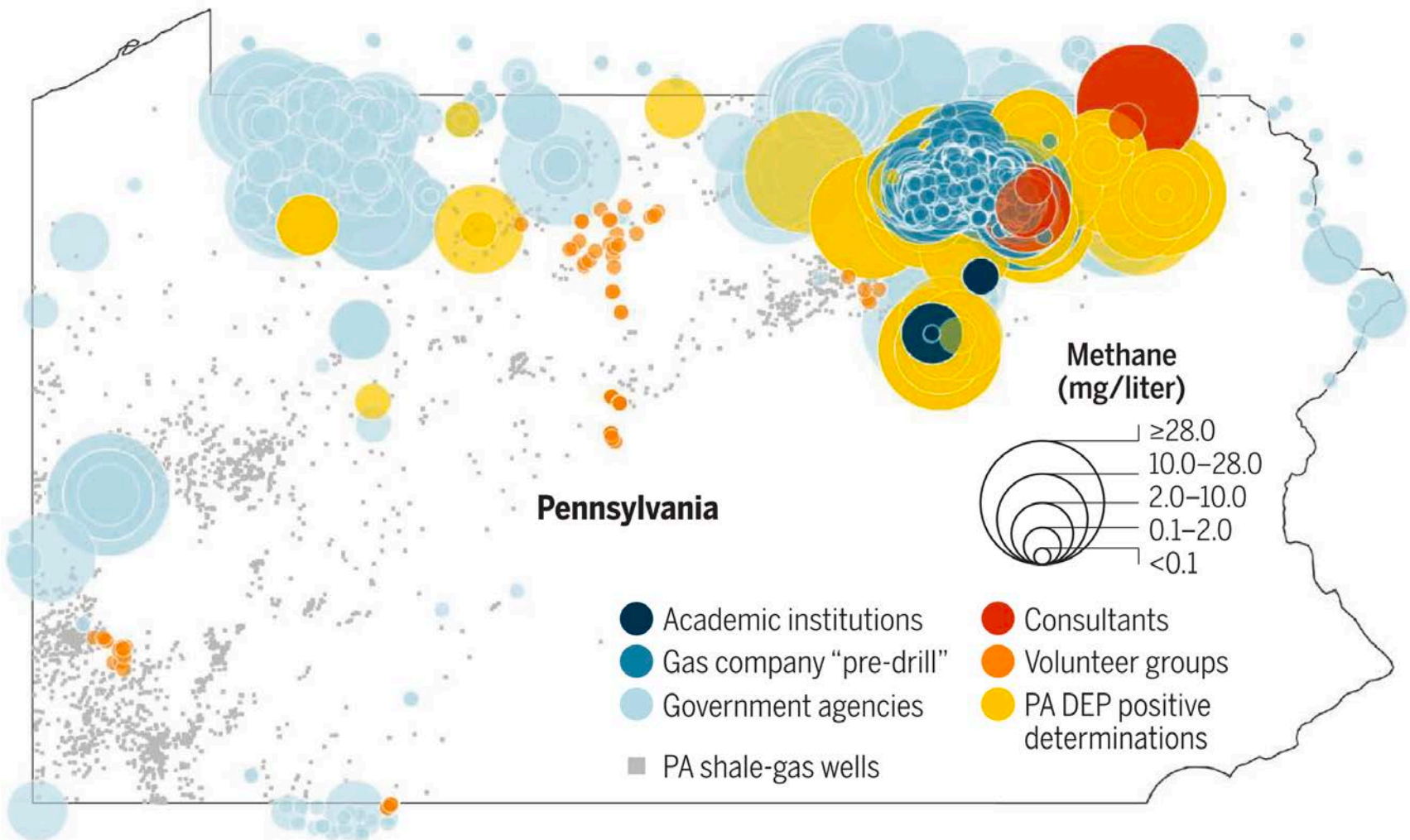
Assessing the impact of shale gas development can be scientifically complicated because e.g.,

- Co-existence of natural and anthropogenic sources, e.g., CH₄
- Heterogeneity in water geochemistry, geology, hydrogeology, and geography

These issues mean that we need baseline data, but...

- Lack of pre drill data (not collected) in some locations
- Where data have been collected the data are not always shared or are not always accessible
- Data sharing tends to be resisted by all data providers: industry, government, academic scientists, consulting firms

We are publishing water chemistry data online for the Marcellus production area in the Shale Network database (www.shalenetwork.org)



