Dr. Jennifer McIntosh

Associate Professor

University of Arizona, Department of Hydrology & Water Resources
Why are they important to consider?

- Presence of hydrocarbons & H₂ 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 CH₄ (dominant), C₂⁺, H₂, N₂, and noble gases; minor amounts of CO₂

- **Kola deep borehole (Russia)**
  - 1-4.5 km: CH₄, N₂, H₂
  - >4.5 km: H₂, He, CO₂

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-CH$_4$, $\delta^D$-CH$_4$, $\delta^{13}$C-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
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$_4$*
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

<table>
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<tr>
<th>Site</th>
<th>Depth (mbs)</th>
<th>CH$_4$ (mM)</th>
<th>Methane-cycling microbes?</th>
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</table>

Modified from Kietavainen & Purkamo (2015)
What’s known about ‘deep’ microbial life?

- Sulfate reducing bacteria and methanogenic archaea dominant

- Enough H₂ (up to 7.5 mM; similar concentration to hydrothermal vents at mid-ocean ridges), CH₄, higher chain hydrocarbons, & N₂ to support microbial activity

- High salinity doesn’t seem to be an issue (halophilic bacteria); high temperatures (>~115°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.

*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)
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)