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Hydrocarbons & other gases in crystalline bedrock

Why are they important to consider?

- Presence of hydrocarbons & H_2 can affect redox conditions and microbial activity

- High gas pressures and significant rises in borehole fluids (e.g. Kola deep) are often observed in deep drilling projects; several accidents and sampling difficulties have been reported

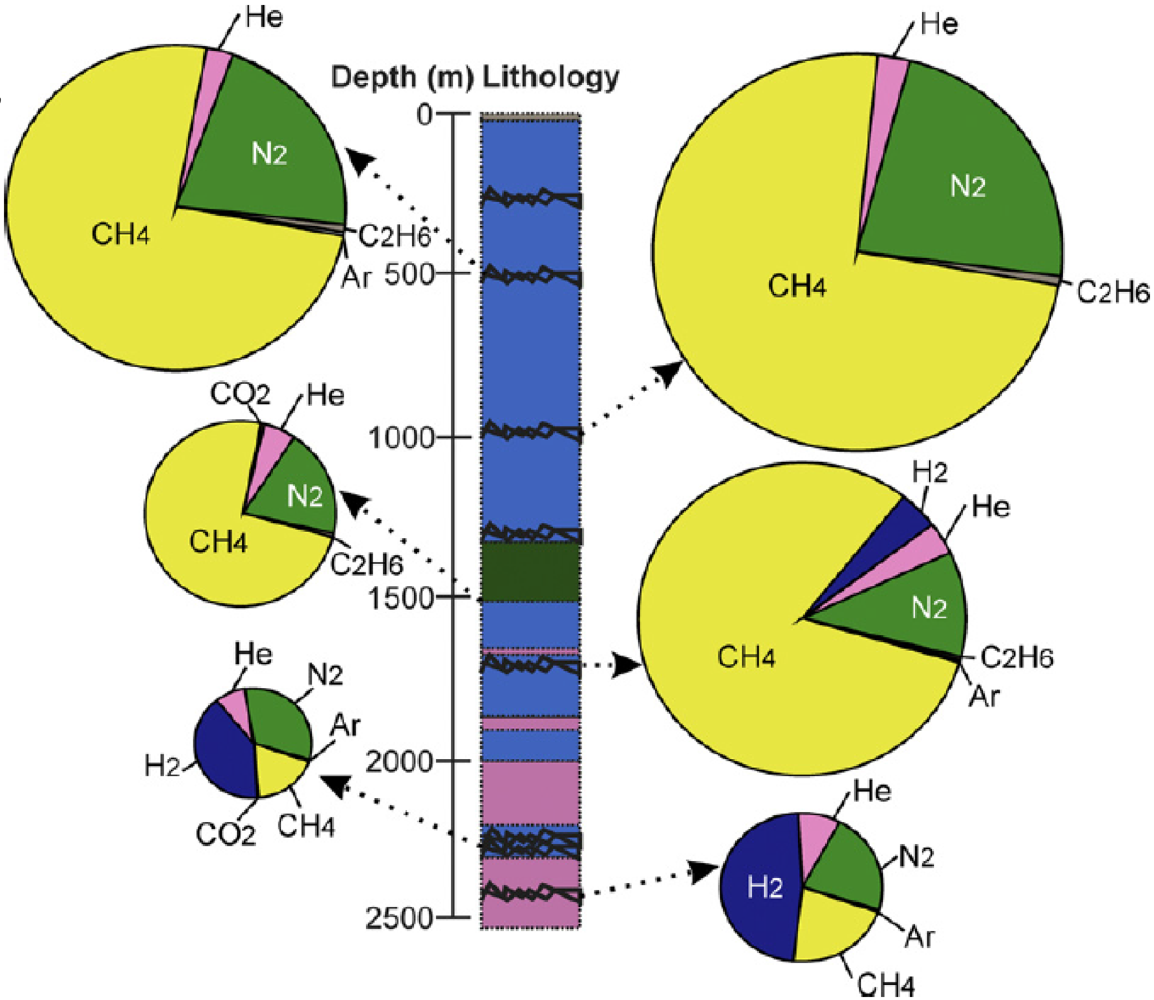
Hydrocarbons & other gases in crystalline bedrock

What's known about 'gases' in deep boreholes?