Circle size = **Methane concentrations in groundwater**

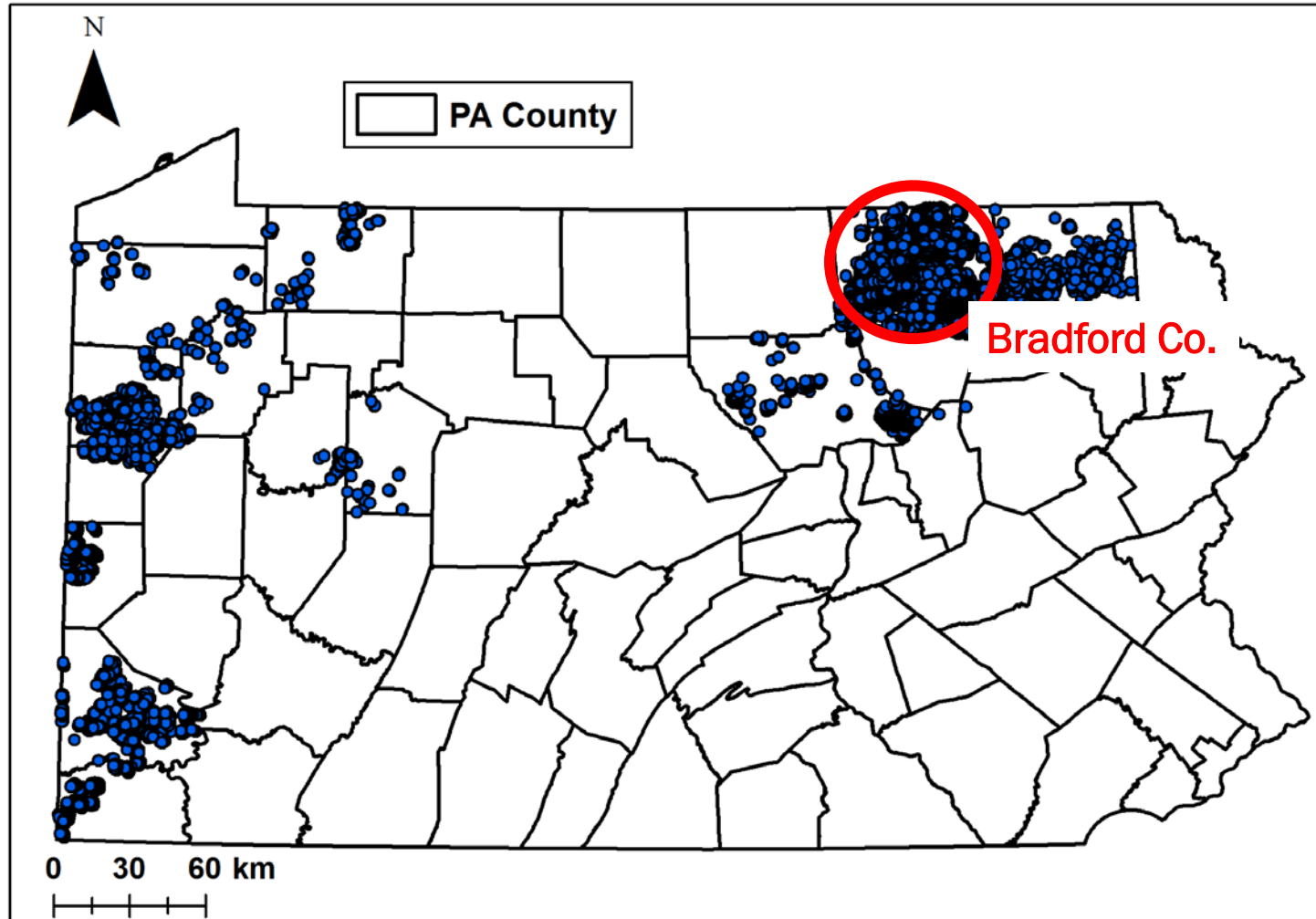
Circle color = **data provider**

Small gray dots = shale gas wells

Most of our data are from oil and gas industry through Pennsylvania Department of Environmental Protection (PA DEP)

- Originally collected by environmental consultants hired by oil and gas companies to establish baseline
- Analyzed in commercial, accredited environmental laboratories
- Data are shared with PA DEP and with us
- These data sets report up to 50 geochemical analytes including CH₄

Pre-drill data that we have compiled in PA so far...



Bradford County has second most shale gas wells among all PA counties

A total of ~20,000 groundwater samples

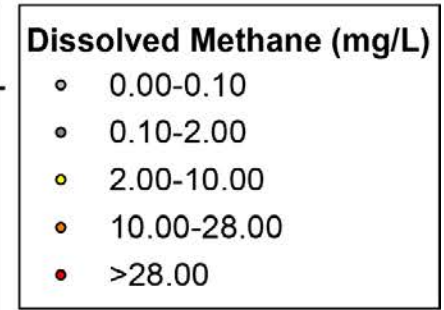
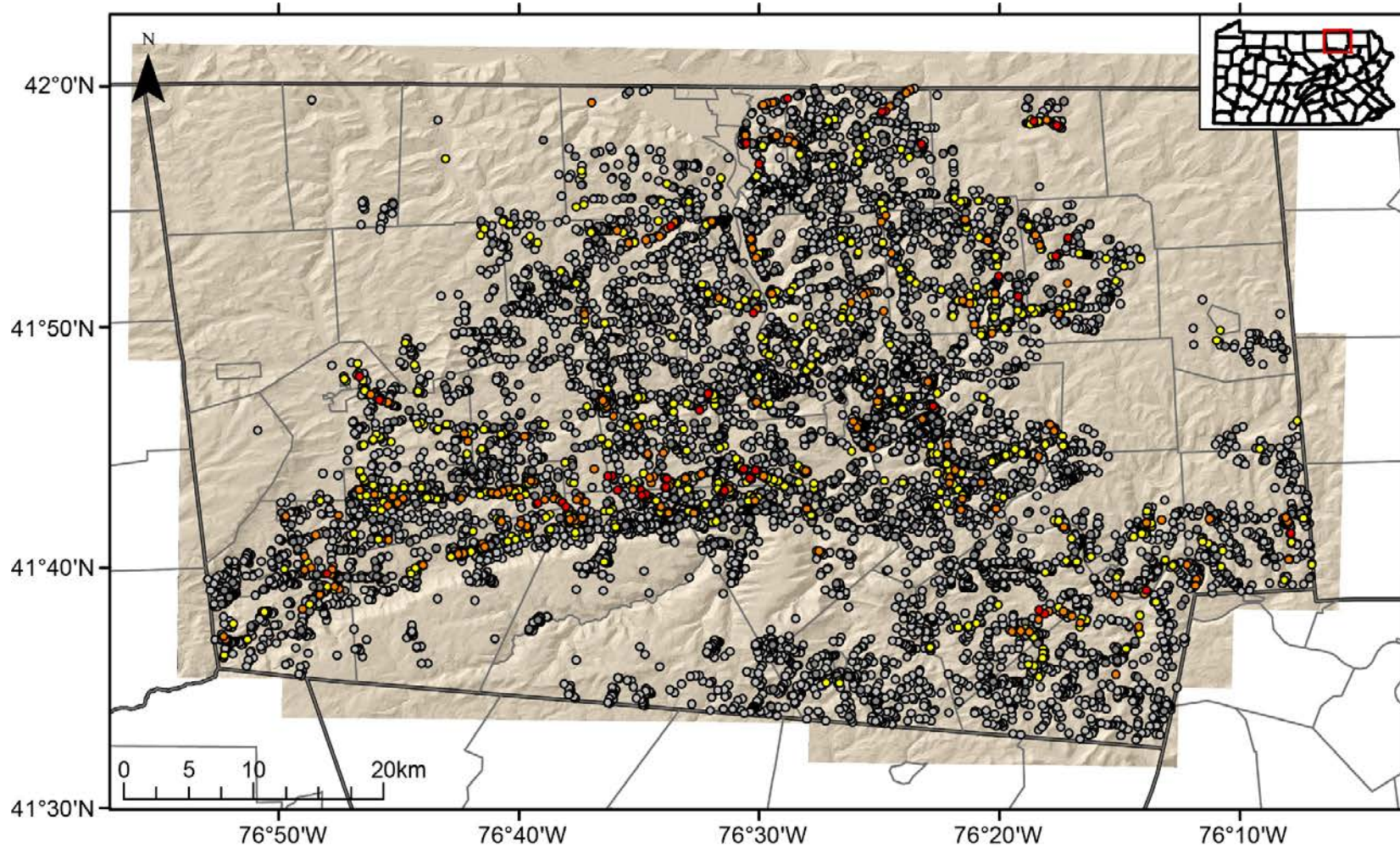
With these large data sets, we can look at spatial distribution of groundwater chemistry

