Elevated Uranium and Arsenic Concentrations in Baseline Water Quality at the Coffee Gold Project: Implications for Geochemical Predictions

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Overview

- Elevated metal(loid) concentrations are often observed in surface and groundwater surrounding mineral deposits
  - Investigating elevated metal concentrations in the baseline environment has the potential to inform the geochemical characterization of local bedrock

- This approach has been applied to the Coffee Gold Project, where elevated U and As observed in baseline water quality.

- The behaviour of these elements can be explained by using a combination of first principles and data collected as part of the geochemical characterization program

- This understanding of the geochemical baseline environment has a number of implications for source term predictions and mine waste management strategies.

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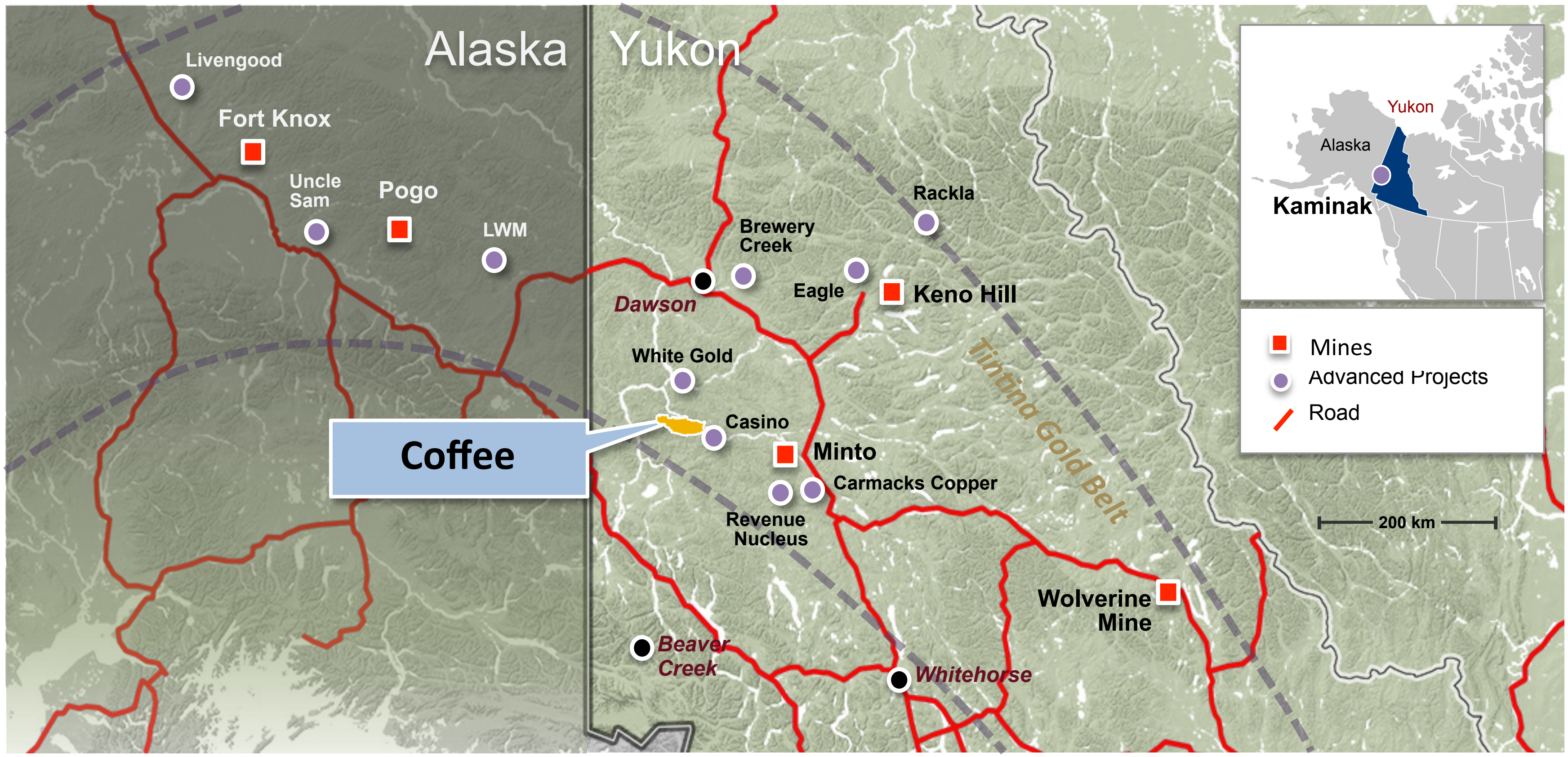
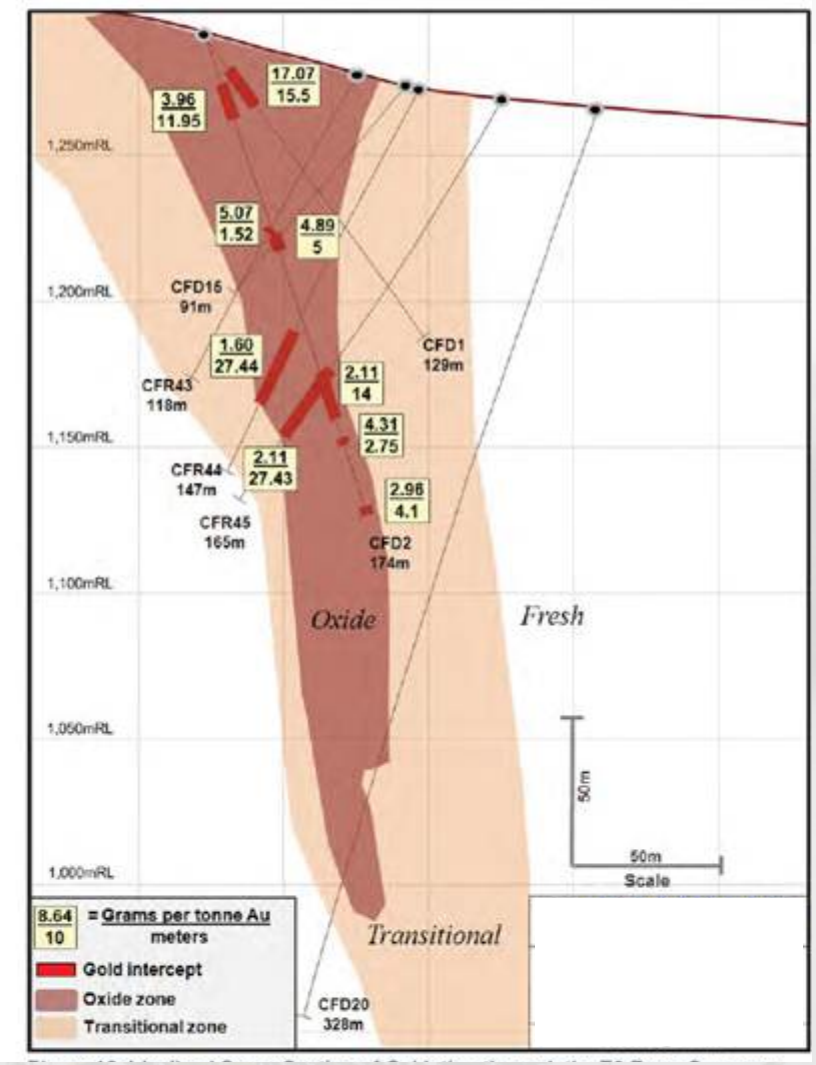
Coffee Gold Project: Location