- Most saline fluids are associated with substantial quantities of CH_4 (dominant), C_{2+}, H_2, N_2, and noble gases; minor amounts of CO_2

- *Kola deep borehole (Russia)*
  - 1-4.5km: CH_4, N_2, H_2
  - >4.5 km: H_2, He, CO_2

Outokumpu Deep Drill Hole (Finland)



Kietäväinen et al. (2013)

Hydrocarbons & other gases in crystalline bedrock

Origin of natural gas?

- Often a mix of abiotic and biogenic gas - Canadian & Fennoscandian Shield, S. Africa craton
- Also evidence of thermogenic gas in some sites (e.g. Canadian Shield)
- In some cases, natural gas may have migrated from source rocks and reservoirs in overlying sedimentary formations into PreCambrian basement rocks (e.g. NE Kansas)

Tracers of gas origin?

- Gas composition and stable isotopes (e.g. $\delta^{13}C\text{-}CH_4$, $\delta D\text{-}CH_4$, $\delta^{13}C\text{-}C_{2+}$) are often used to distinguish between biogenic, thermogenic, and abiotic gases; however, isotopic signatures are often convoluted to interpret and affected by other processes, such as mixing, migration, and oxidation
- Noble gases - help identify crustal vs. mantle and atmospheric gases
- New clumped isotope methods are promising for distinguishing gas sources

Microbial activity in crystalline bedrock

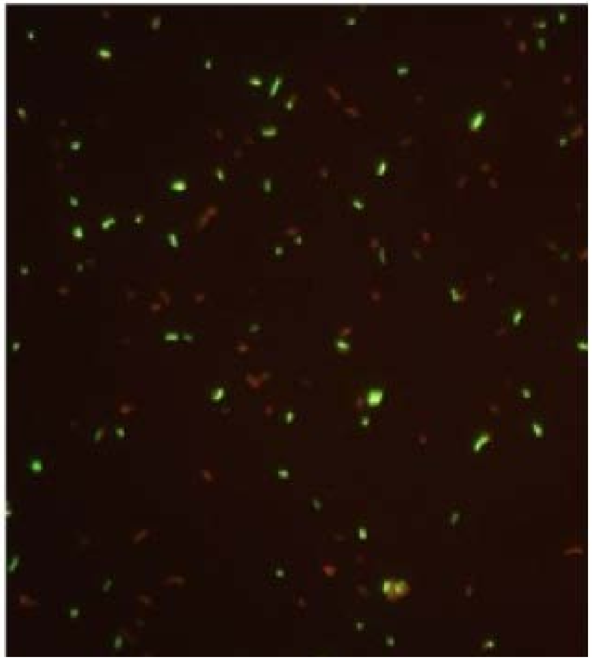
Why is it important to consider?

- Increased microbial activity may alter pH and redox conditions, which can affect solubility (i.e. corrosion) of waste containers and transport of radionuclides

- Increased microbial activity can also lead to biofilm growth and clogging of pore spaces

- Drilling activities and downhole instrumentation/sampling may introduce non-native microbial populations, carbon sources (e.g. CH_4) and electron acceptors (e.g. SO_4)

Outokumpu native microbes enhanced by addition of CH_4 & SO_4



Rajala et al. (2015)

Microbial activity in crystalline bedrock

What's known about 'deep' microbial life?

- Microbes are widespread in deep crustal environments
- Few locations found no microbial cells, but unclear if this was due to low cell densities, sampling issues, or actual lack of microbial activity
- Microbial population density similar to deep sedimentary basin environments & oligotrophic marine sediments

Site	Depth (mbs)	CH_4 (mM)	Methane-cycling microbes?
USA			
Homestake	1478	0.00037	YES
CANADA			
Lupin	1130	35	NO
FINLAND			
Hastholmen	985	0.009	NO
Kivetty	855	0.006	NO
Olkiluoto	960	41.4	YES
Outokumpu	2480	32.3	YES
Palmottu	417		NO
Romuvaara	566	0.003	NO
SWEDEN			
Aspo	860	1	YES
Forsmark	1002	0.21	YES
Laxemar	922	0.039	YES
SOUTH AFRICA			
Beatrix	1390	35.2	YES
Driefontein	3300	17.5	YES
Evander	2230	15.8	YES
Kloof	3400	29.8	NO
Mponeng	3300	20	YES

Modified from Kietavainen & Purkamo (2015)

Microbial activity in crystalline bedrock

What's known about 'deep' microbial life?