Take data from Bradford County as an example

- Methane
- Other organic compounds

- Arsenic (As)
- Lead (Pb)
- Barium (Ba)

Methane concentration in **Bradford** groundwater



Samples collected in 2010-2016

~11,000 data points/samples

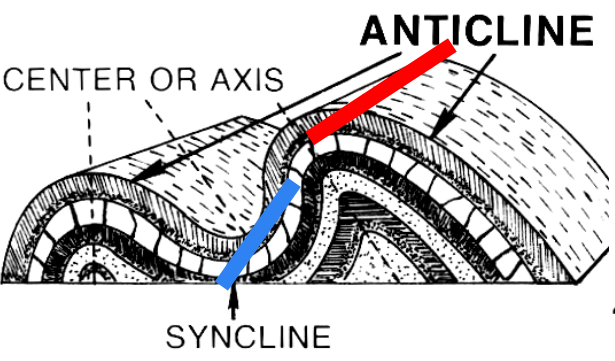
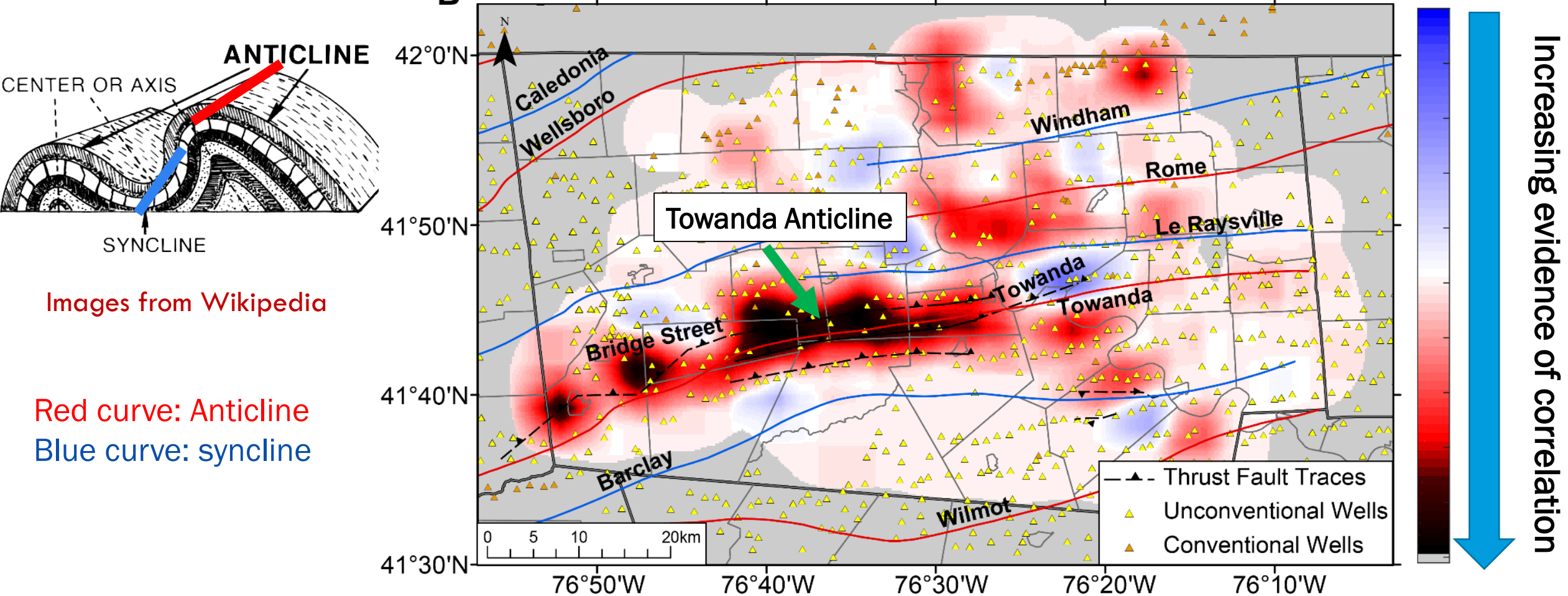
~3000 values above reporting limits

284 samples > 10 mg/L (orange and red symbols)

Sliding window technique (codes released to git.io/vNdsd)

Is methane in groundwater increasing as moving closer to anticline (fold)?