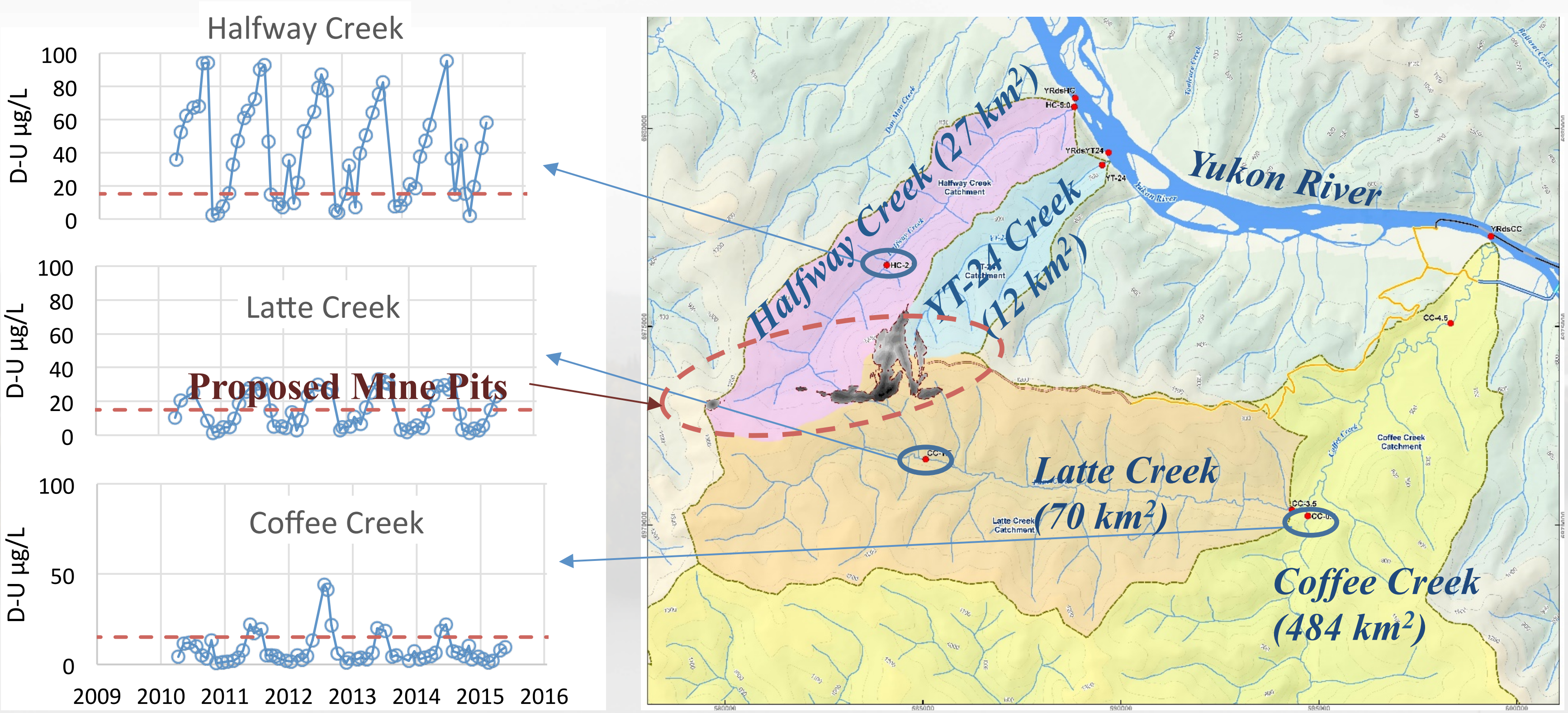
- Located 130 km south of Dawson in western Yukon
- The project is on the traditional territory of the Tr'ondëk Hwëch'in and the asserted territory of the White River First Nation.