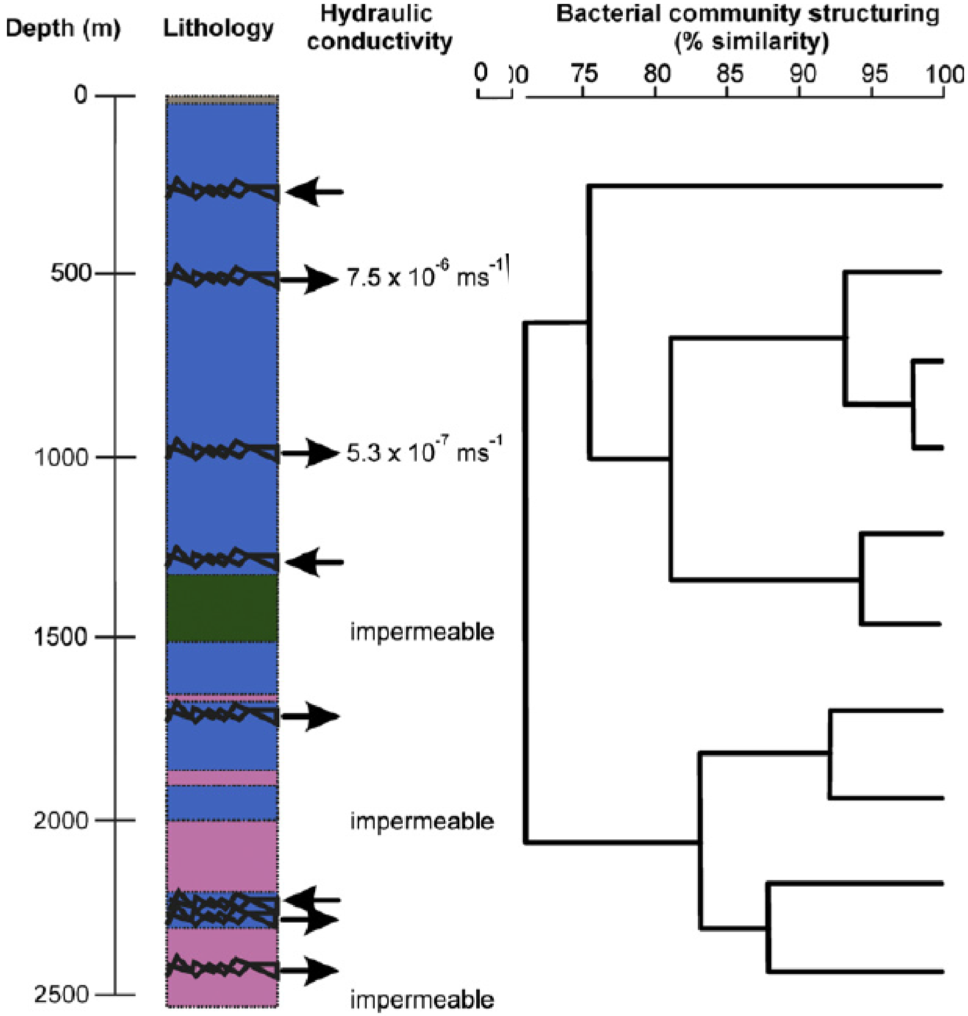
- Sulfate reducing bacteria and methanogenic archaea dominant
- Enough H_2 (up to 7.5 mM; similar concentration to hydrothermal vents at mid-ocean ridges), CH_4, higher chain hydrocarbons, & N_2 to support microbial activity
- High salinity doesn't seem to be an issue (halophilic bacteria); high temperatures (>~115^{o}C) likely limit life at depth

Microbial activity in crystalline bedrock

What's known about 'deep' microbial life?

