Legacy hydrocarbon production contributing to degraded groundwater quality in Ontario

Stewart Hamilton, Ph.D., P.Geo.

May 31, 2023

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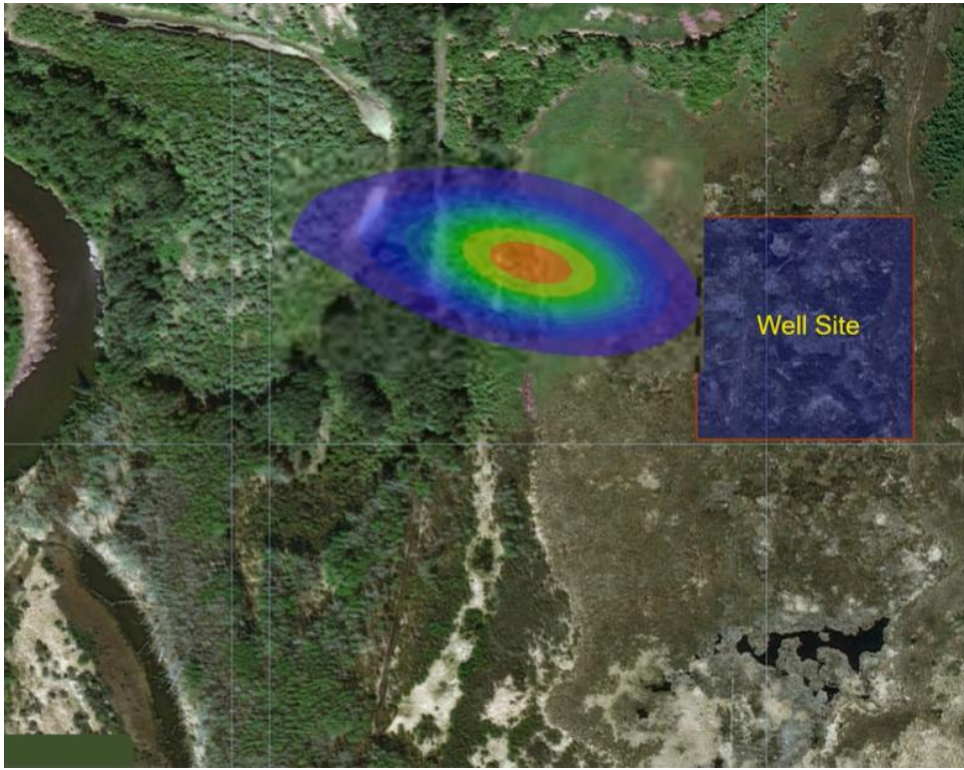
Outline

1. Ontario's **old** hydrocarbon industry in historical context
2. The geographic problem
3. Degraded water quality and how legacy gas wells are implicated
4. How geology + gas wells + microbes create H_2S
5. Ontario's problems in perspective and what can be done about it



Key takeaway: when seen in context, the problems with Ontario's legacy gas wells are both understandable and manageable

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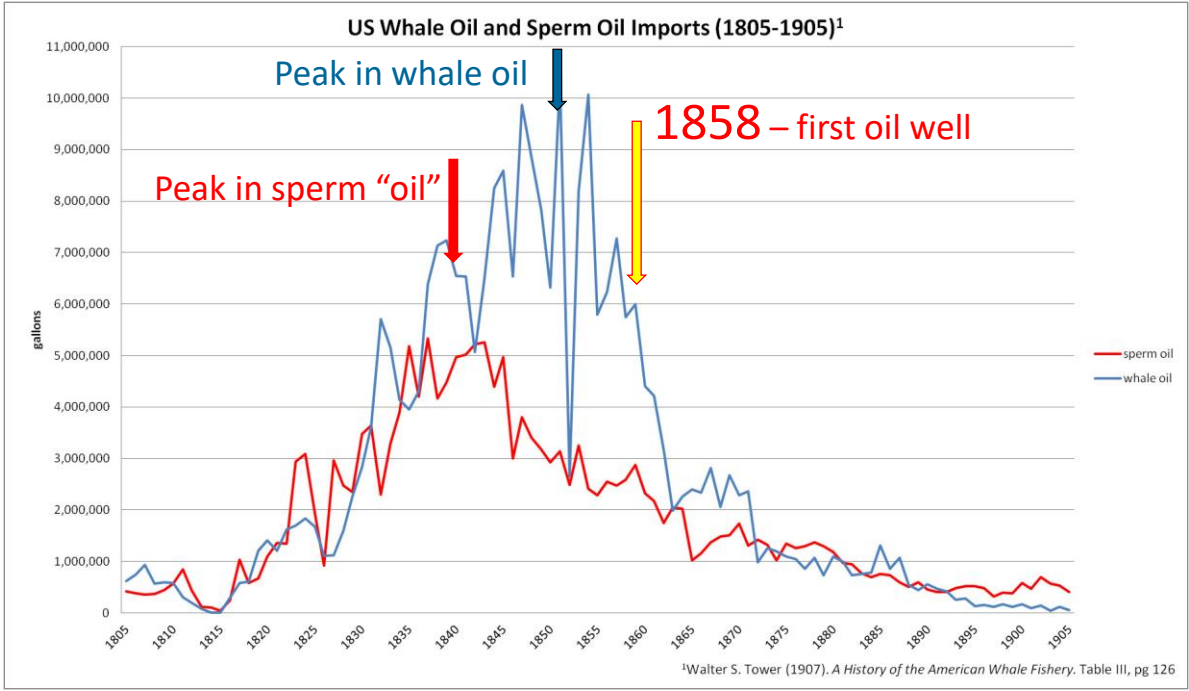
Ontario's OLD Oil & Gas Industry

- The first oil well in Canada started out as a water well in 1858 north of Chatham Ontario in a town later known as Oil Springs.
- A year later, the famous 1859 oil discovery in Pennsylvania kicked off the modern oil industry in United States
- The arrival of the oil drilling industry was not entirely accidental – it was driven by demand for mineral oil which before 1858 had been extracted from oil seeps or as a fouling byproduct in brine wells used for salt production

National Archives of Canada

An existing market, waiting for a product

- In the 1850s, the industrial revolution was in full swing and lubricated and lighted mostly by train (i.e., whale) oil, which was in steep decline
- The decline in whale oil began before the first oil wells and was driven by scarcity, first of spermaceti, then a decade later of all whale oil
- There was an economic incentive to find ways to access and use mineral oil
- (the whales were saved by accident)



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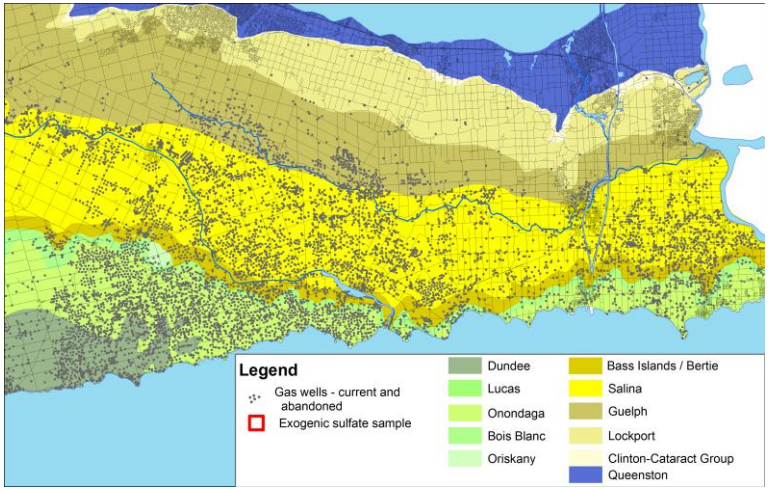
Oil Industry Expansion Ontario

- Gas is much more common than oil in southern Ontario strata and drilling for gas by landowners was very common, especially on the Niagara Peninsula
- (land granted in most parts of Canada before 1921, had no separation of surface and mineral rights)
- Gas wells were often drilled by farmers who had only to cable-tool drill down 200m to get gas most of the time.

Photo, S.M. Hamilton (2015)

An *operating* gas well, Niagara Peninsula

Wooden gas well casing at OGSRL

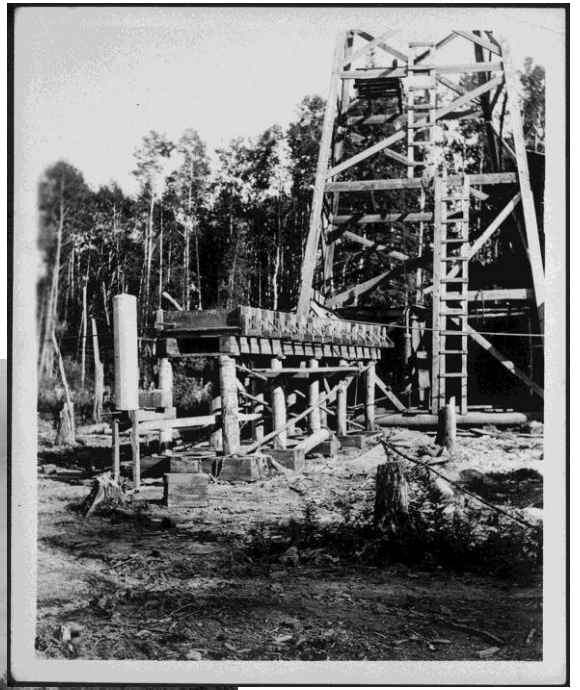


Recorded gas wells on the Niagara Peninsula

Map: Ontario Geological Survey (OGS) MRD 219; Data, Oil, Gas and Salt Resources Library (OGSRL)

The Early Oil Industry in Alberta

- Following minor attempts at oil extraction in places such as Waterton, the large Turner Valley gas (later oil) field was discovered (1914)
- However, the modern Alberta Oil industry started with the discovery of the Leduc Field in 1947.
- In Alberta, land surface rights do not include mineral rights and therefore a regulatory oversight system was required from the beginning, in order to lease-out exploration and drilling rights to oil and gas companies



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Takeaways – Ontario vs. Alberta Industries

- In Ontario
  - The oil and gas industry started arguably earlier than any other (1858)
  - On private land, often by farmers who held the mineral rights
  - Exploiting mostly small, shallow gas deposits
  - Operated for decades before regulations were developed
- In Alberta
  - The industry started almost ~90 years later (1947)
  - Operations, mostly by large companies, on public land or land where the surface rights were held by others
  - Exploiting larger, deeper oil & gas deposits
  - Operations developed in lock-step with regulations

Legacy of gas wells in Ontario

- Problems related to legacy gas wells have been in the news a lot lately
- Wheatley, Marentette Beach, Forestry Farm Road are just some of the better know areas where legacy hydrocarbon infrastructure has caused problems, including injuries and fatalities
- Much of my work at Matrix since I joined is still bound by client confidentiality. So, rather than talk about Matrix projects specifically, I am discussing the problems of legacy wells in a regional context.
- I will be relying on data from my former position as Science Leader for Geochemistry at the Ontario Geological Survey but all of it is in the public domain.