Coffee Gold Project: Mineralization



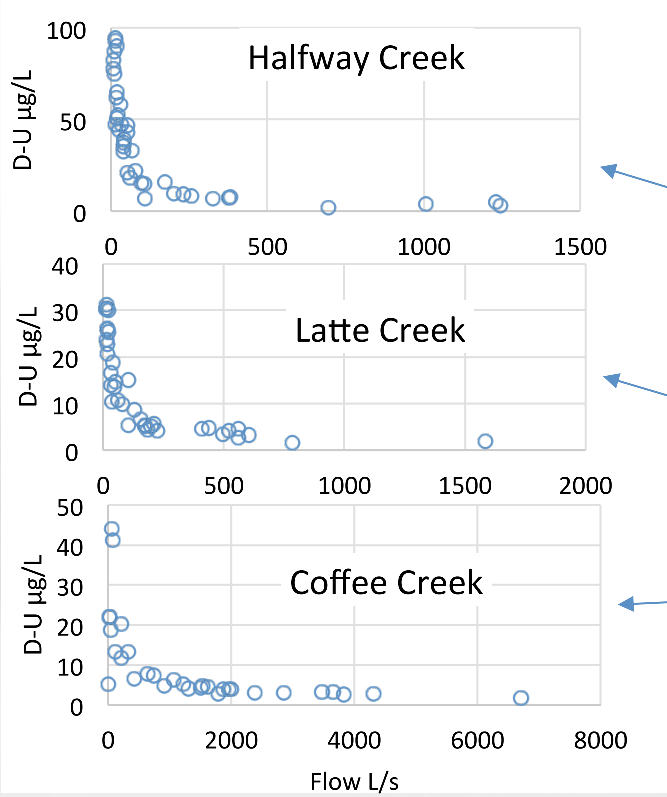
- Gold mineralization at the site is hydrothermal in origin and structurally controlled.
- Structural weaknesses associated with gold mineralization have allowed for extensive in-situ weathering and oxidation along near-vertical corridors. Weathering horizons include:
  - Oxide zone
  - Transition Zone
  - Fresh (unweathered) zone
- Gold bearing structures transect three distinct lithologies:
  - Gneiss
  - Schist
  - Granite