B Distance to Nearest Anticline



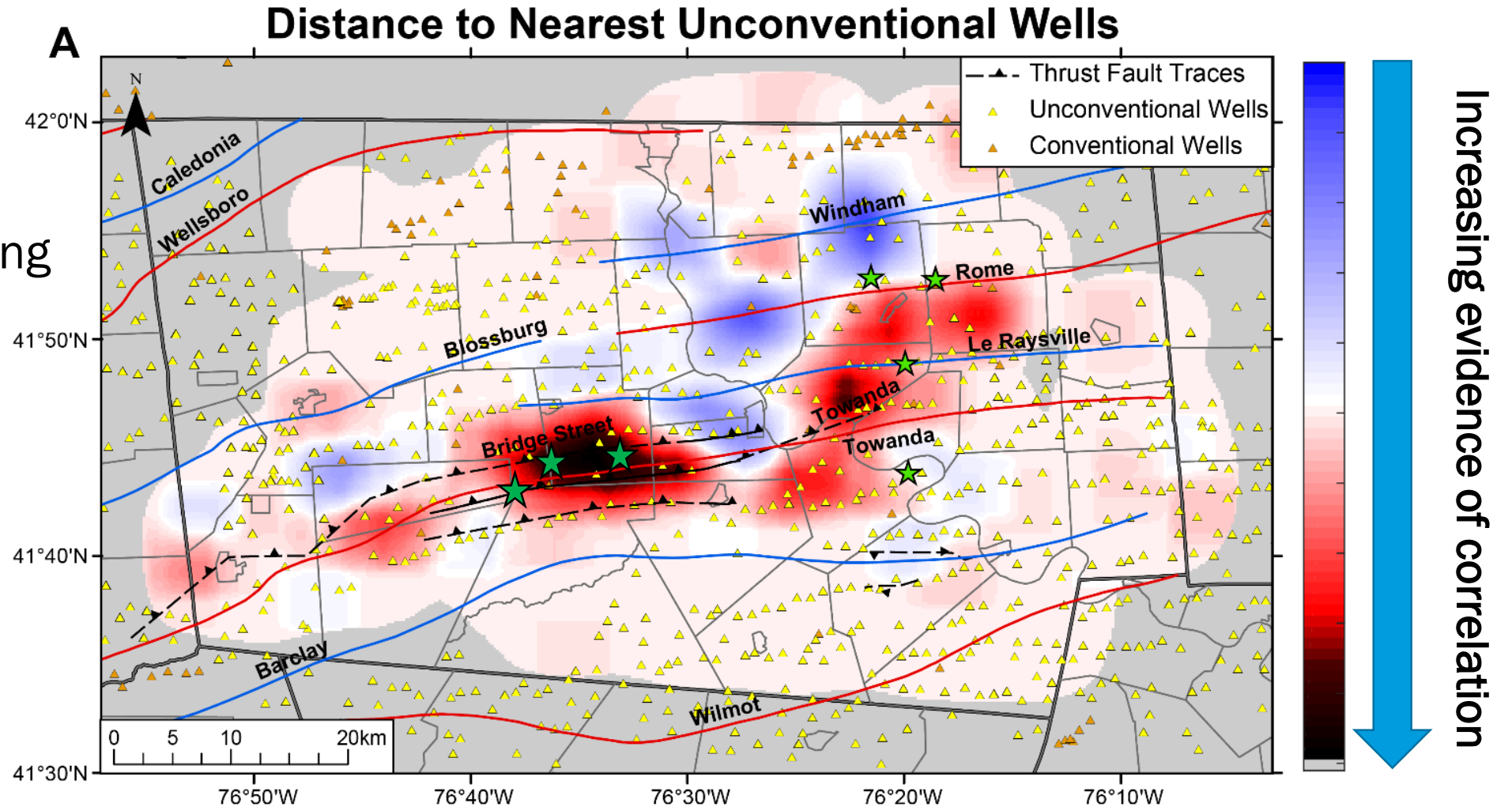
Images from Wikipedia

Red curve: Anticline
Blue curve: syncline

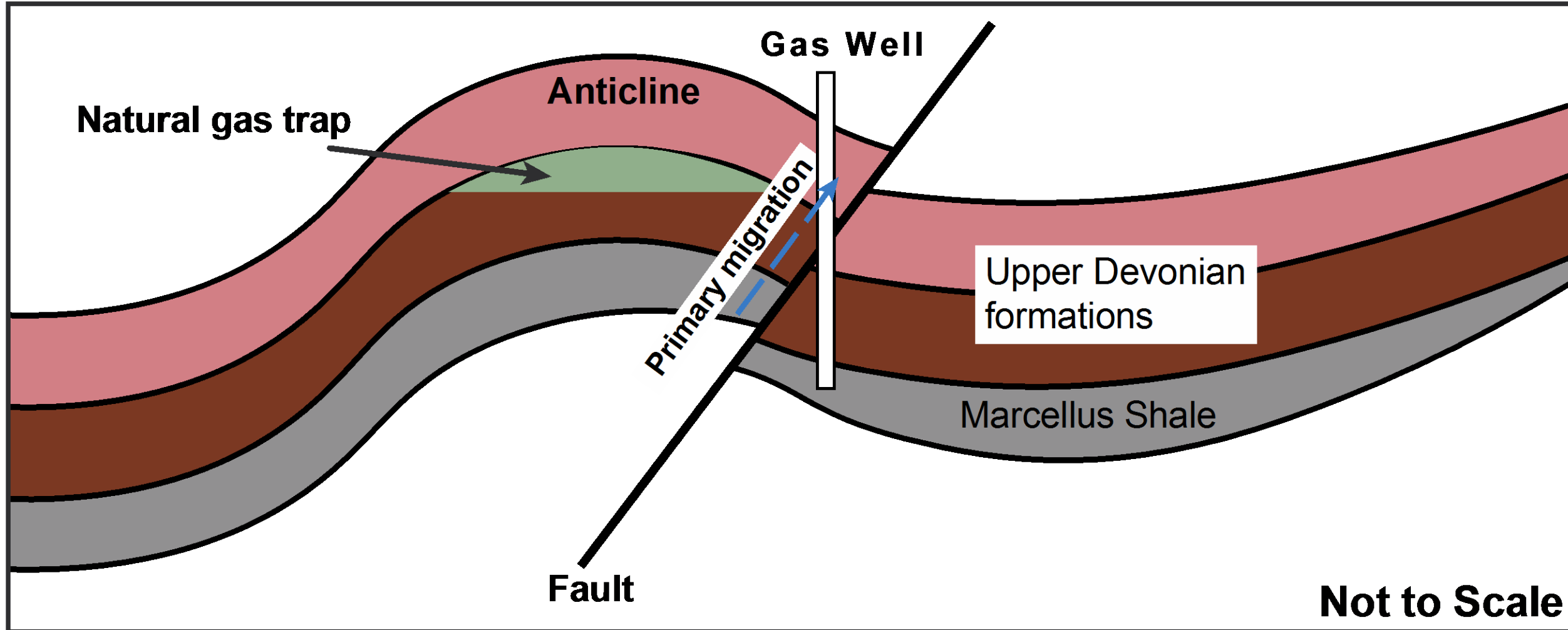
Sliding window technique (codes released to git.io/vNdsd)

Is methane in groundwater increasing as moving closer to shale gas wells?