THE GLOBE AND MAIL
INVESTIGATION

Globe and Mail, August 19, 2022

Where are Ontario's abandoned gas wells, and what risks do they pose? Inside The Globe's investigation

Photo, S.M. Hamilton

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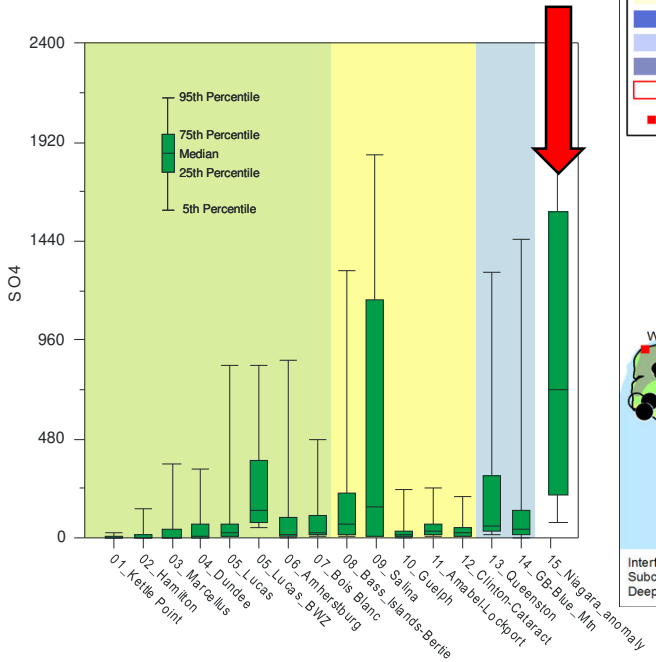
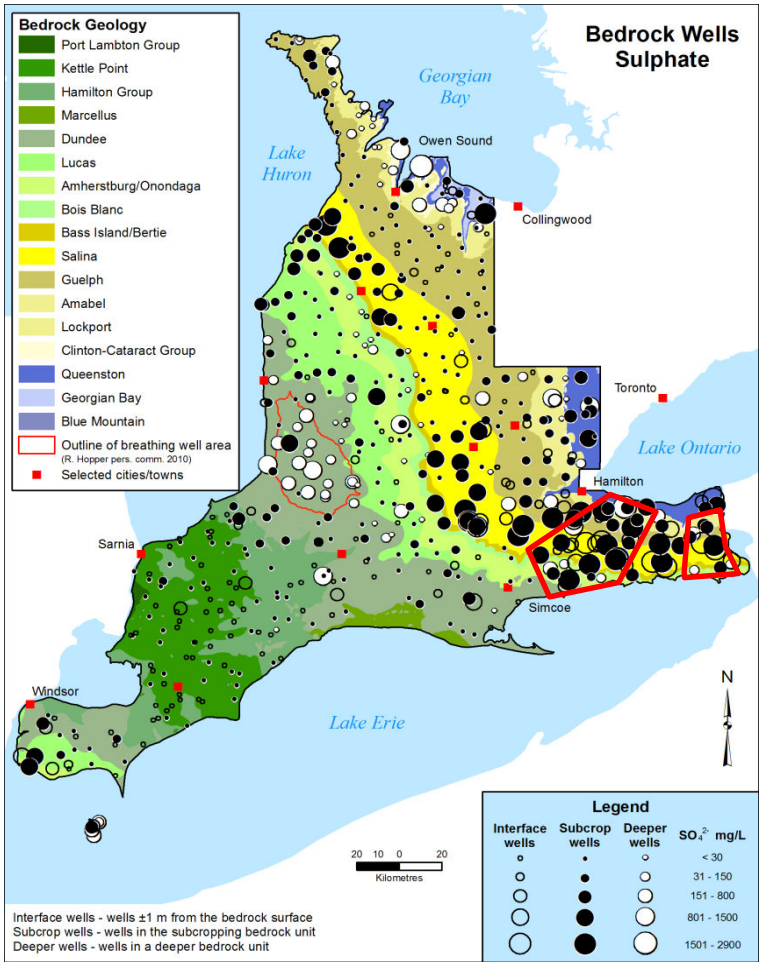
Sulphate in well water OGS data

- All the major bedrock units in southern Ontario have characteristic groundwater chemistry – this is sulphate as one example
- One big exception is on the Niagara Peninsula, where they share no relationship, and the water is uniformly poor
- Multiple repeat studies, including 2 theses showed similar results and implicated legacy gas wells





From Hamilton (2011)

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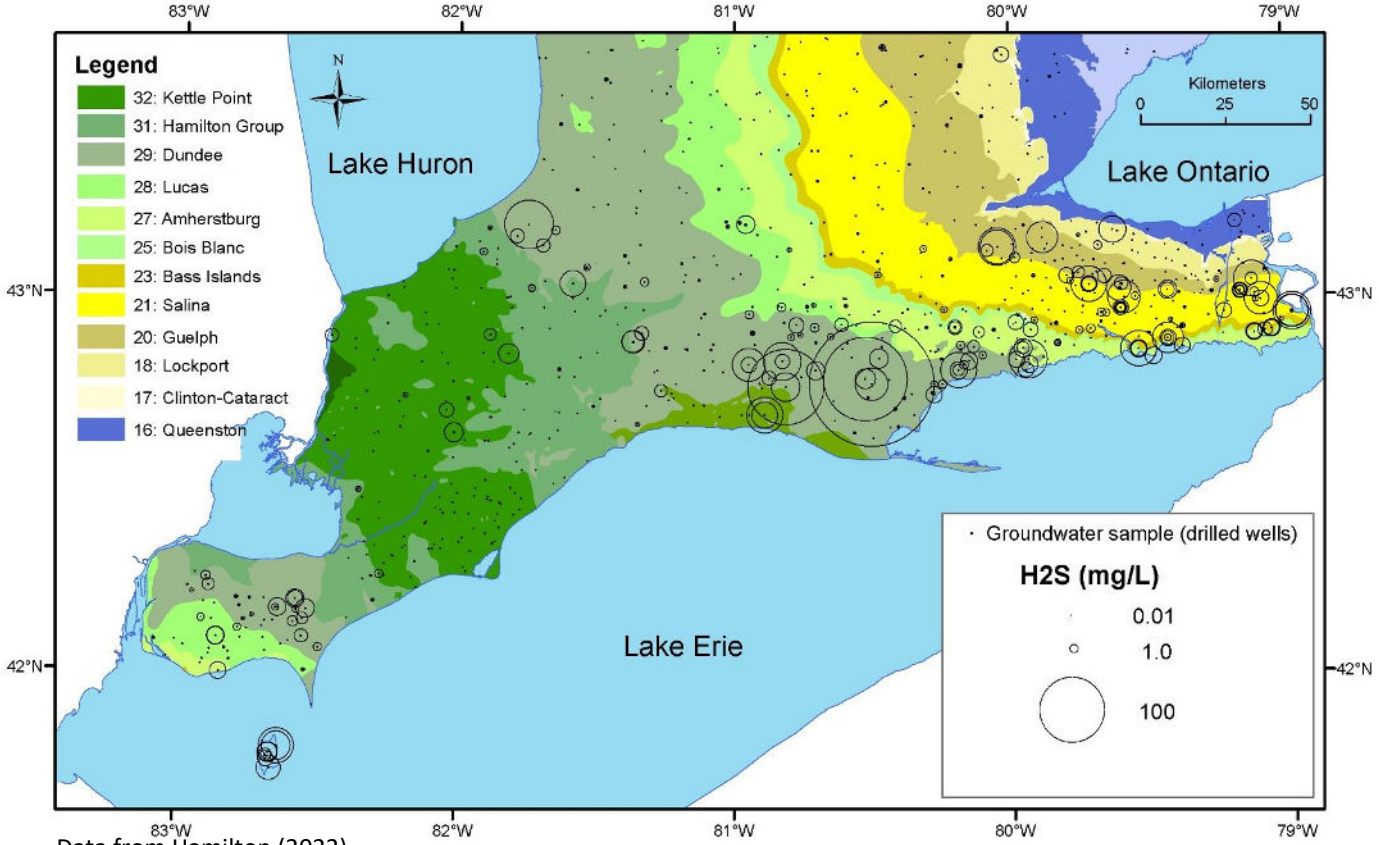
Hydrogen sulphide groundwater domains



Data from Hamilton (2022)

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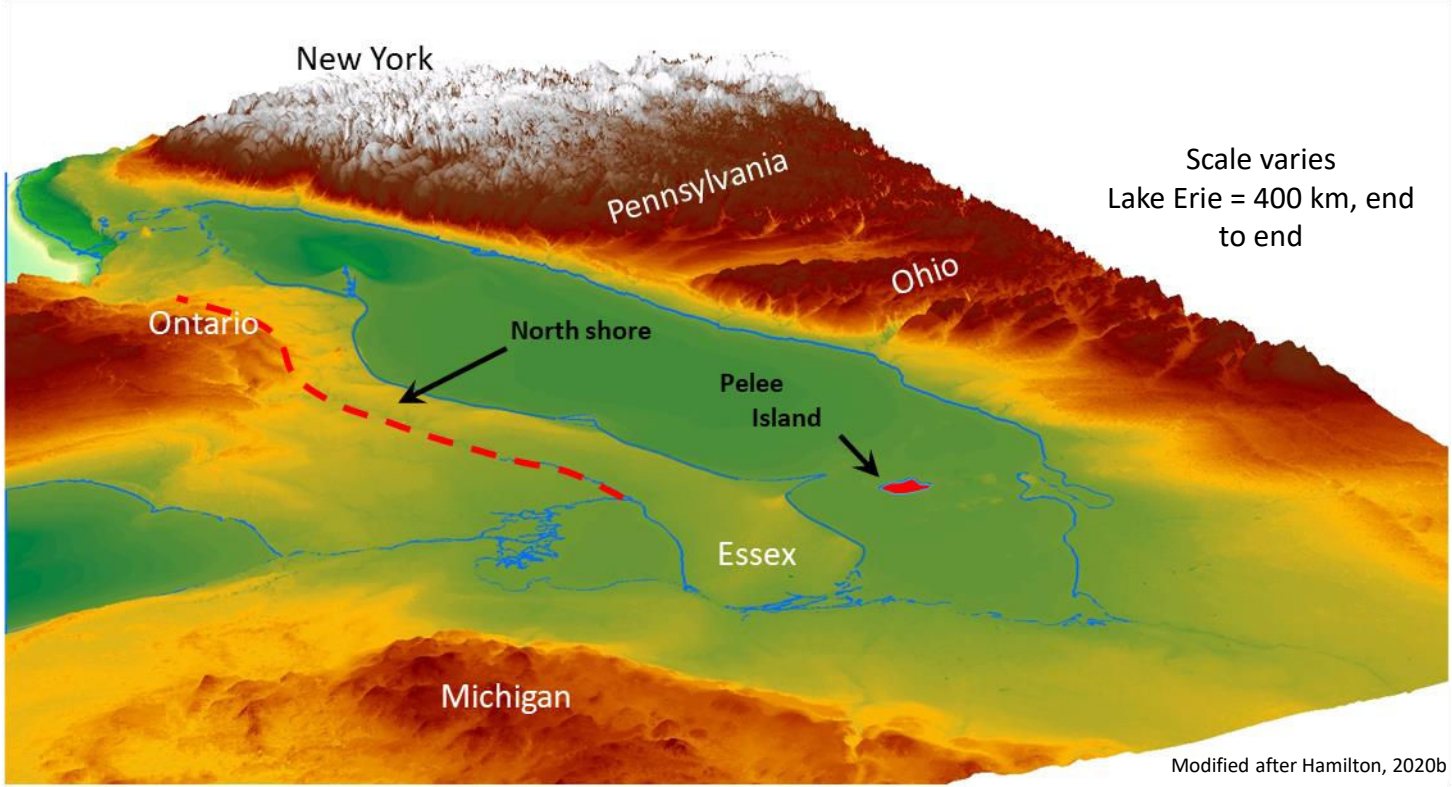
The geographic problem in southwestern Ontario