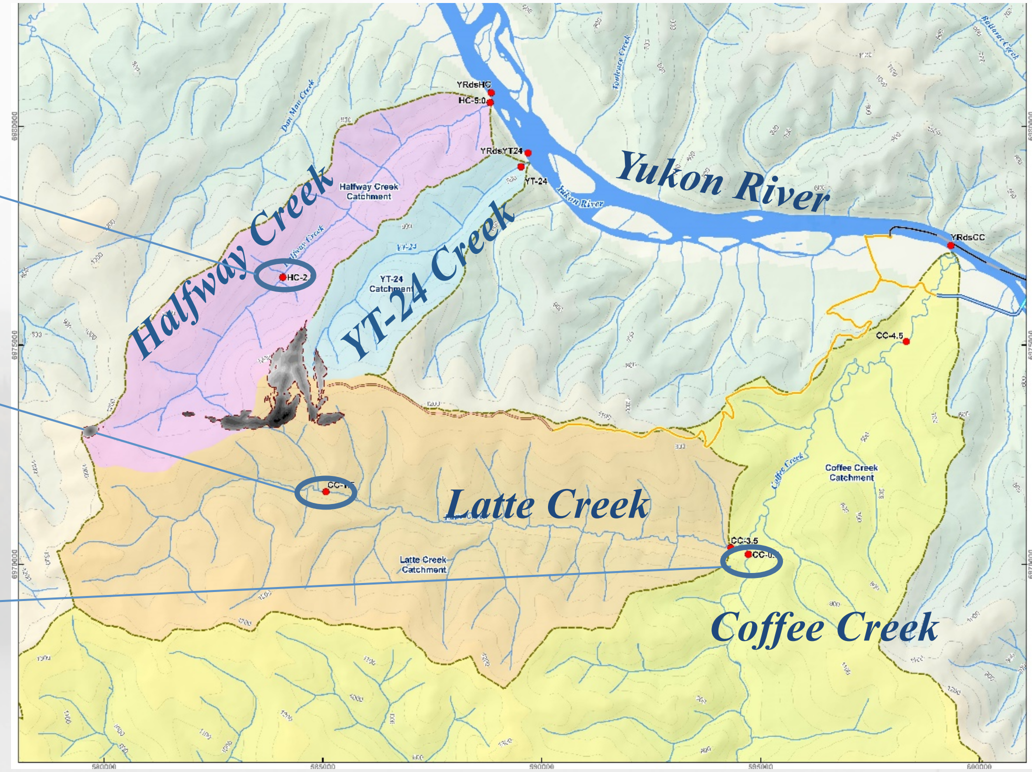
Surface Water Quality Monitoring: Uranium



- Naturally elevated uranium is observed in surface water
  - Typical surface water in Canada is between 1 and 3 µg/L
  - Site maxima range from ~30 to 100 µg/L
- Uranium concentrations are regionally elevated as shown by Coffee Creek
- Strong seasonality to U concentrations

Surface Water Quality Monitoring: Uranium

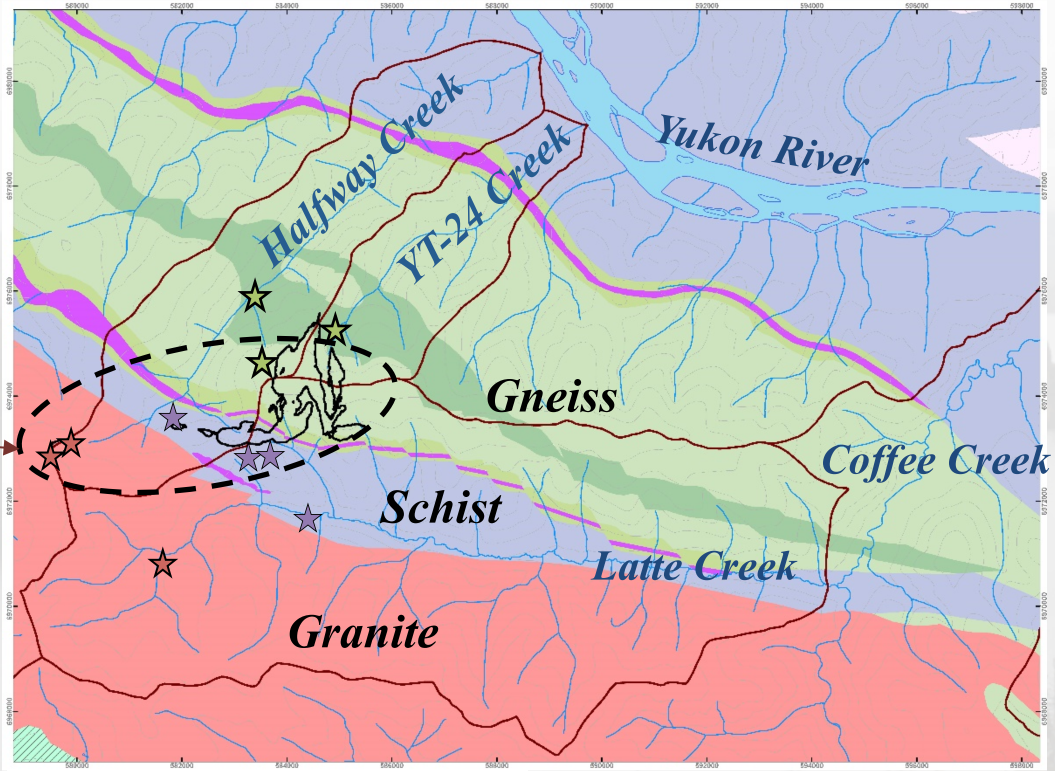




- Inverse relationship exists between flow and U concentration.
  - High flow conditions (freshet, high runoff); Surface water flow >>> groundwater discharge = low [U]
  - Low flow conditions (winter, low runoff); Surface water flow <<< groundwater discharge = high [U]
- Indicates that groundwater is the dominant source of U in these catchments