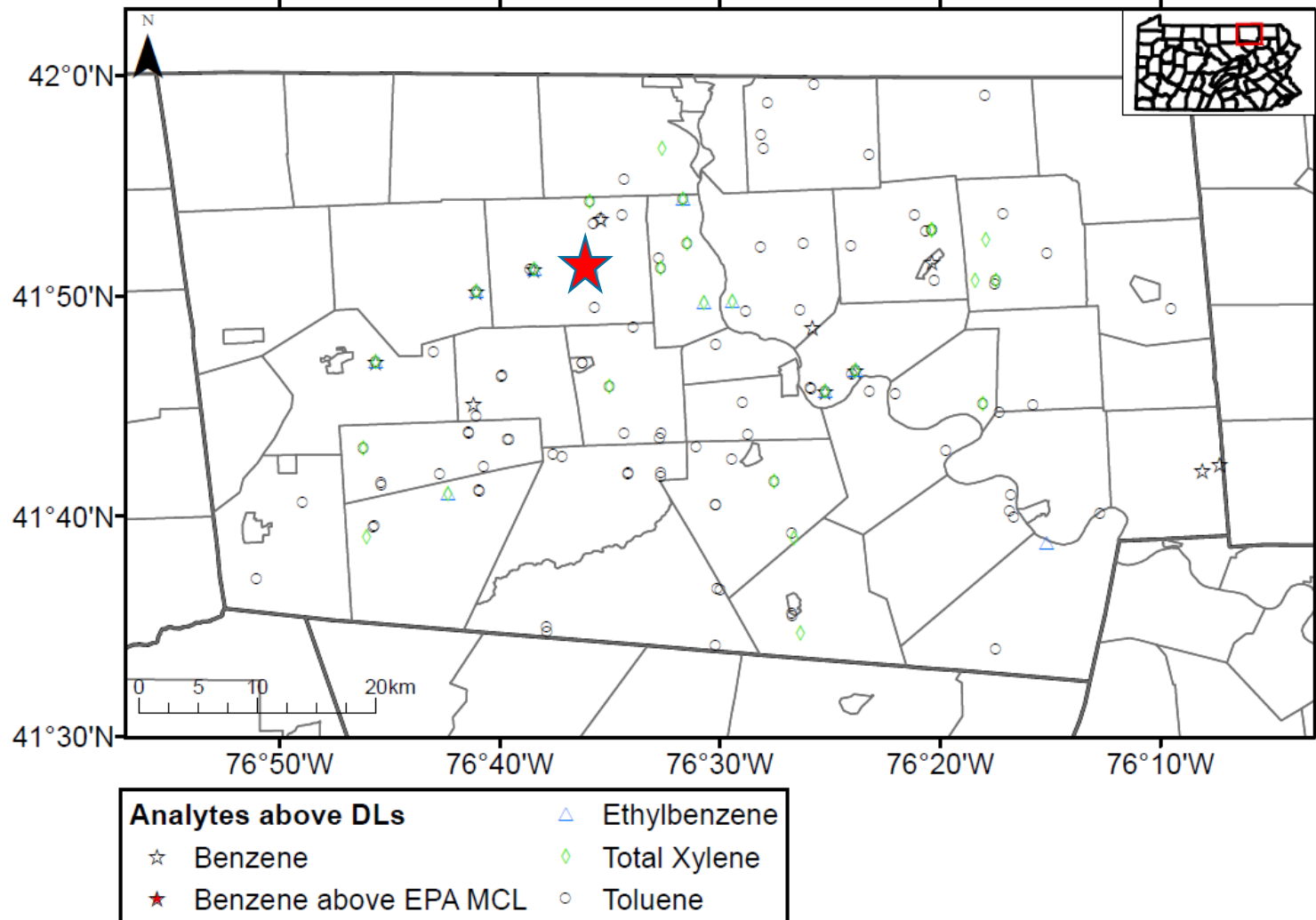
We identify 7 shale gas wells that might allow methane leaking into shallow aquifer



Schematic of gas wells lacking intermediate casing...



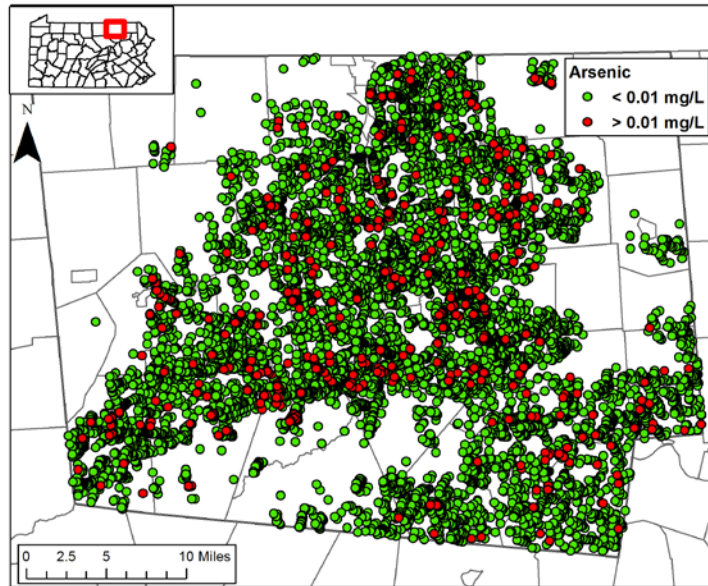
Locations of Bradford samples with other organic analytes presented at concentrations above the reporting limits