- Allegheny Plateau dominates the local relief of the entire direct catchment area of Lake Erie
- Little Pelee Island has bedrock artesian water levels that are ~4m above lake level (176 mASL)



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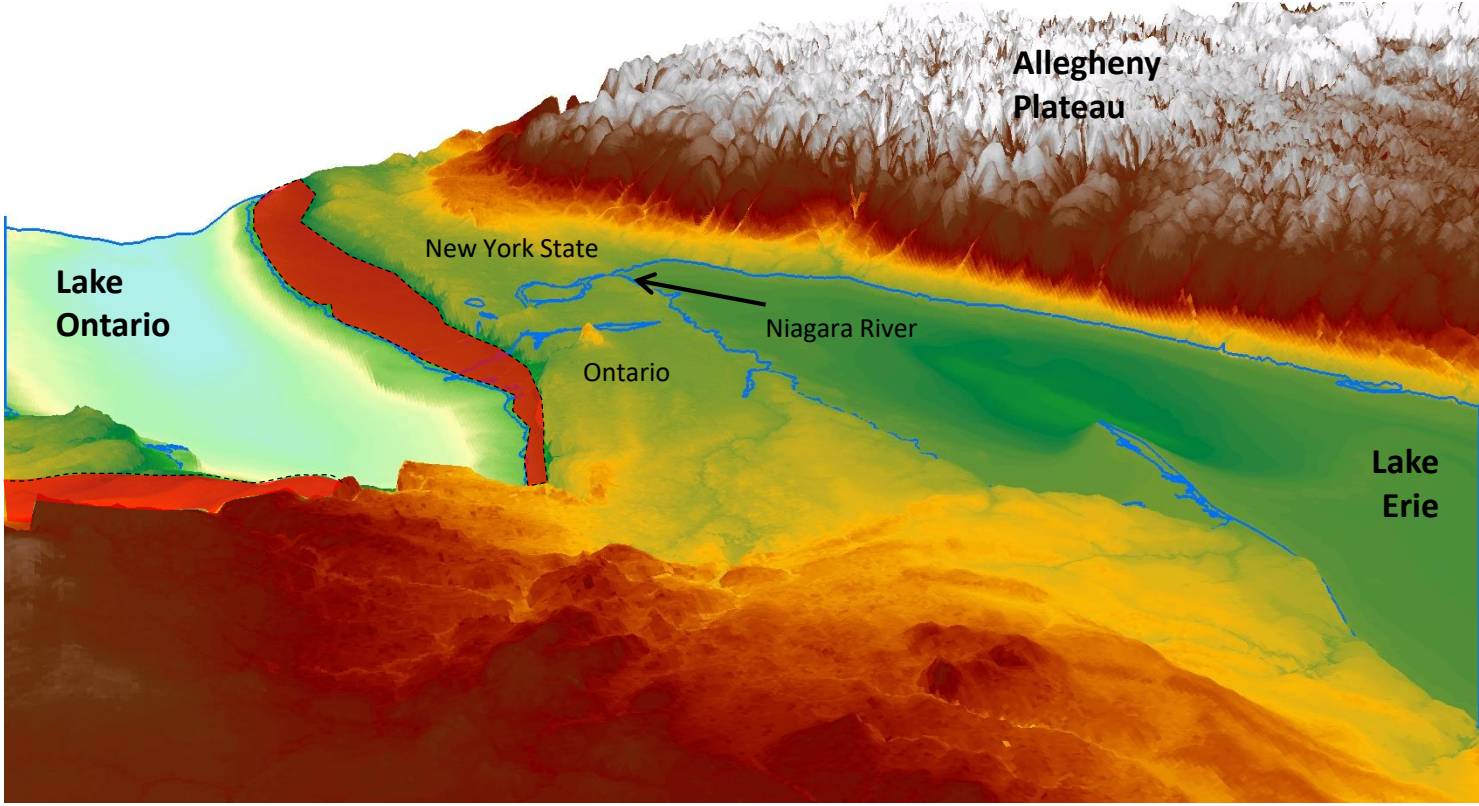
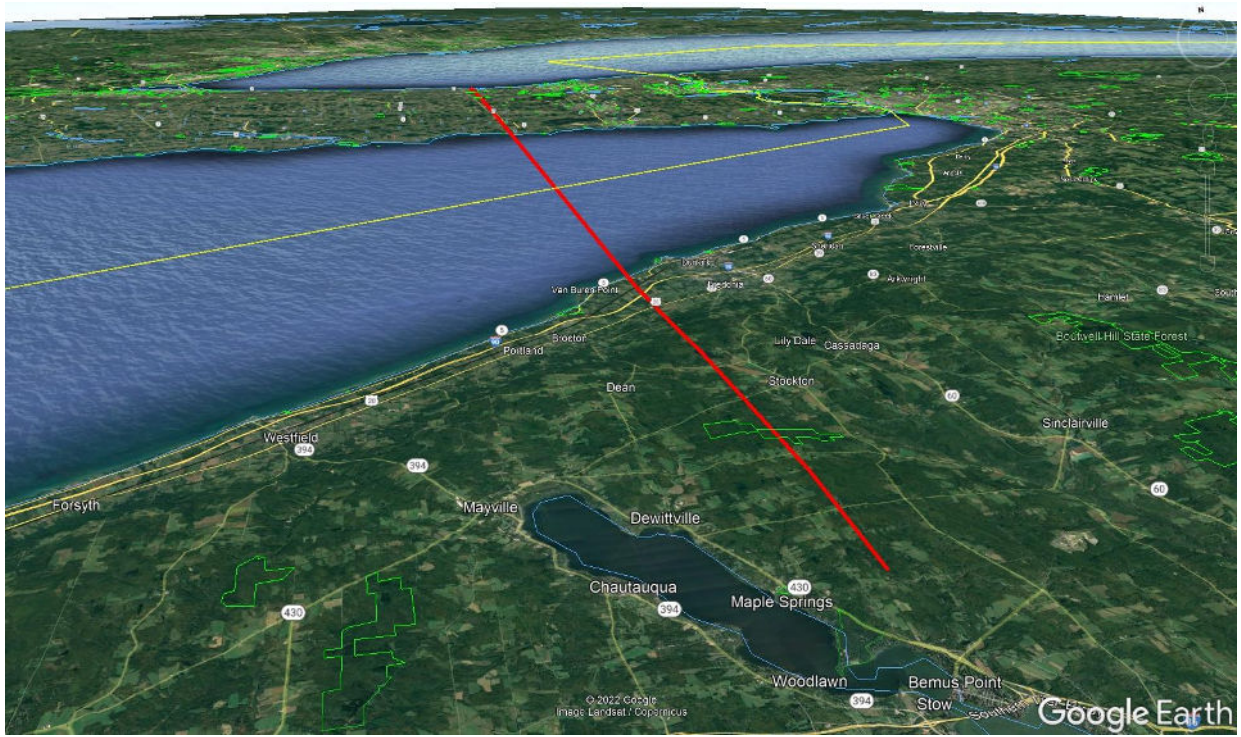
So, what causes the upward fluid movement?

- Niagara Peninsula in regional context
- Far higher relief on the US side, just across the lake
- Queenston Formation underlies the whole peninsula at a depth of 200 m at its centre



Modified after Hamilton, 2020b

Hydrostratigraphic cross section – Lake Ontario to Allegheny Plateau



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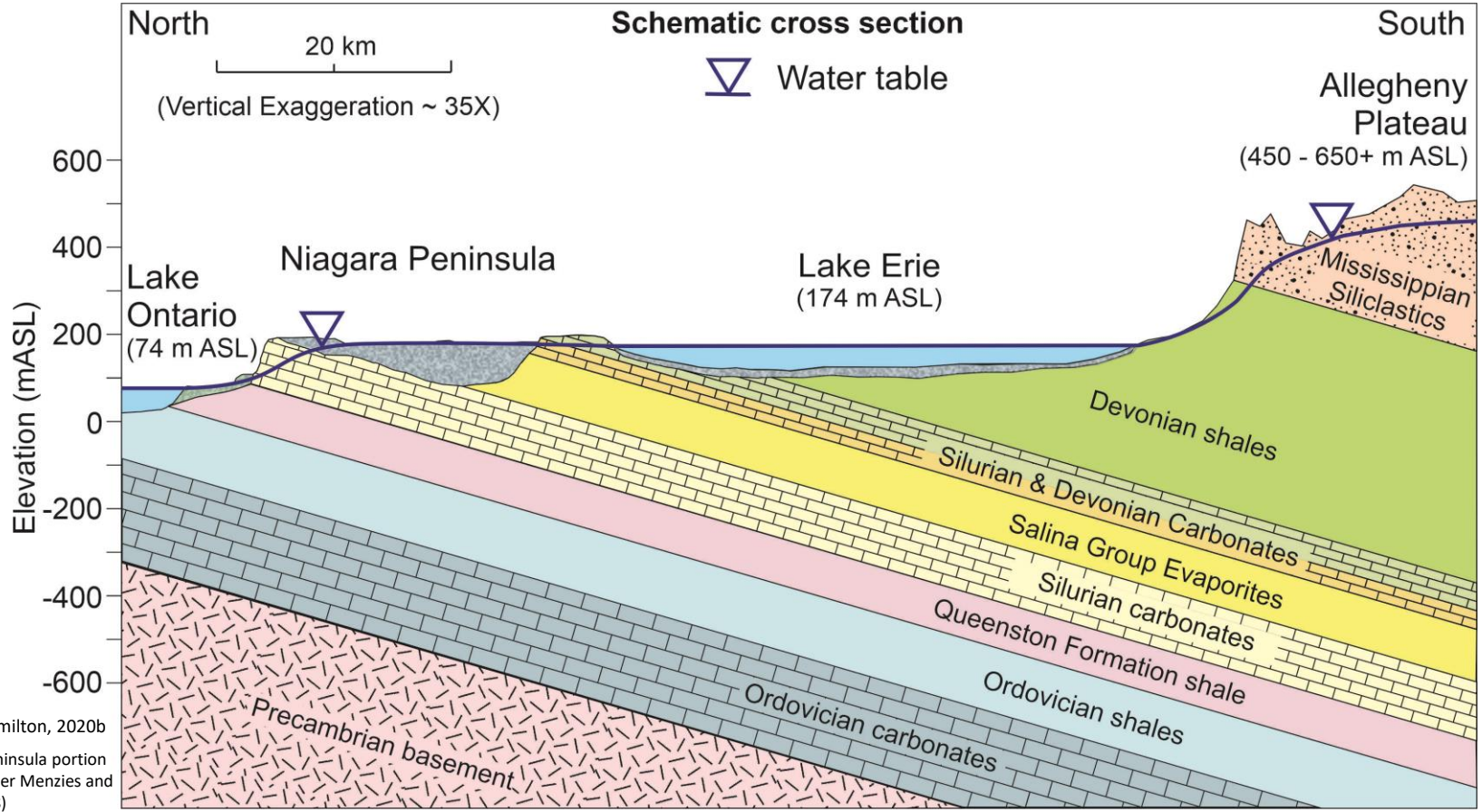
North-south cross section: Lake Ontario & Lake Erie



Modified after Hamilton, 2020b

(Niagara Peninsula portion modified after Menzies and Taylor, 1998)