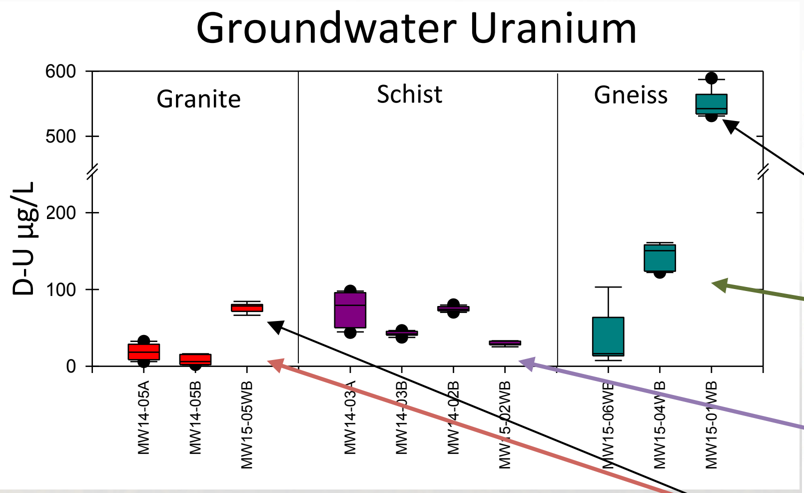
Groundwater Quality Monitoring: Uranium

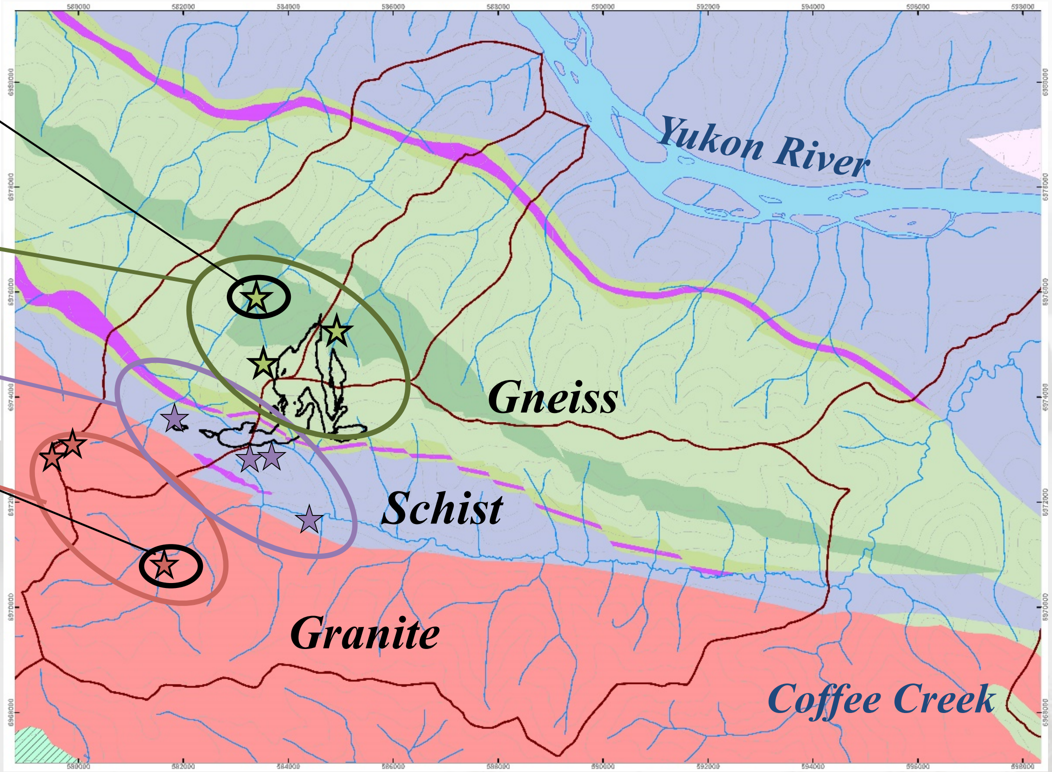
Proposed Mine Pits



☆ Groundwater Wells

Groundwater Quality Monitoring: Uranium

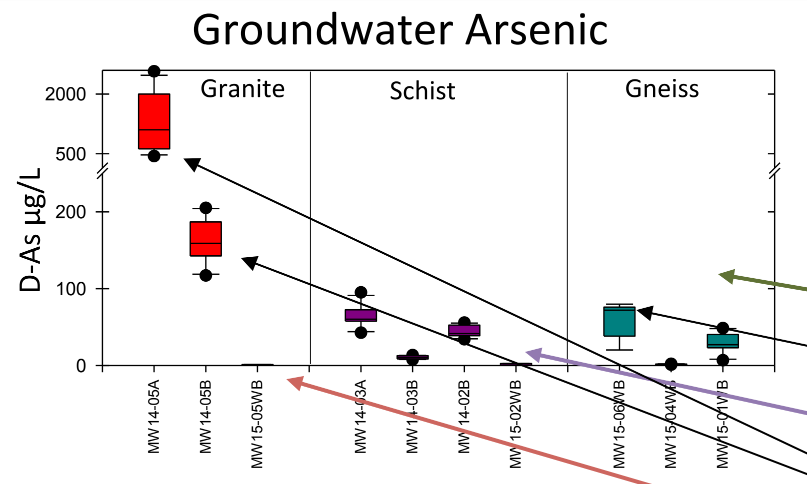


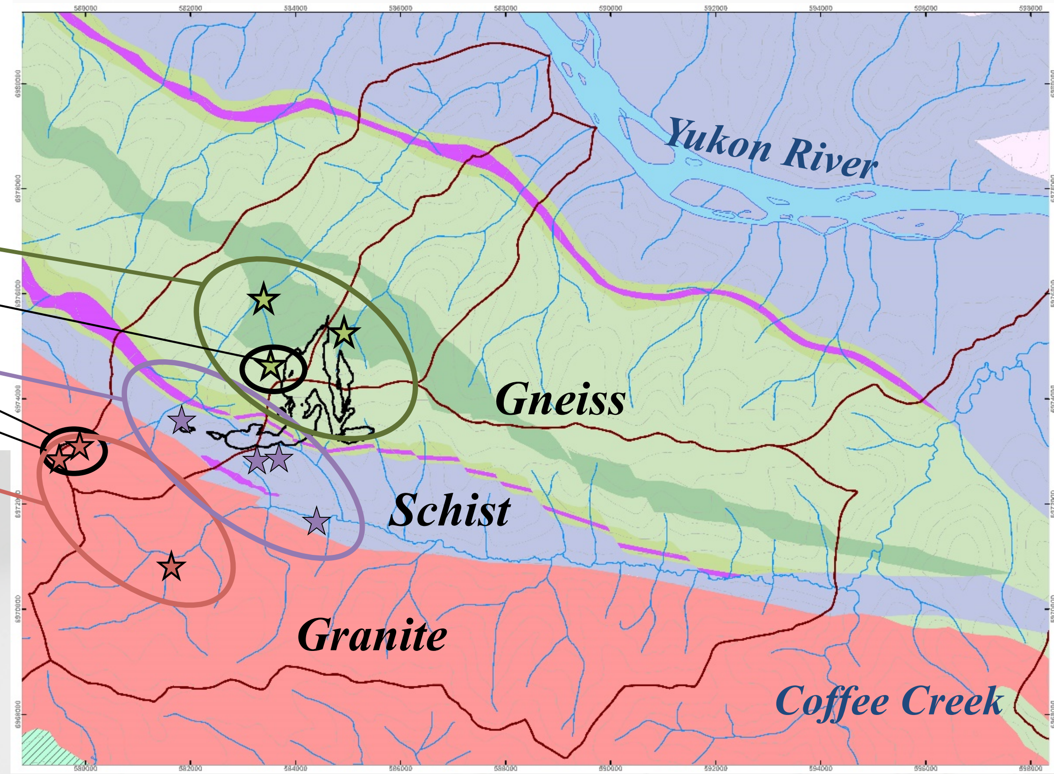


- Uranium elevated in all lithologies, with highest concentrations in gneiss wells
- Peak U concentrations are not adjacent to mineralization zones.

- Results are consistent with surface water data, which indicated that source of uranium is groundwater seepage