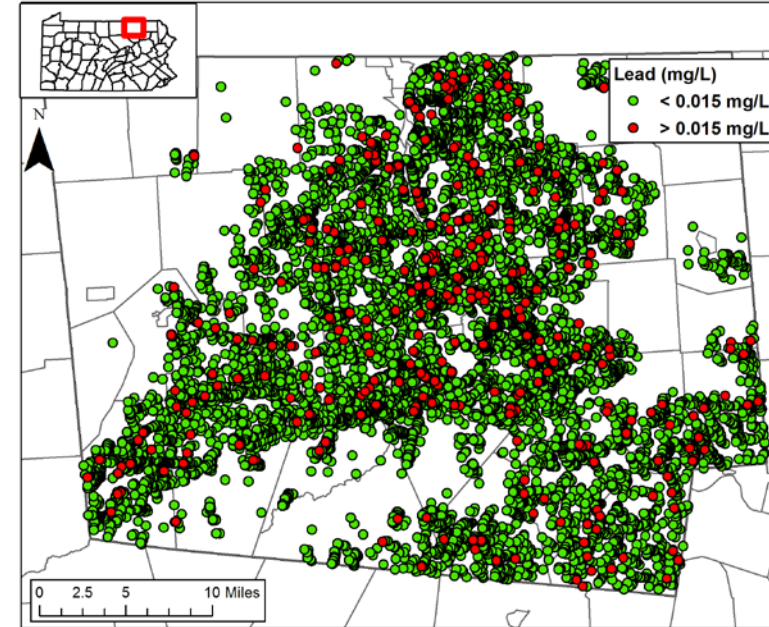
Five volatile organic compounds (VOCs: 1,2-DCE, benzene, toluene, ethylbenzene, and xylene), one glycol (ethylene glycol), three alkanes (methane, ethane, and propane)

Only benzene was ever found to exceed the EPA drinking water standard (5 ppb)

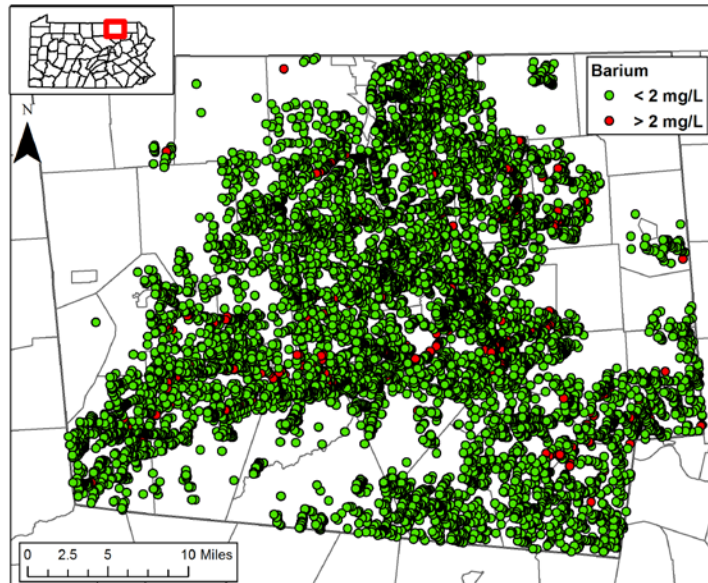
Metal (As, Ba, Pb) concentrations in Bradford groundwater



As



Pb



Ba

Red color: concentrations > corresponding EPA drinking water standards

All samples collected in 2010-2016

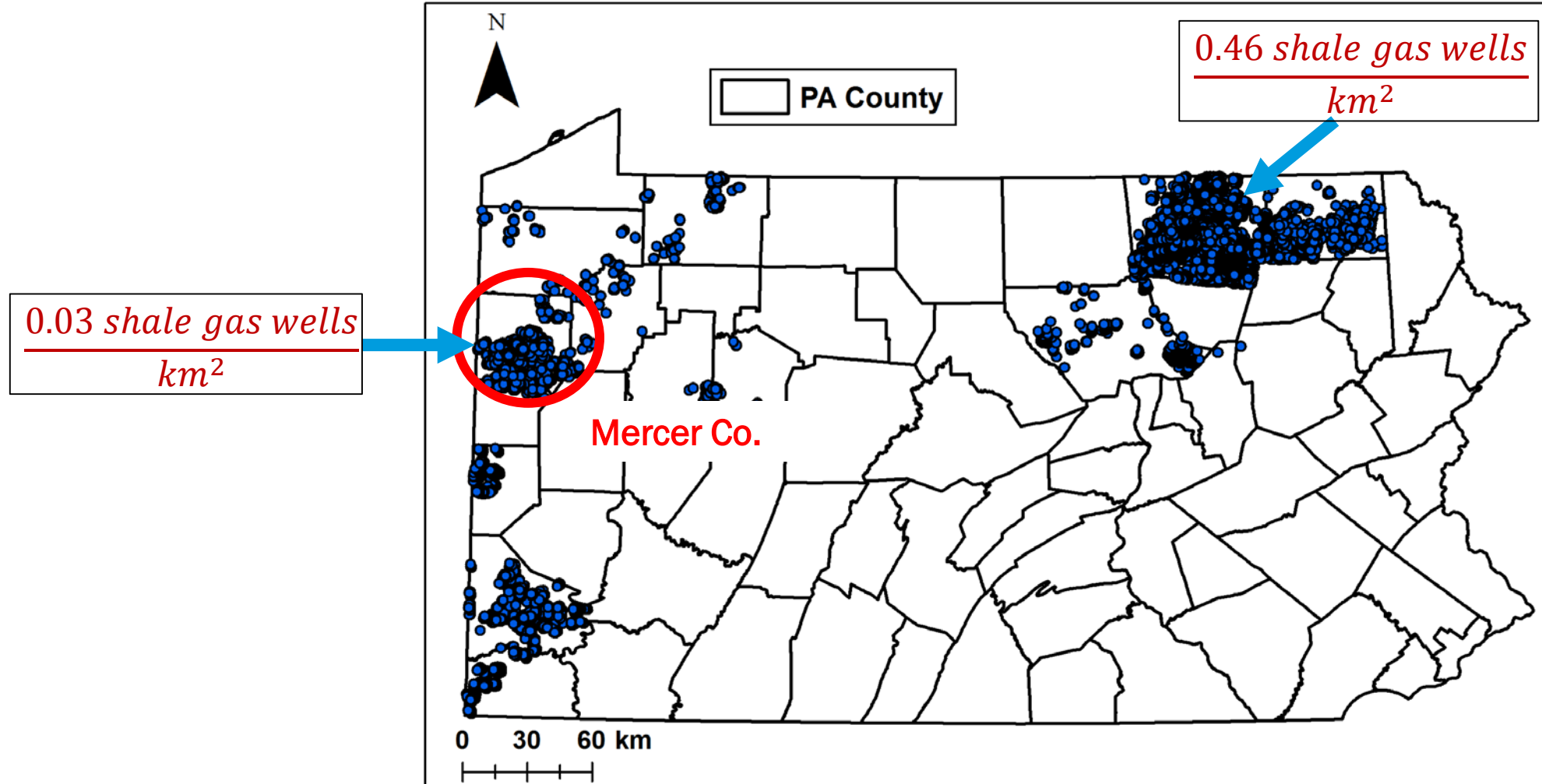
As and Ba tend to be controlled by geology features;
Pb tends to be controlled by in-house factors