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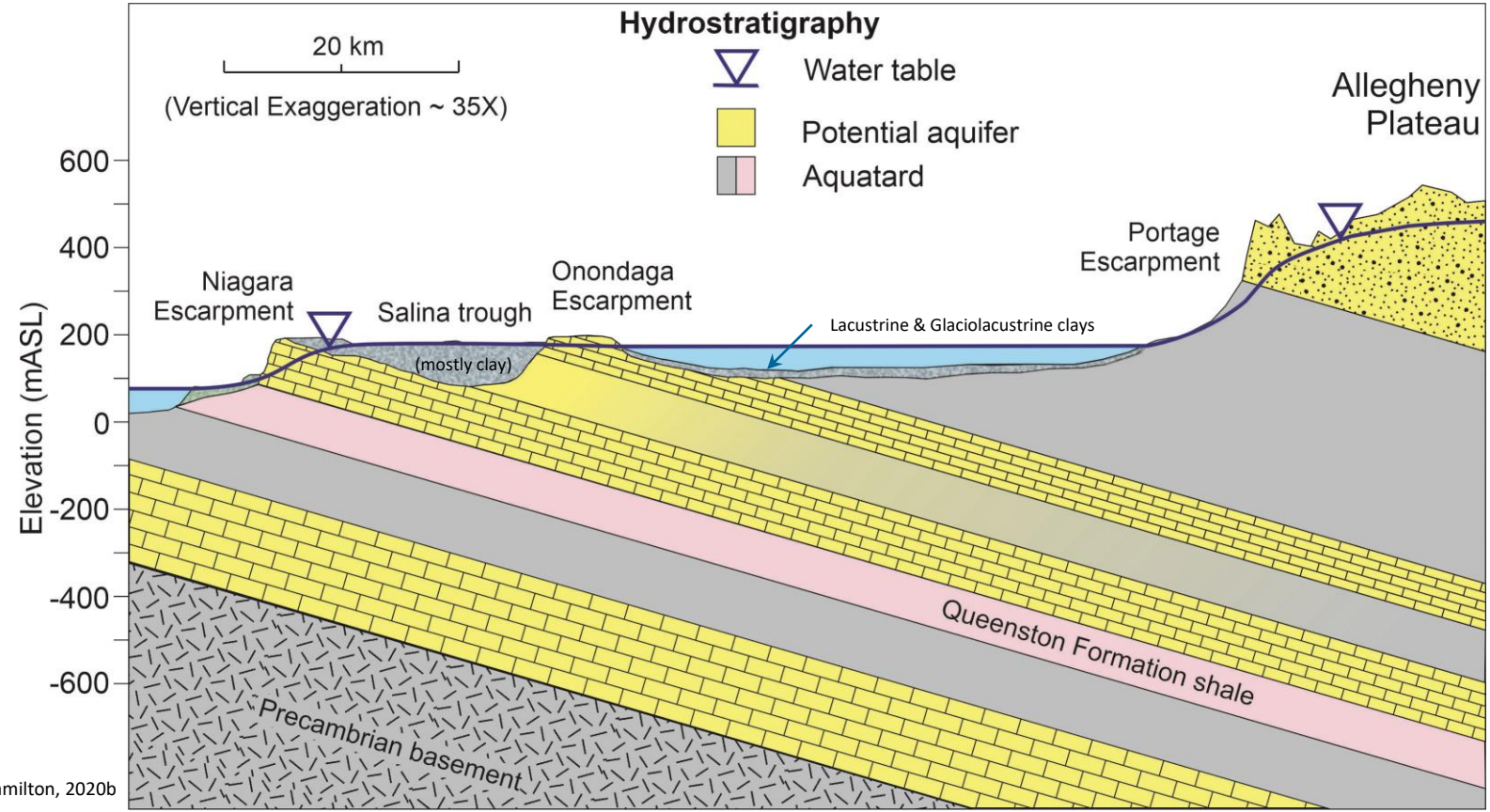

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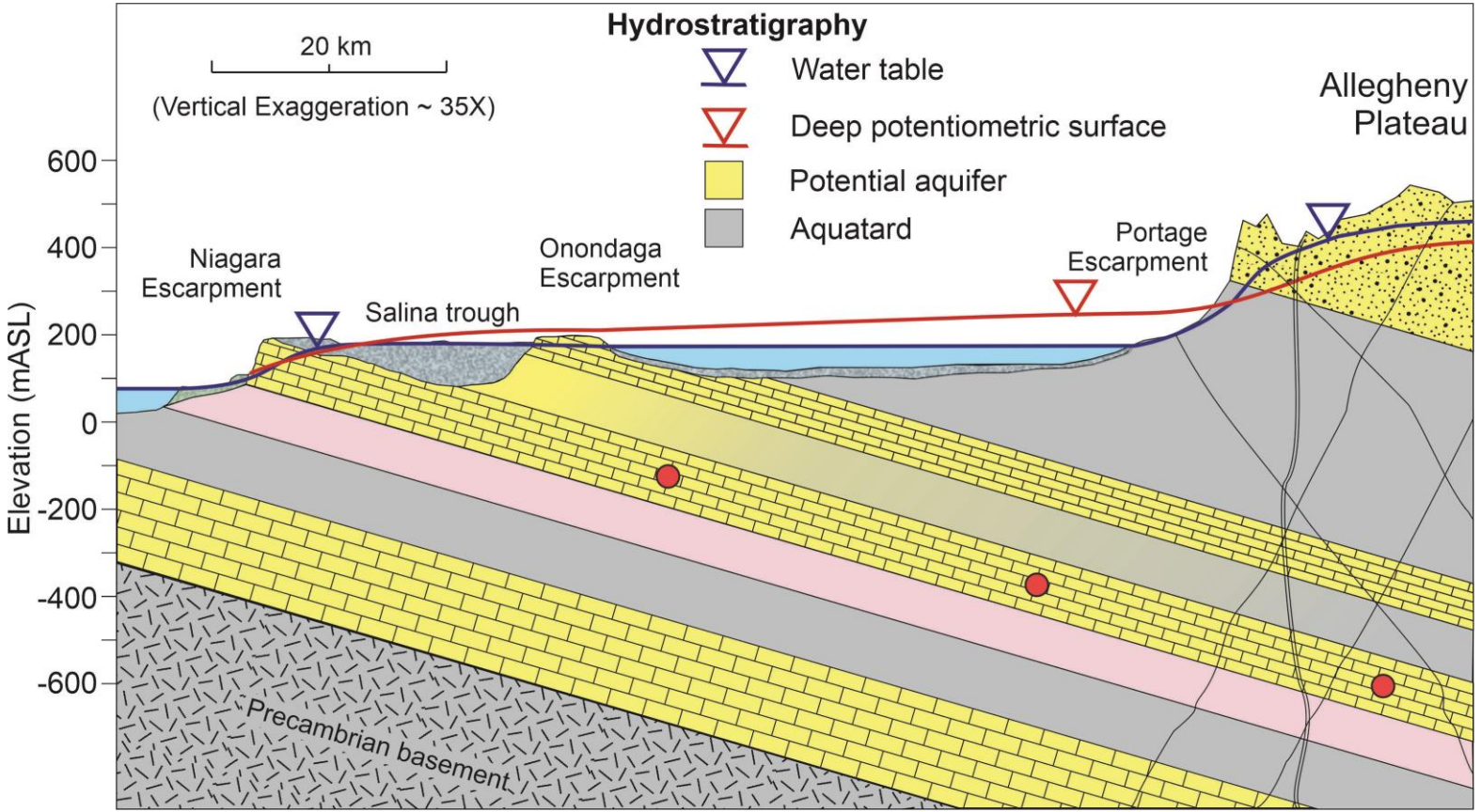

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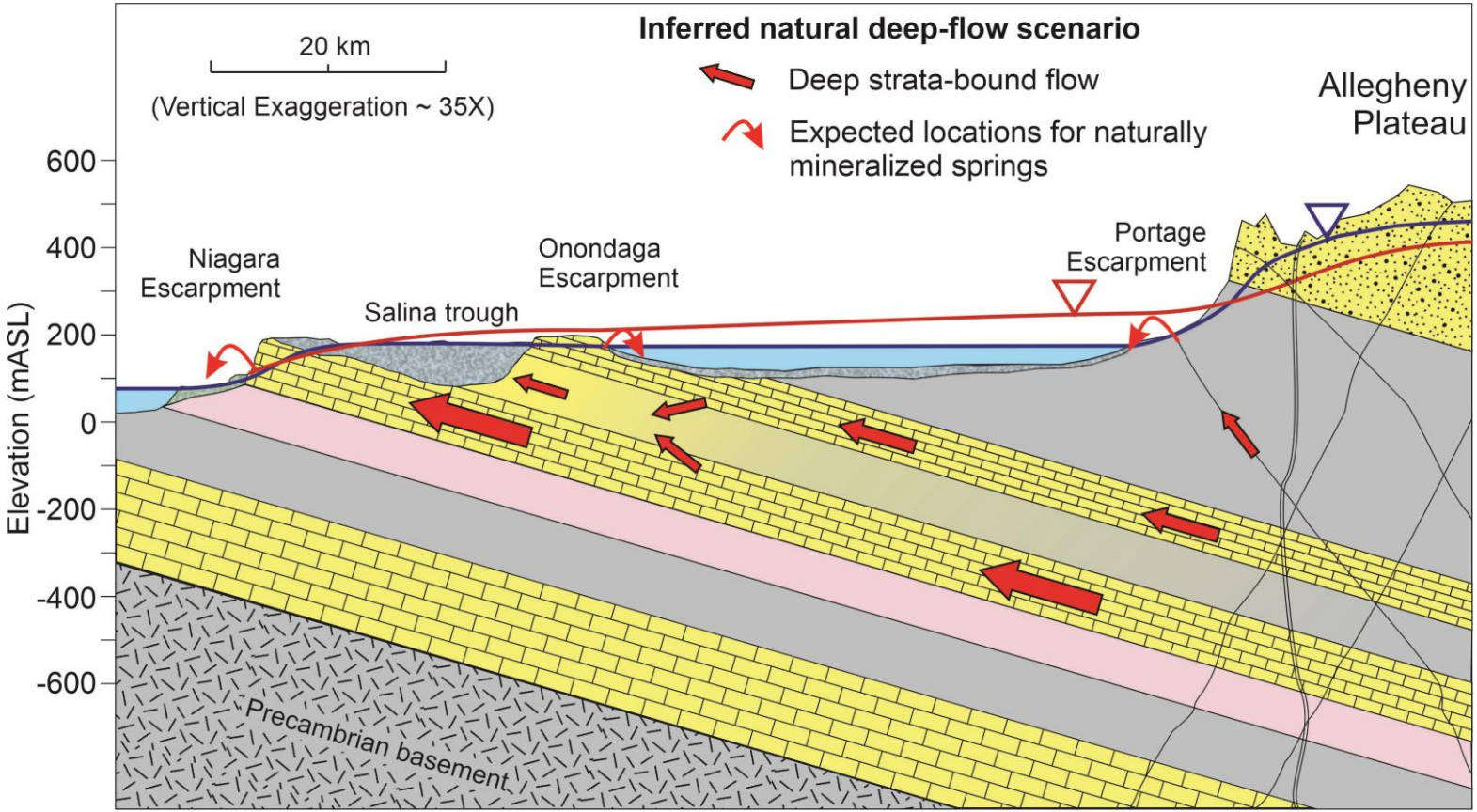