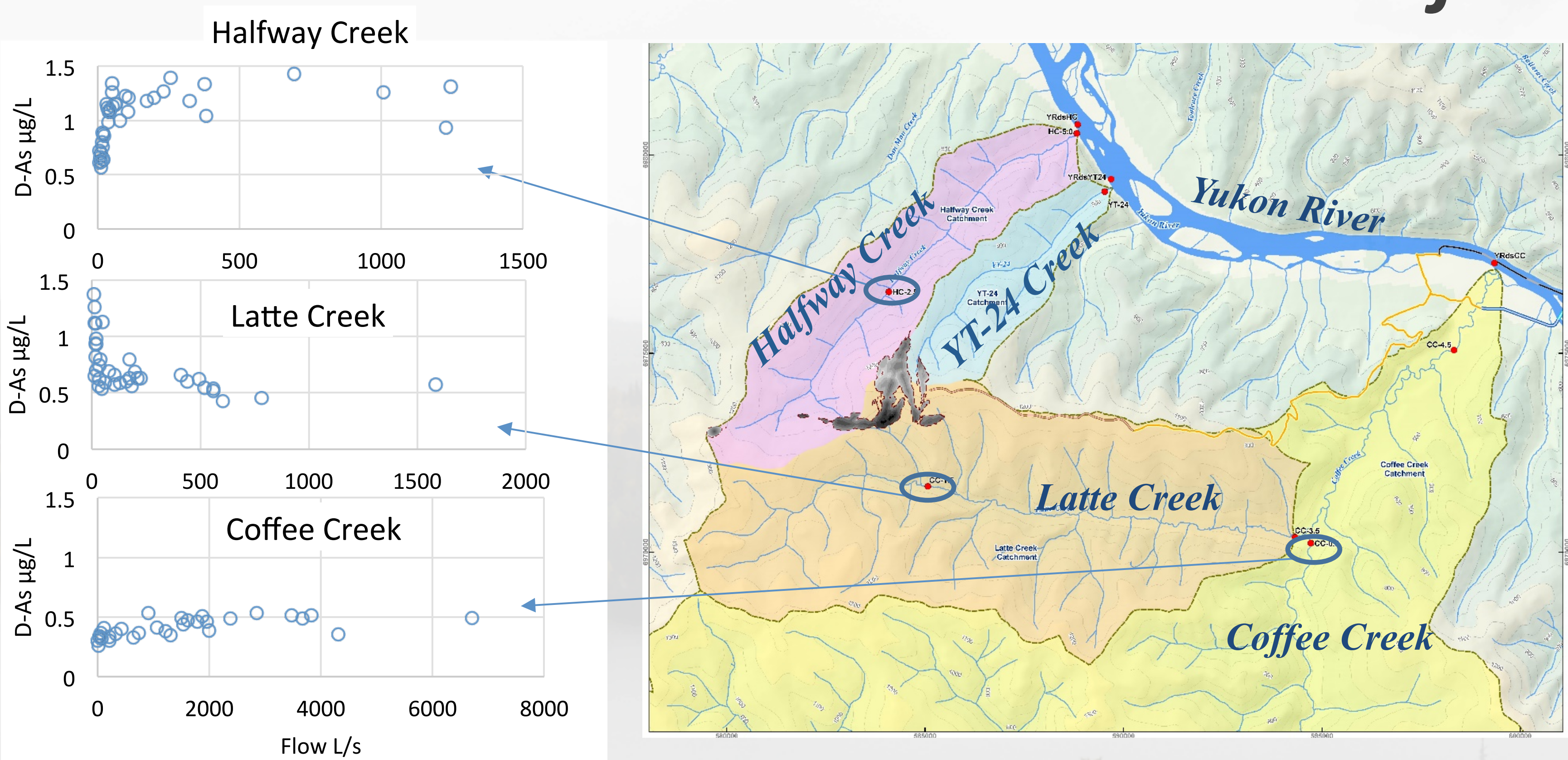
Groundwater Quality Monitoring: Arsenic





- Arsenic concentrations are also elevated in groundwater
  - Highest As concentrations observed in granite wells
  - In contrast to U, peak As concentrations tend to be adjacent to mineralization zones.

Arsenic concentration in relation to flow



- Elevated [As] in groundwater does not manifest as high [As] in surface water
- Seasonal signature of arsenic:
  - Halfway and Coffee Creeks show lowest concentrations during low flow
  - Latte Creek shows peak concentrations during low flow
- Data shows that As groundwater load is being attenuated.

Key Questions:

- **What processes lead to the mobilization of arsenic and uranium in groundwater?**
- **Why does uranium remain elevated in surface water while arsenic appears to be attenuated?**



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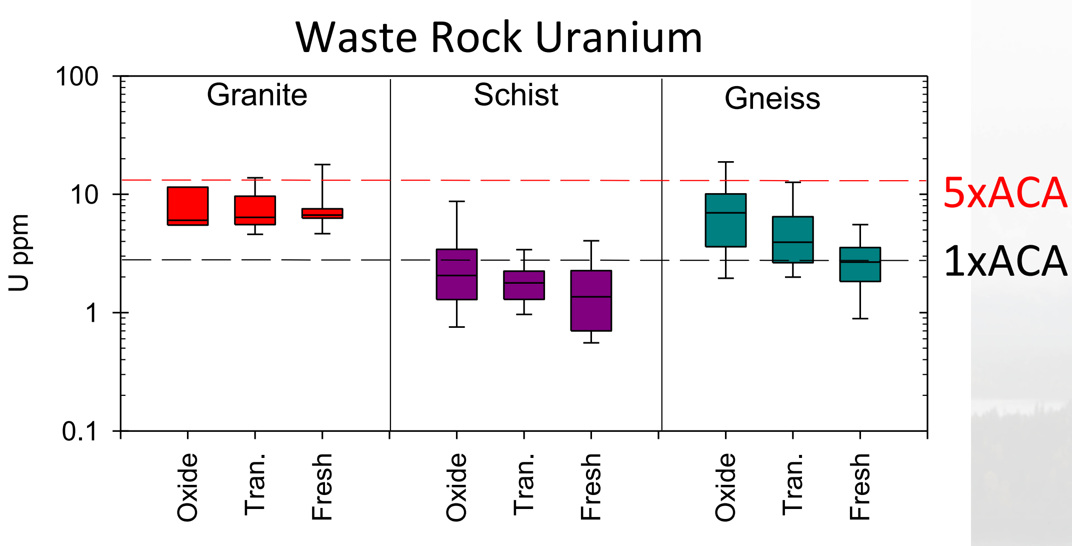
Uranium Enrichment in Bedrock