- Microbial communities vary with depth/between different fracture zones, and are associated with ancient fluids, suggesting in some cases they've been isolated for millions to billions of years
- Microbes in borehole waters are different than fracture fluids

Outokumpu Deep Drill Hole (Finland)

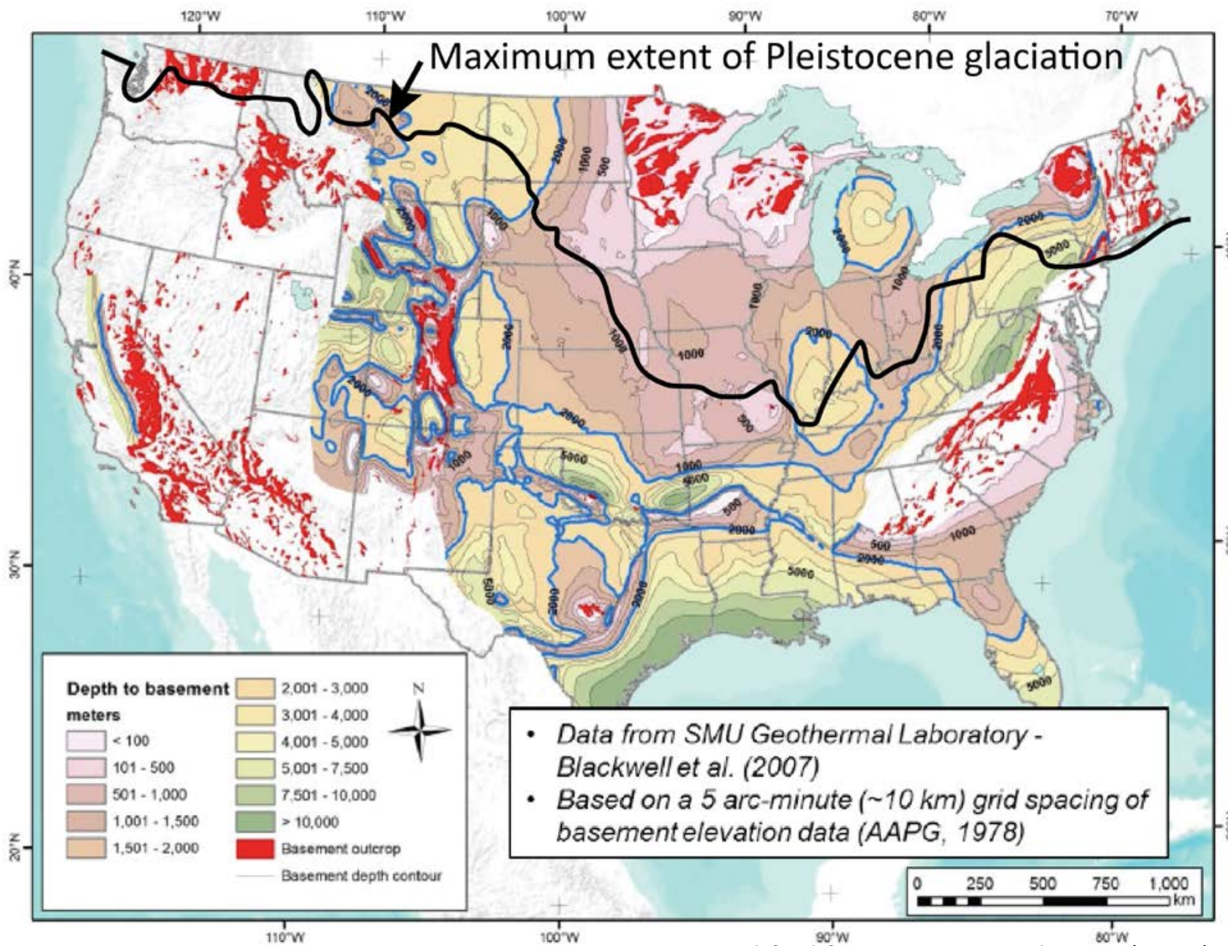


Modified from Kietäväinen et al. (2013)

Impacts of future glaciations?

Why is it important to consider?