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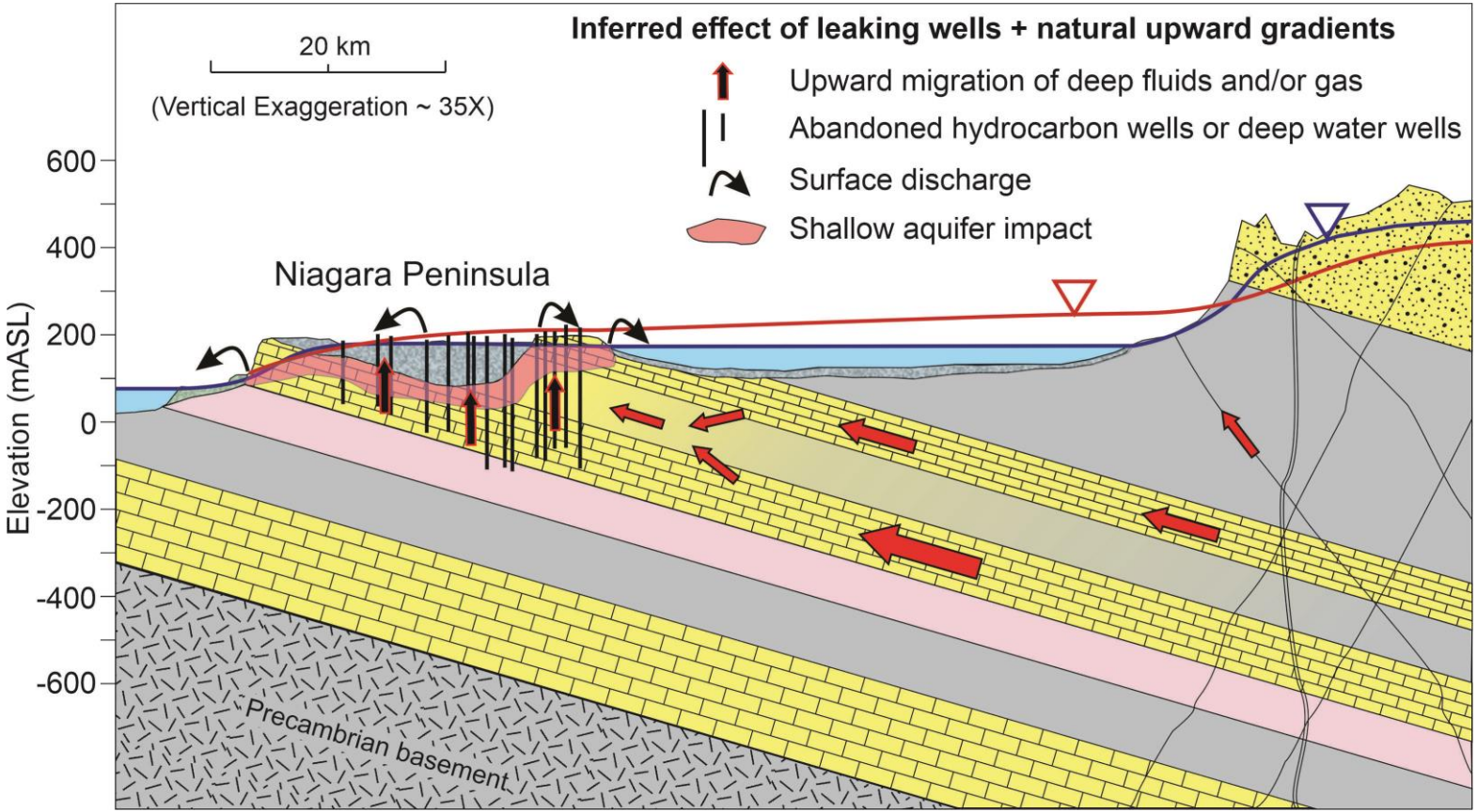
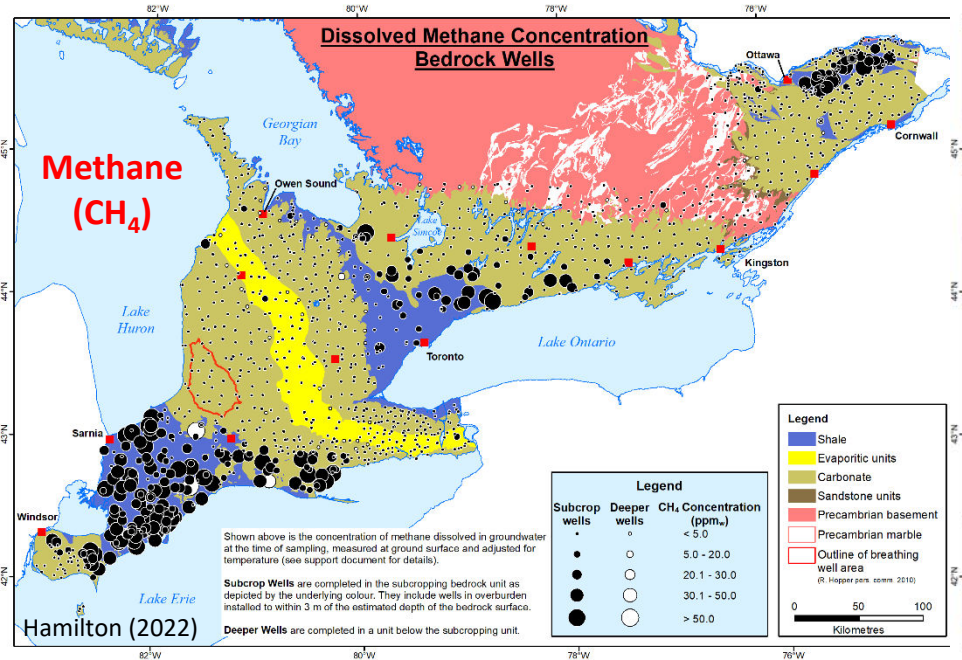
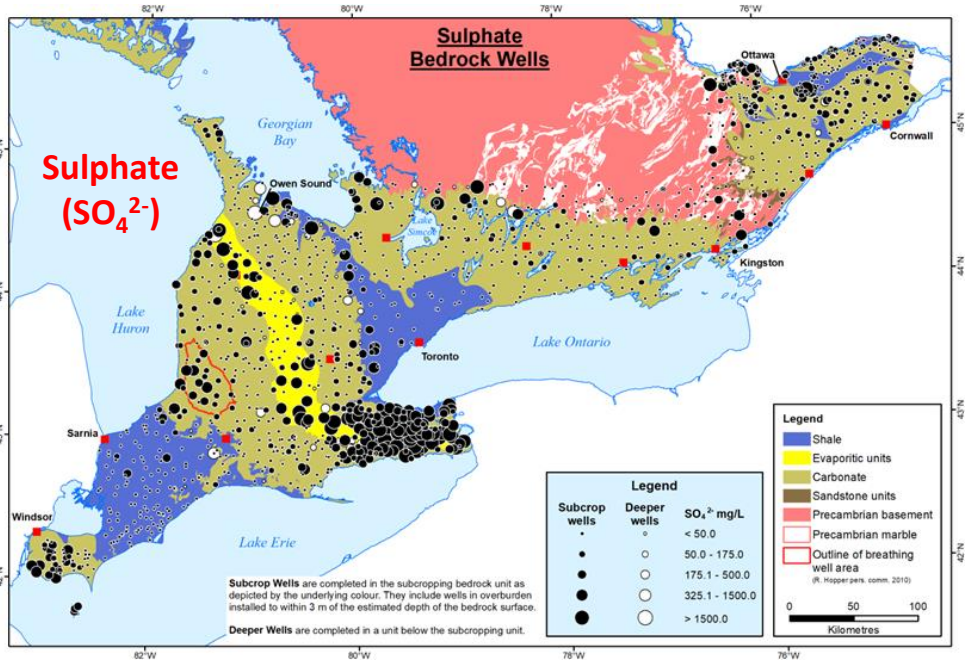


Gas + Sulphate = H_2S

- Naturally occurring hydrogen sulphide (H_2S) is widespread in Ontario groundwater with more than half of all drilled wells having water with at least some H_2S.
- But it can also be related to human drilling activities and infrastructure that either directly release deep H_2S ('sulphur water', sour gas) or more commonly bringing together <u>two incompatible materials</u> that react to generate H_2S as a biproduct

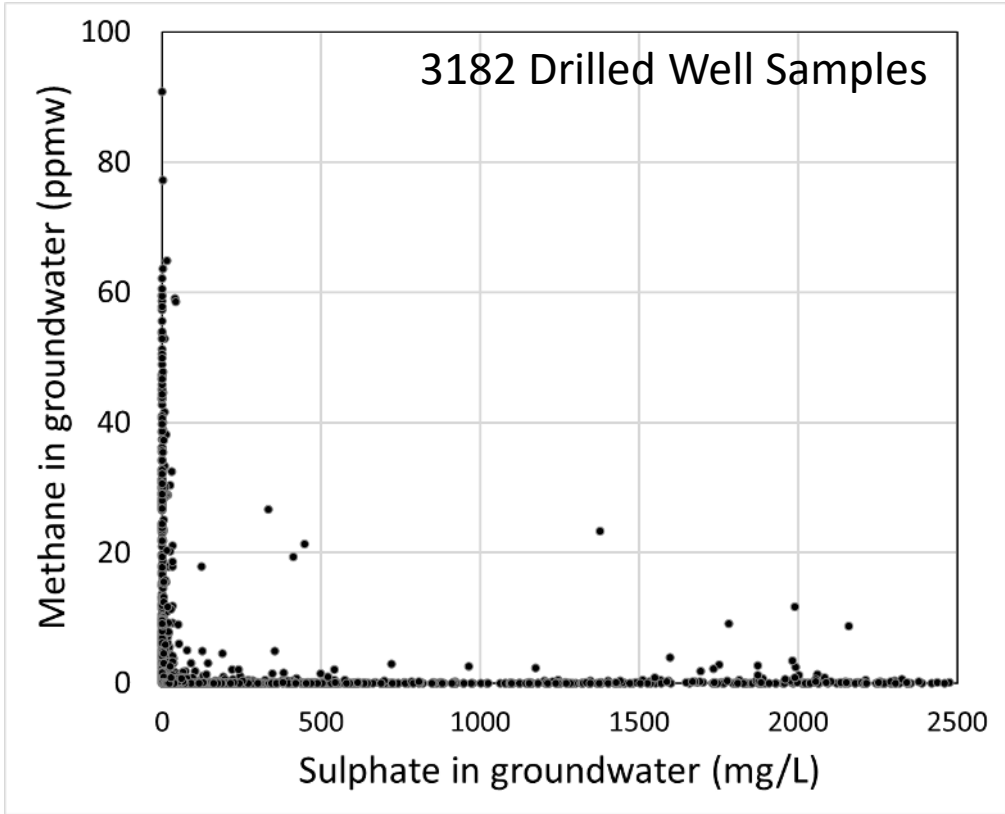


Hamilton (2022)



Origin of Hydrogen Sulphide – $CH_4 + SO_4^{2-}$

- As expected, most samples have either SO_4^{2-} or CH_4 but not both



Data from Hamilton (2022)