The comparison of these 2010s groundwater chemistry data with 1980s USGS data in Bradford County indicates the improvement of groundwater quality

- Total dissolved solids (TDS), Fe, Mn, sulfate, and pH show statistically significant evidence of slight improvement
- Other analytes show no statistically significant change

Why might this have happened? Improvements in groundwater quality could be caused by the **decrease in acid rain** (pH, sulfate improvements) since the imposition of the Clean Air Act or **decreased steel production** (Fe, Mn improvements).

We also assess the temporal change in groundwater quality in one NW PA county: Mercer County



A total of ~20,000 groundwater samples

The comparison of 2010s and pre-2000 groundwater chemistry data in Mercer County indicate degradation of groundwater quality

- pH shows a statistically significant decrease
- Mg, Ca, Na, Fe, Cl, TDS, total alkalinity, hardness, specific conductance, and turbidity show statistically significant increases

The most likely explanations of the slight groundwater deterioration in NW PA but not in NE PA:

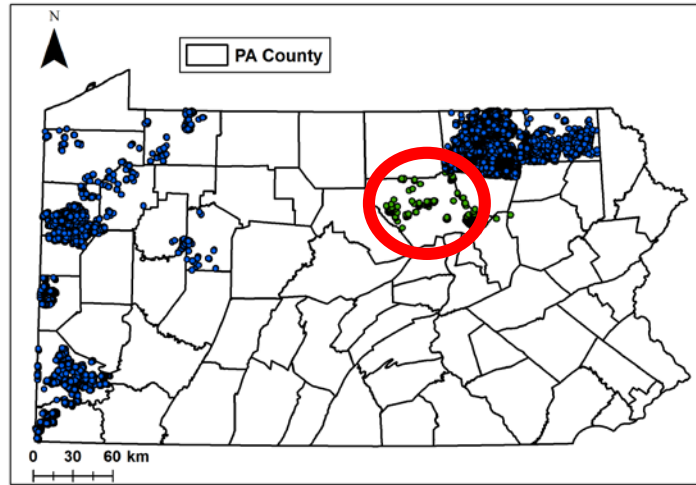
- More historical oil and gas (conventional) in NW PA than NE PA...abandoned or orphan wells have more tendency to leak
- More roads in NW PA...more salts used for de-icing in NW PA
- Production brines (from conventional wells) are used on roads for dust abatement in NW PA but not in NE PA

Can we distinguish between waters with naturally-occurring methane and those with anomalous methane?

- Anomalous methane

invading into the shallow groundwater **recently** caused by human activities (e.g., shale gas development); in contrast to **long-standing** naturally-occurring CH₄

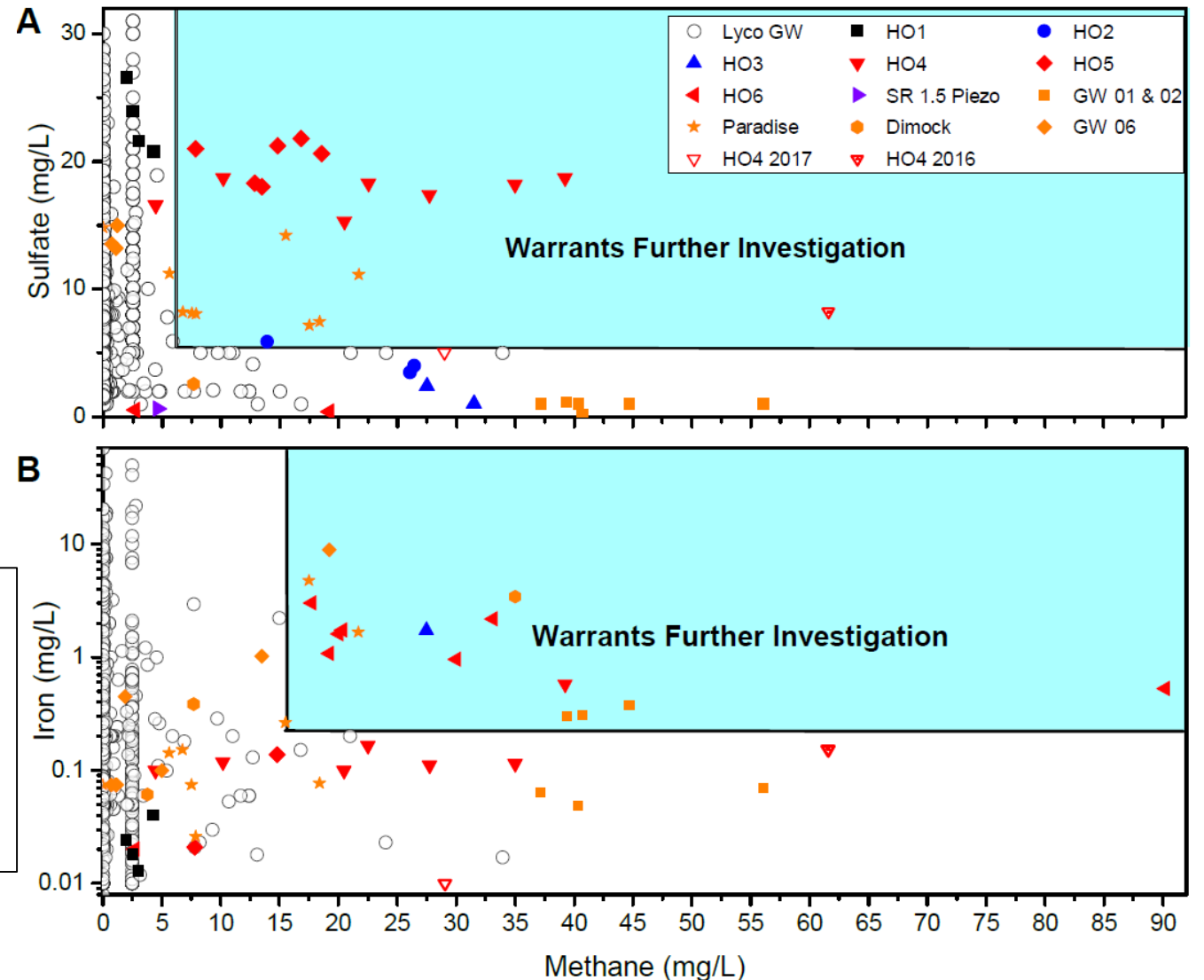
In large geochemistry data sets, how can we find sites associated with leakage of methane (or other contaminants)?