- Many northern US areas with bedrock near surface was glaciated
- Next ice age expected within 100,000 to 200,000 years (although slightly delayed due to anthropogenic climate change)
- Multiple studies have shown continental glaciation altered subsurface hydrologic and geochemical conditions, fluid and solute transport (e.g. deep brine migration), and microbial activity

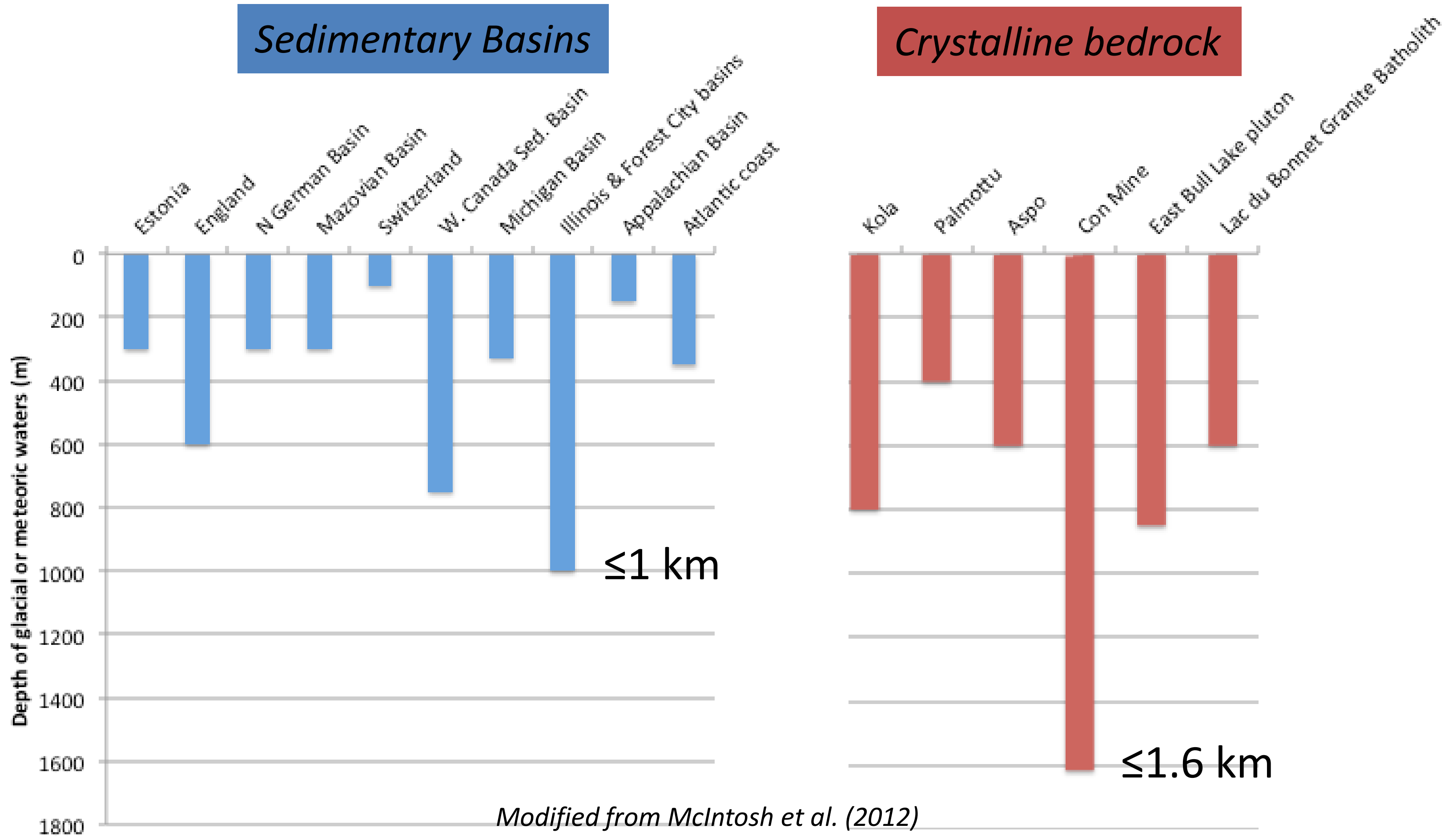


Modified from Sassani and Perry (2015)

Impacts of future glaciations?

What's known about glacial meltwater penetration?

- Common to find relatively dilute, isotopically depleted glacial meltwaters at depth (≤1.6 km) in crystalline bedrock and sedimentary basins in previously glaciated regions



Modified from McIntosh et al. (2012)