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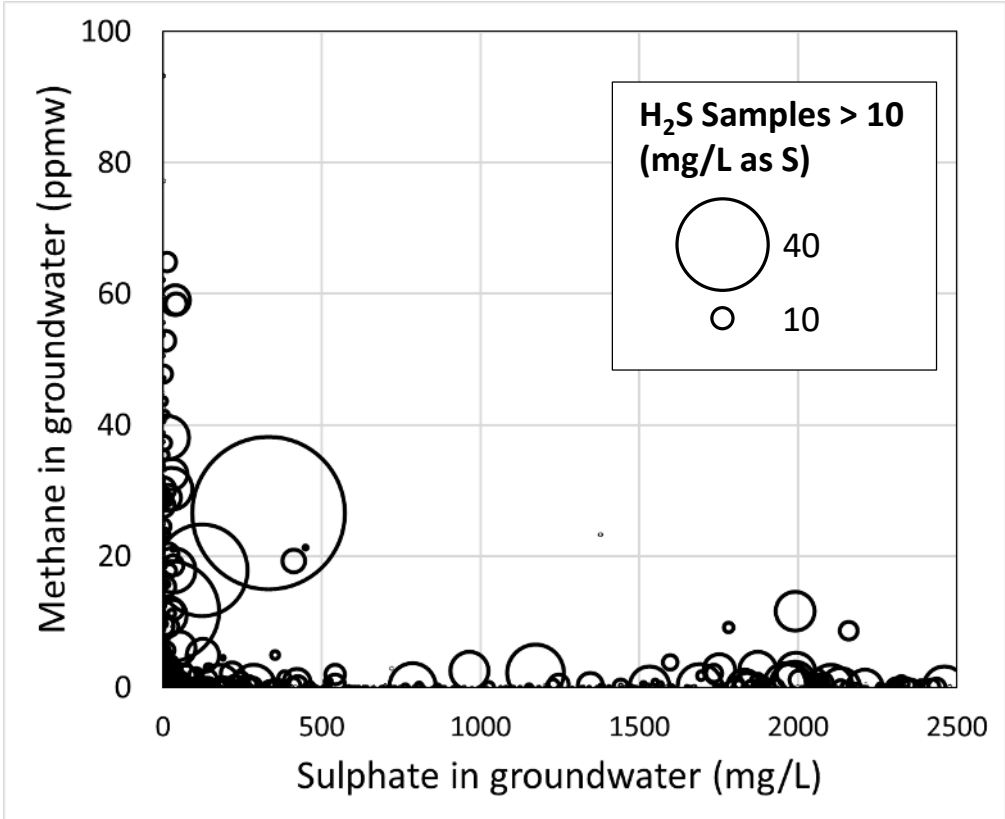

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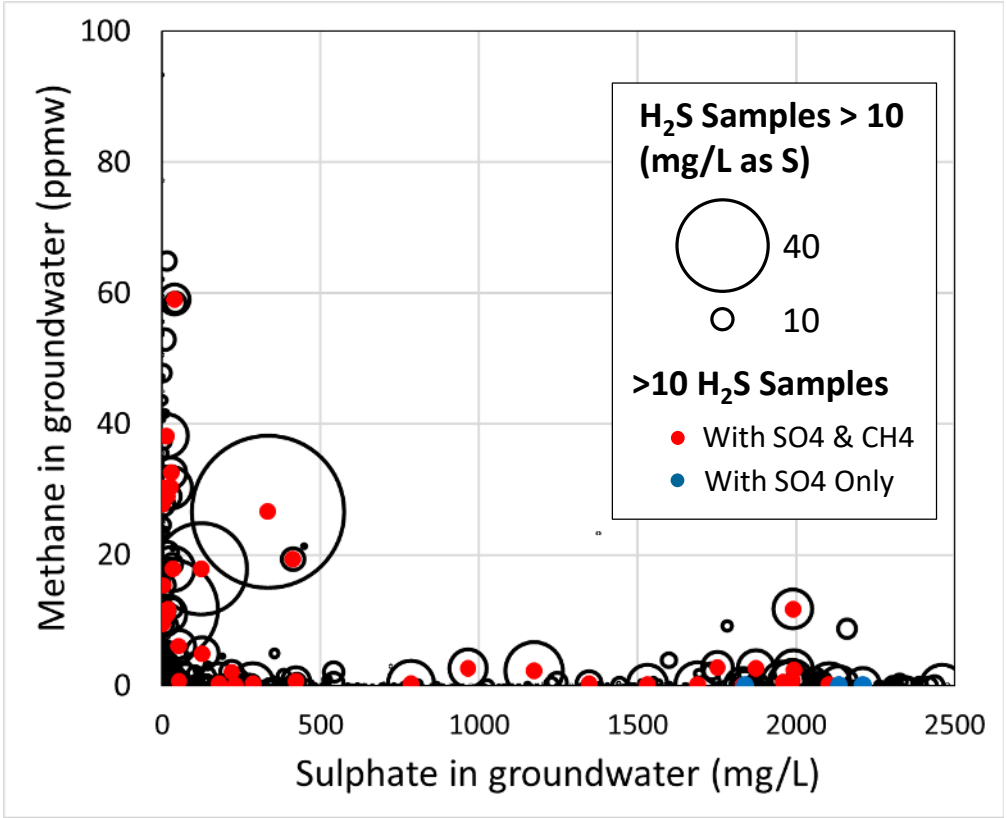
- The highest H_2S samples are approaching the origin because they are trending toward zero on one or both axes
- Only 3 of 41 with >10 mg/L H_2S, have no methane (shown in blue)



Data from Hamilton (2022)

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Hydrogen Sulphide – sour gas

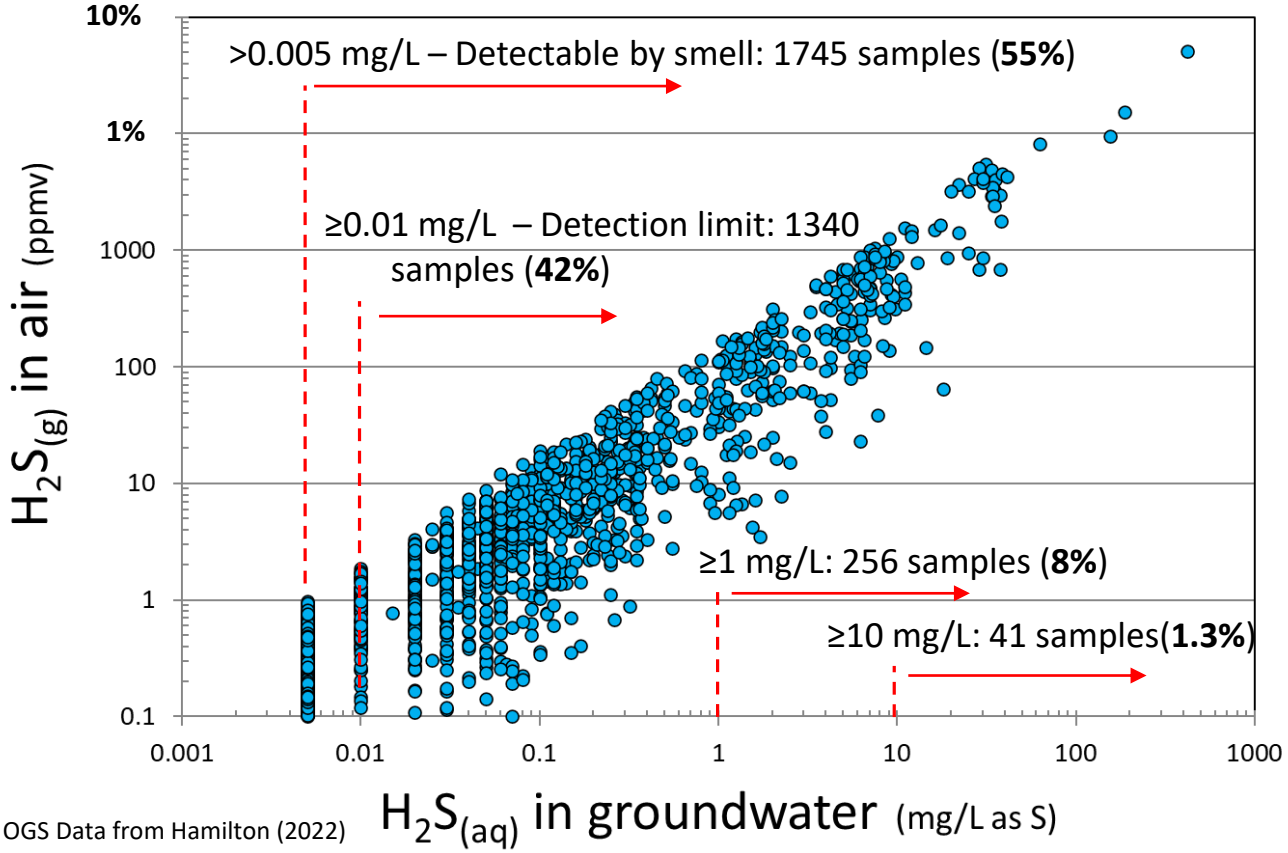
- Sour gas is natural gas that contains hydrogen sulphide
- In Alberta H_2S in sour gas can exceed 70%; in Ontario it rarely exceeds 2% but this is still far above the instantly lethal concentration of 1000 ppmv (0.1%)
- Fortunately, it is comparatively rare, except in far Southwestern Ontario in two geological units – the Guelph Formation and A1/A2 carbonates in Essex and Kent Counties (and offshore Lake Erie)
- According to the final reports that were just released, the hydrogen sulphide at Wheatley, where the explosion took place in 2021, was sour gas. In that case, H_2S was around 4000 ppmv.

Biogenic Hydrogen Sulphide

- In groundwater, this reaction is always microbially mediated, yielding biogenic H_2S.
- CH_4 and SO_4^{2-} do not coexist naturally because the reaction is fast (weeks to months) consuming one or both the reactants, resulting in:
  1. H_2S & CH_4 with no SO_4^{2-}
  2. H_2S & SO_4^{2-} with no CH_4
- When SO_4^{2-} & CH_4 are found together in groundwater, it often indicates non-natural processes adding:
  - $CH_{4(g)}$ into a SO_4- rich aquifer
  - SO_4^{2-} (fluid) into a CH_4- rich aquifer

Sulphur *oxidizing* bacteria (sulphur reducing bacteria doesn't photograph well)

Aqueous vs. Gas-Phase H_2S



- OGS data: 3182 Drilled well samples with non-null H_2S data
- By Henry's Law, the concentration of a dissolved gas in a closed system is directly proportional to concentration in the gas phase (if present)

OGS Data from Hamilton (2022)