Sugar Run, Lycoming County

Open symbol: background sample collected from Lycoming County

Closed color symbol: groundwater samples collected from presumably impacted sites



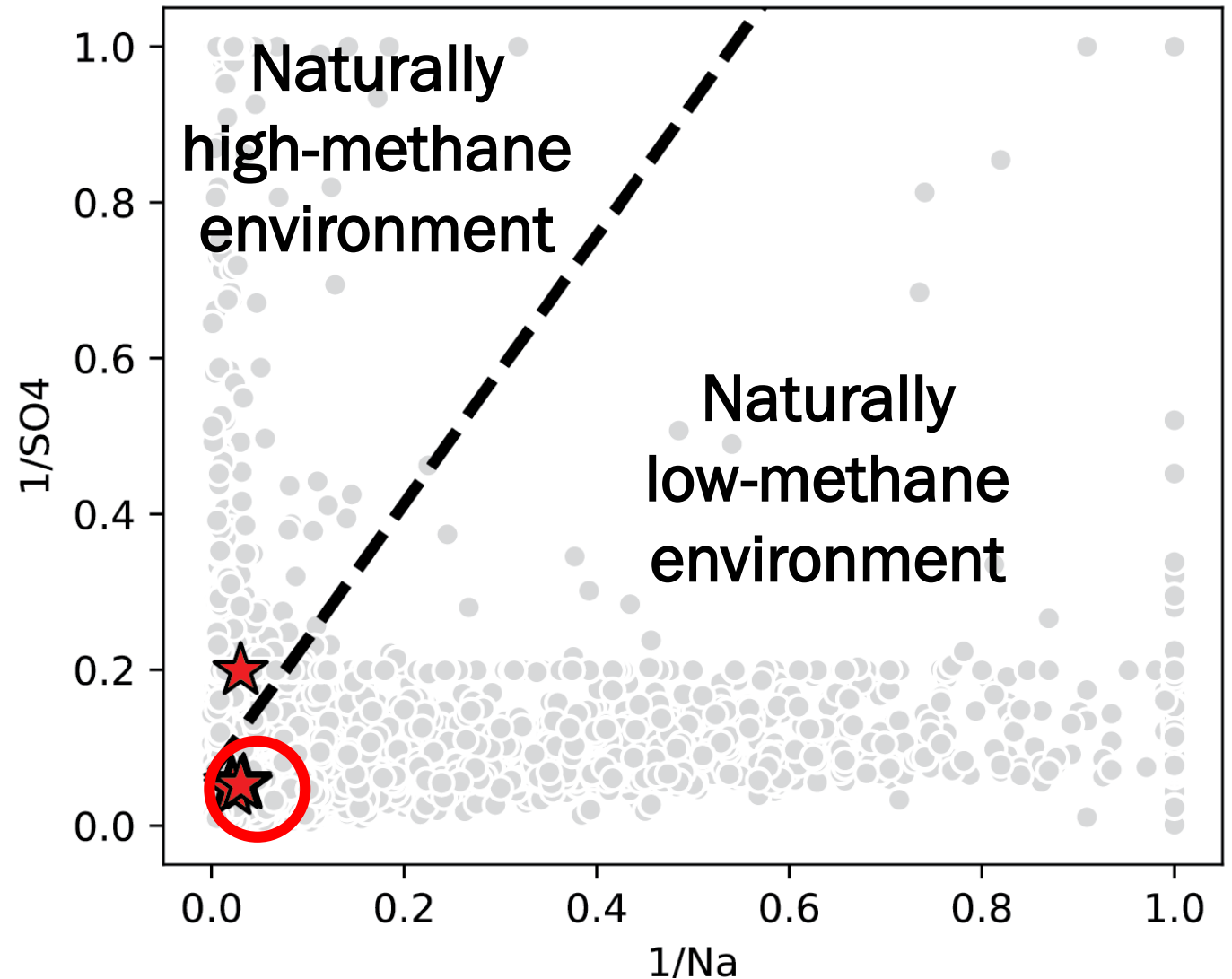
Applying machine learning models on our large data set to help find out such helpful geochemical analytes

For example: $1/\text{SO}_4$ vs. $1/\text{Na}$

Symbol color: methane concentration

Stars: high-methane samples from a site that is presumably contaminated by one or more leaking shale gas wells

This graph (and others) can help detect contaminated waters in large datasets



Conclusions

- Using our new sliding window technique, we identify potentially problematic shale gas wells and evidence that elevated methane is associated with anticlines and faults
- We saw no evidence that shale gas development is impacting regional groundwater in NW or NE PA; however, use of salts for de-icing and production waters for dust abatement may impact groundwater, along with leakage from older, conventional gas or oil wells
- Machine learning techniques can help us detect where gas wells may be leaking...when data are shared

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