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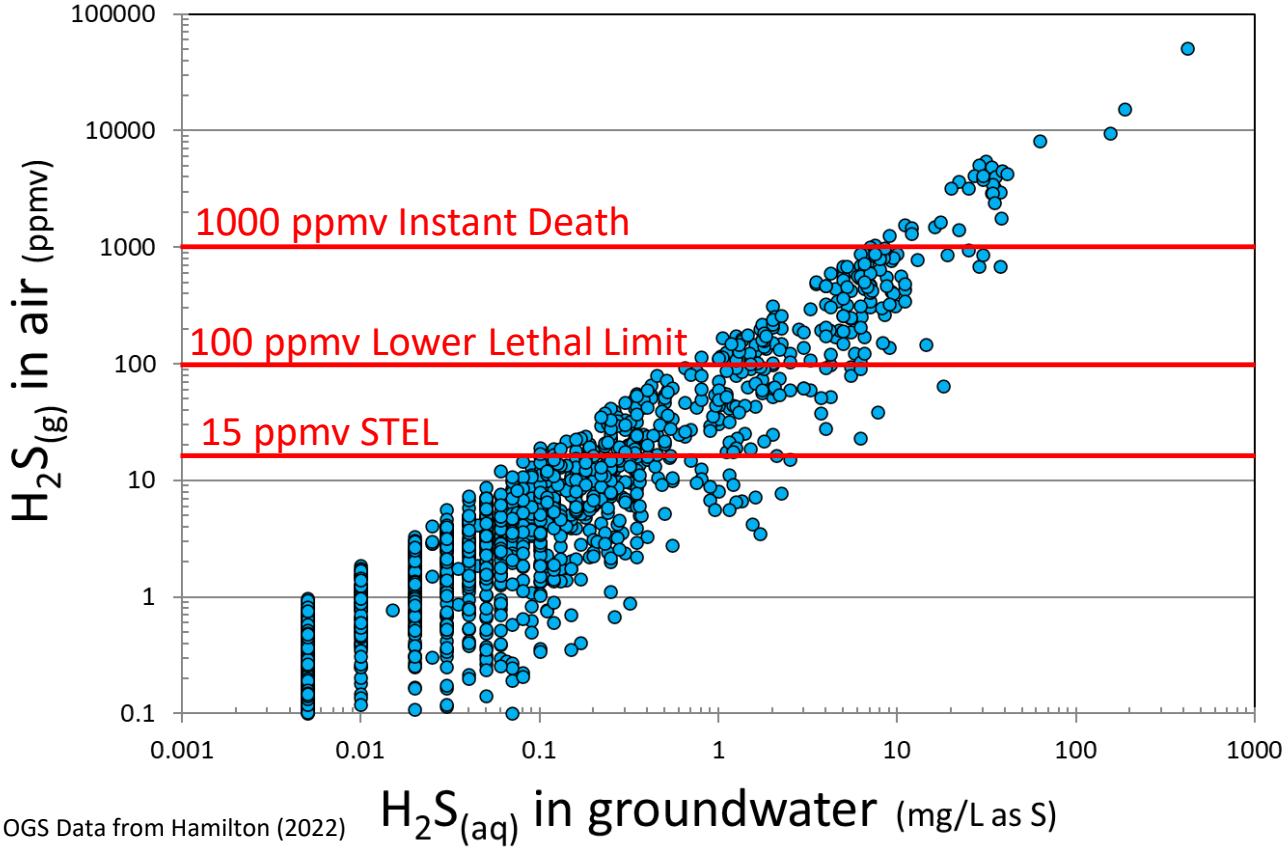
Aqueous vs. Gas-Phase H_2S
Potential Gas Concentrations in Context



- About ¼ of all groundwaters tested by the OGS could produce gas above the short-term exposure limit (STEL) of 15 ppmv
- About 1% of groundwater, under specific circumstances, could produce gas concentration > 1000 ppmV

OGS Data from Hamilton (2022)

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Aeration to Remove H_2S Can Be Extremely Dangerous

H_2S Removal Systems in Groundwater

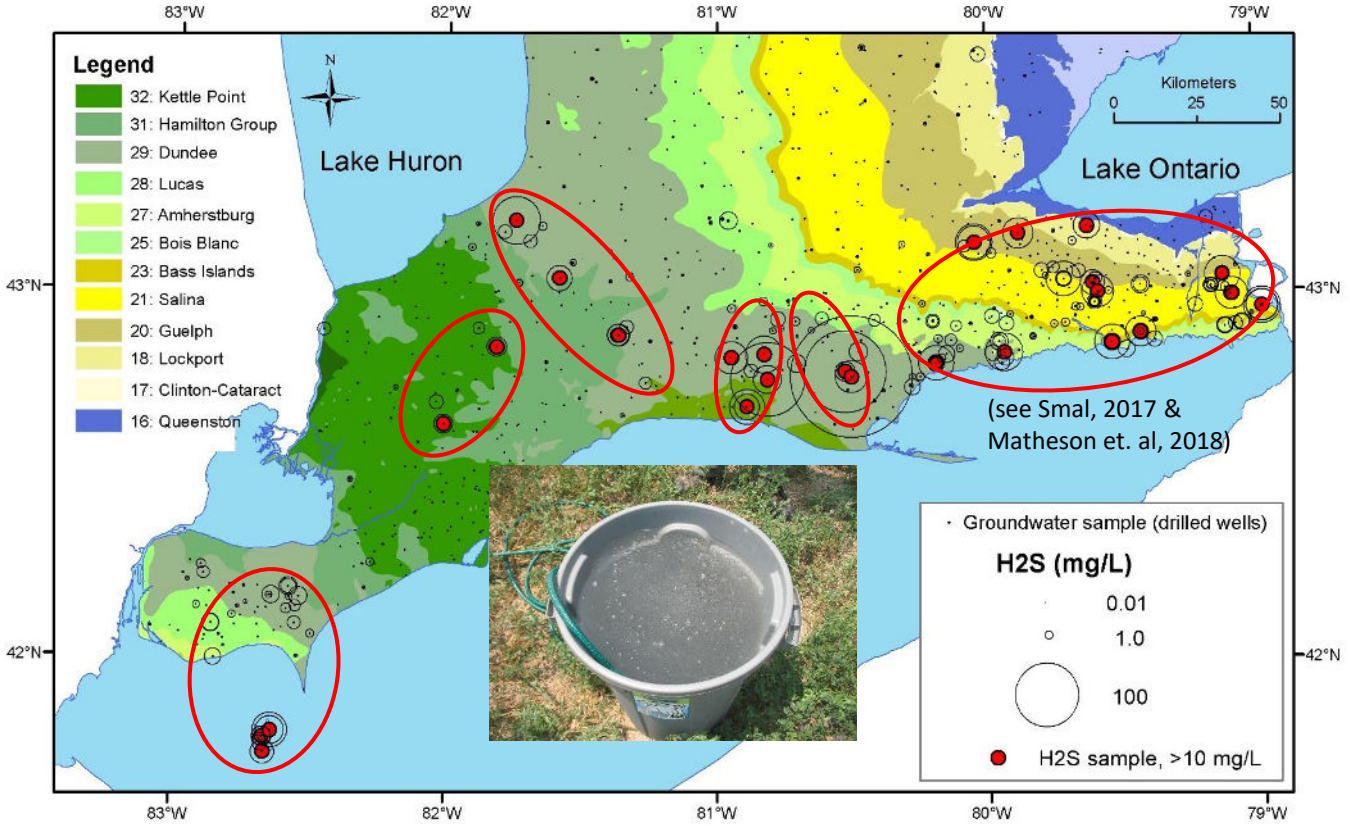
Isotopic domains of H_2S – rich groundwater

Not related to gas wells

- Kettle Point, – near surface SO4 into methaniferous groundwater <u>natural</u>
- Ipperwash trough – Lucas SO4 mixing in <u>water wells</u> with methaniferous groundwater

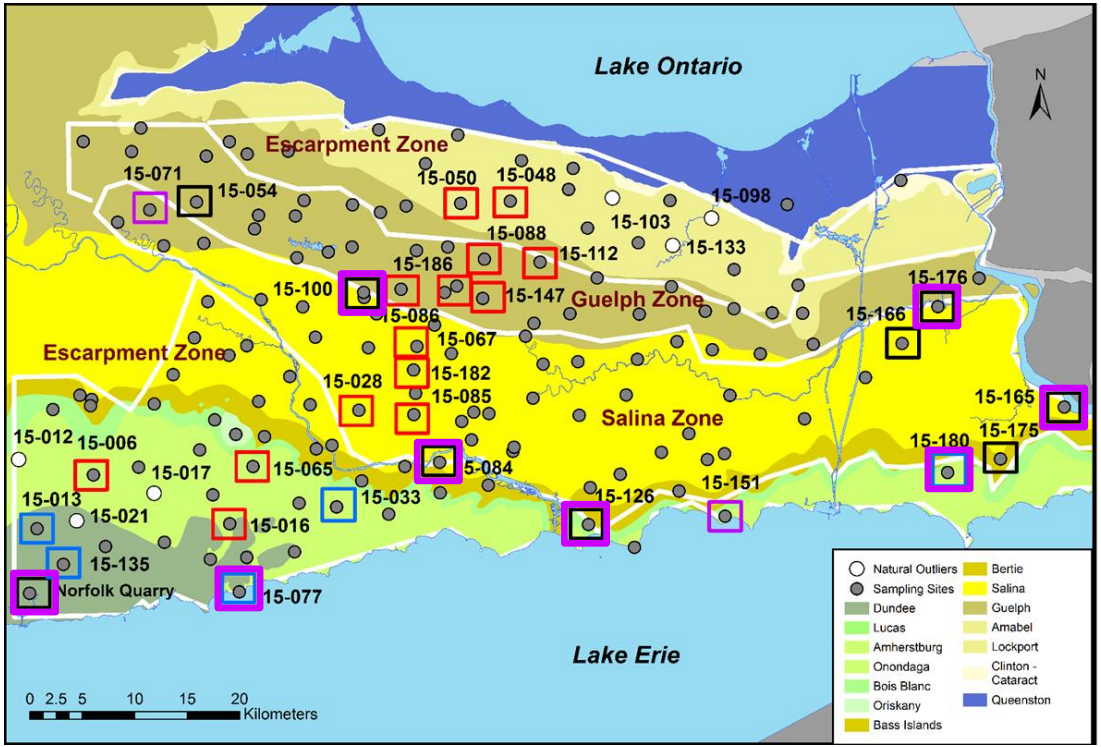
Likely gas-well related:

- Leamington-Pelee Island, deep fluids + deep gas
- Norfolk Sand Plain, incised valleys – SO4 from intermediate strata + deep thermogenic gas
- Niagara Peninsula: deep/shallow SO4-rich fluids; deep/shallow gas



From Hamilton (2023)

Results of Smal, 2017 Study (MSc, McMaster)



Exogenic sulfate Biogenic CH_4 Thermogenic CH_4

Sulfate reduction: unknown carbon source CH_4 carbon source

From Smal, 2017

- Isotopic data for sulphur isotopes & carbon in methane were collected along with the usual comprehensive suite of Ambient Groundwater parameters

The results show two major trends:

- An "exogenic" sulphate trend with very high SO4 that is strangely depleted sulphate ($\delta^{34}S_{SO4}$ = -5 to +10‰ VCDT)
- Evidence of sulphate reduction by either and both biogenic and thermogenic methane

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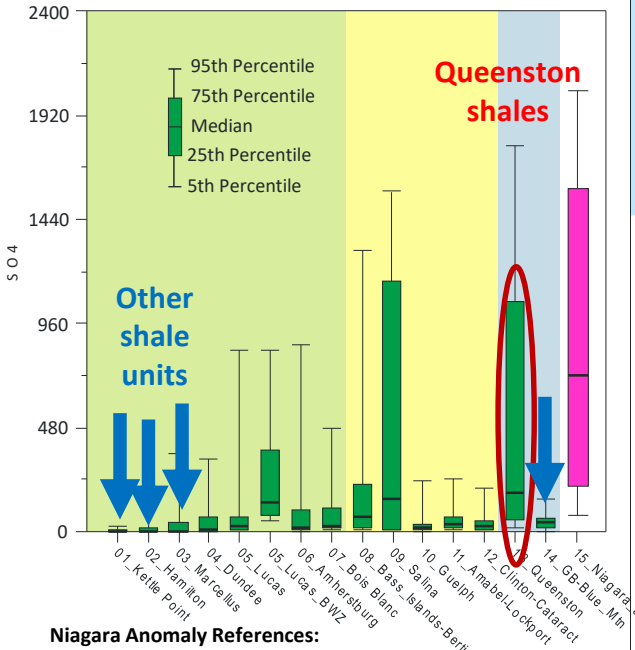
SO_4^{2-} Sulphate in well water

(mg/L)

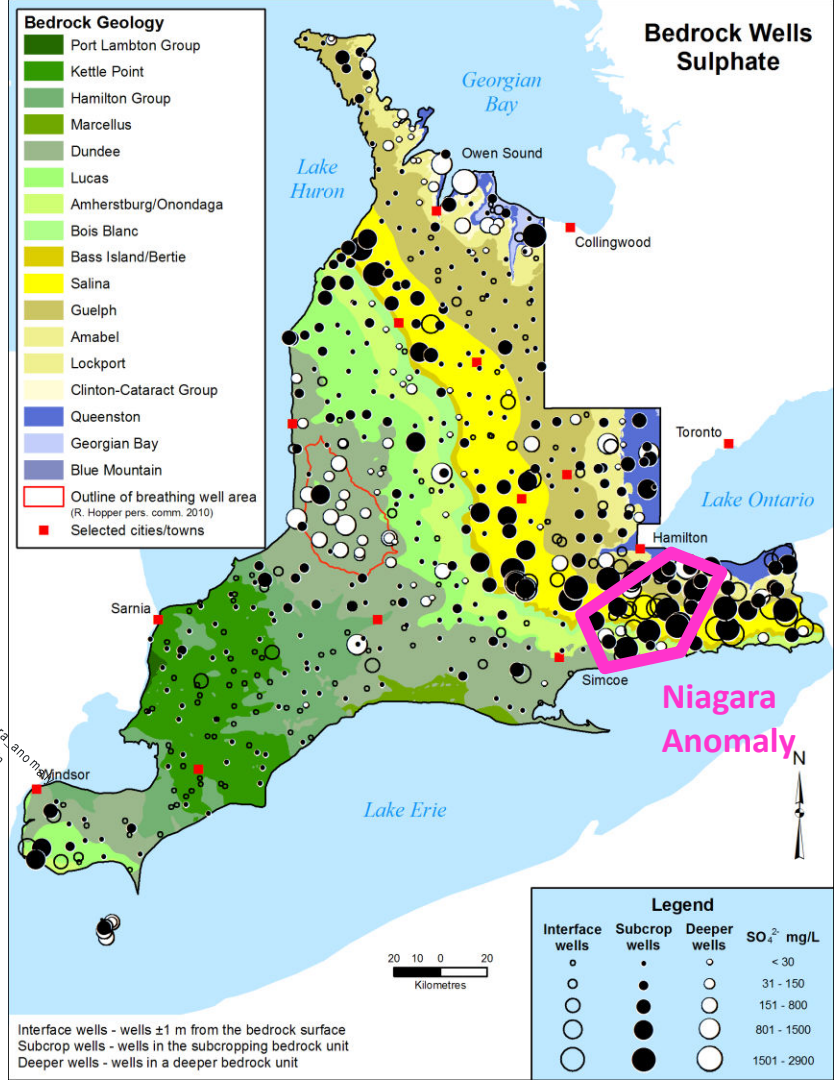


Niagara Anomaly References:

Matheson,E.J.2012.Analysis of the anomalous groundwater geochemistry of the Niagara Peninsula, Canada. B.Sc. thesis, Queen's University, Kingston, Ontario.

Smal (2017). Natural and anthropogenic sources controlling regional groundwater geochemistry on the Niagara Peninsula. McMaster University, M.Sc. thesis.

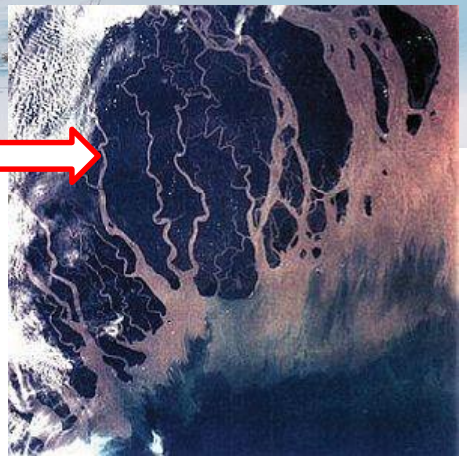
Matheson,E.J , Hamilton, S.M. and Kyser, K.., 2018. Shallow groundwater salinization of the Niagara Peninsula, Ontario, Canada, Geochemistry: Exploration, Environment, Analysis, 18, 155-174



Terrestrial Evaporites

Queenston Formation, Niagara Peninsula

White Sands, New Mexico



Ganges – Brahmaputra Delta

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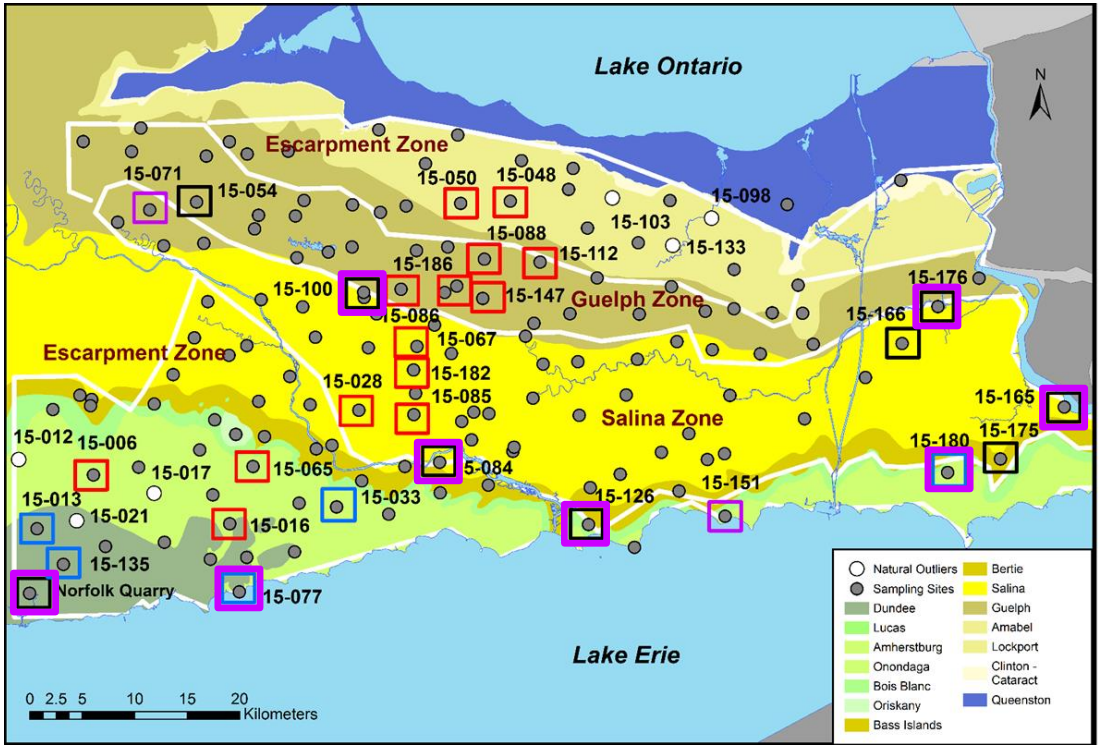

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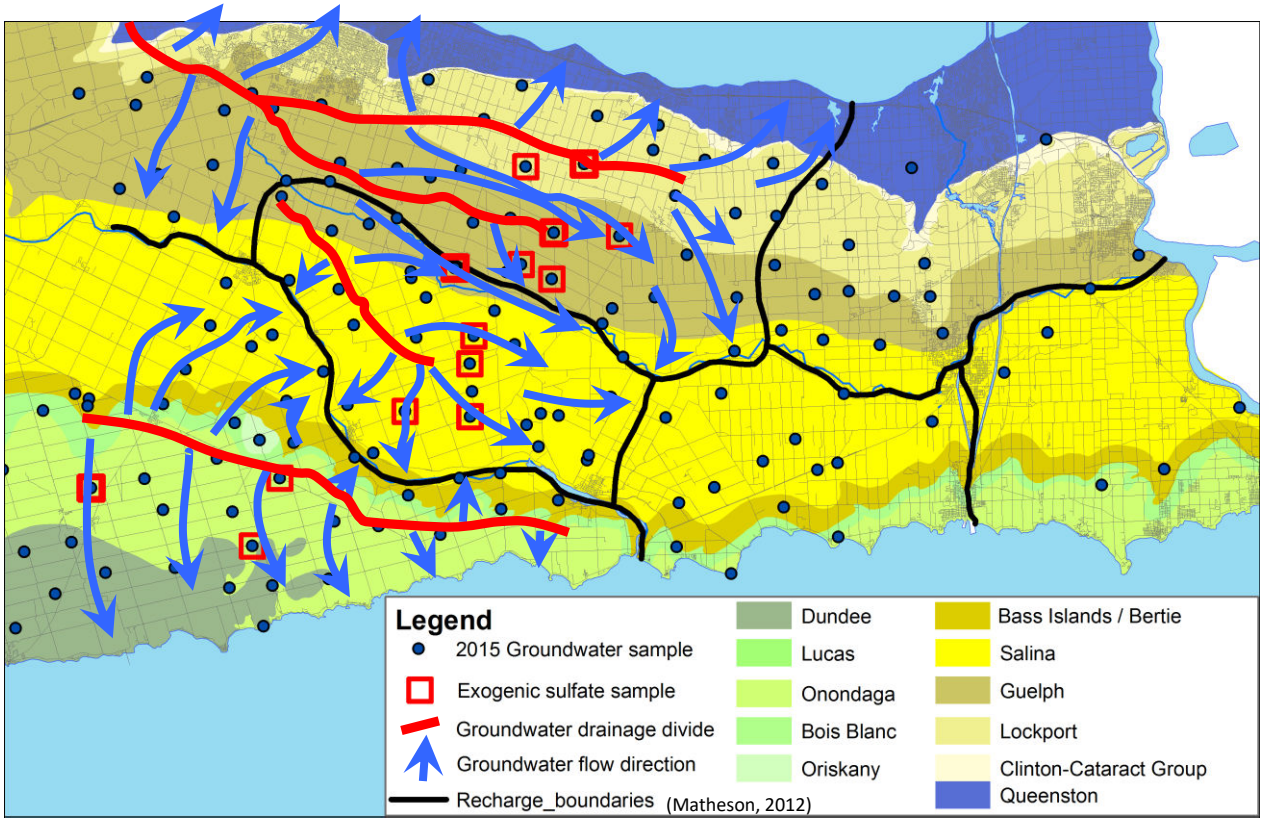
Groundwater flow from Matheson, 2012 Study (B.Sc. Queens)



From Smal, 2017 & Matheson, 2012

- Anomalous trend in exogenic sulphate crosses multiple groundwater flow systems
- Downstream impact is reduced or minimal relative to core of anomaly, therefore impact is modern and likely to be anthropogenic

Ontario's Oil & Gas Legacy

1. Ontario has arguably the oldest oil and gas industry in the World, with the first oil well installed in 1858, one year before the famed "first oil well" was drilled in Pennsylvania
2. For the next 50 years or so, best drilling practices could not have been followed because they had not been developed yet
3. Drilling practices improved after that, but it would decades more before adequate decommissioning practices were widely followed anywhere, including Ontario
4. Therefore, the serious groundwater problems related to legacy gas wells in southwestern Ontario are nobody's 'fault'
5. It also important to first realize our industry is tiny compared with some jurisdictions – Alberta, for example, has 450,000 recorded wells to our 27,000 …

Concluding Thoughts

1. When I started at Matrix, I was very surprised to hear that over several decades Matrix has worked on tens of thousands of well abandonments in Western Canada
2. When one considers that Alberta decommissions ~3000 wells per year and that one company alone has supported 10s of thousands it put the, admittedly very serious problems in Ontario into perspective
3. There are 27,000 wells on the books but only a small fraction of those will be problematic and we know, regionally, where they are – I have worked in all 3 of the main problem areas in the time that I've been at Matrix.
4. With proper prioritization and ranking of the problem wells, there is every chance we could get a handle on this issue in the not-too-distant future.