Average Continental Abundance (ACA) = 2.7 ppm

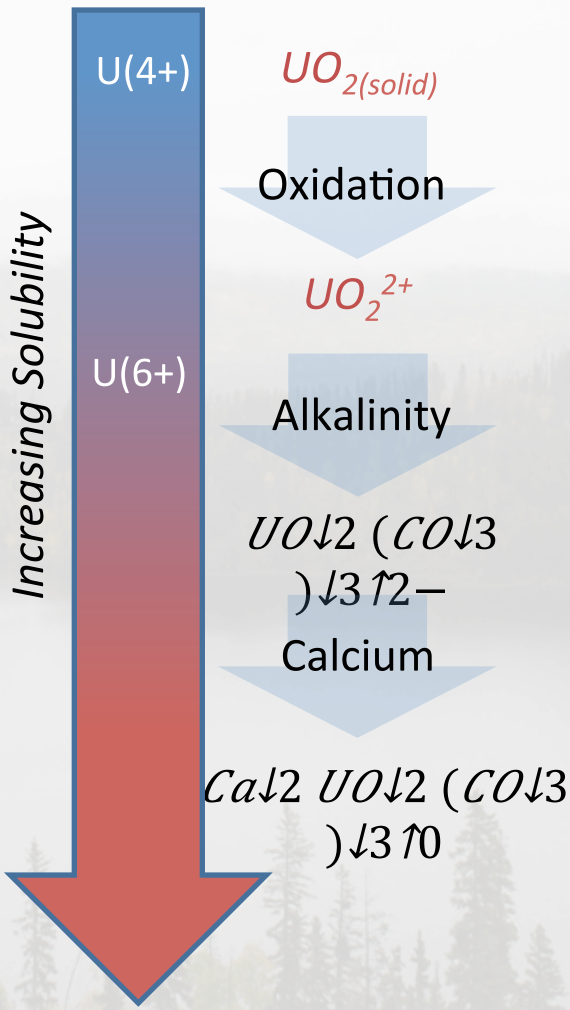
Uranium

– Slightly elevated in gneiss and granite (1-5x ACA); not elevated in schist (≤1x ACA).

– Ore shows similarly degree of U enrichment as waste rock.

– The lack of significant U enrichment bedrock indicates that U must be present in a form that is readily soluble in groundwater and surface water.

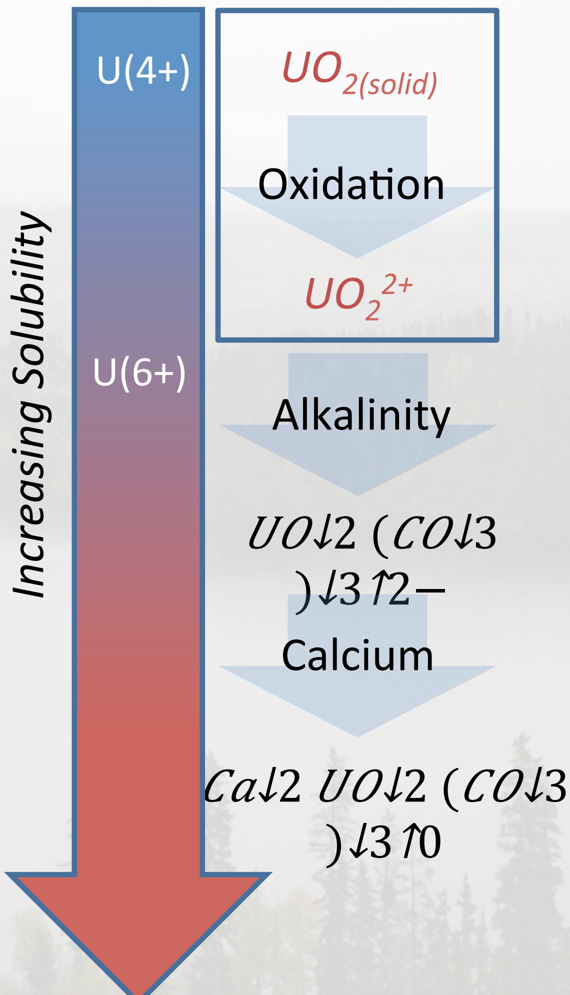
Uranium Solubility

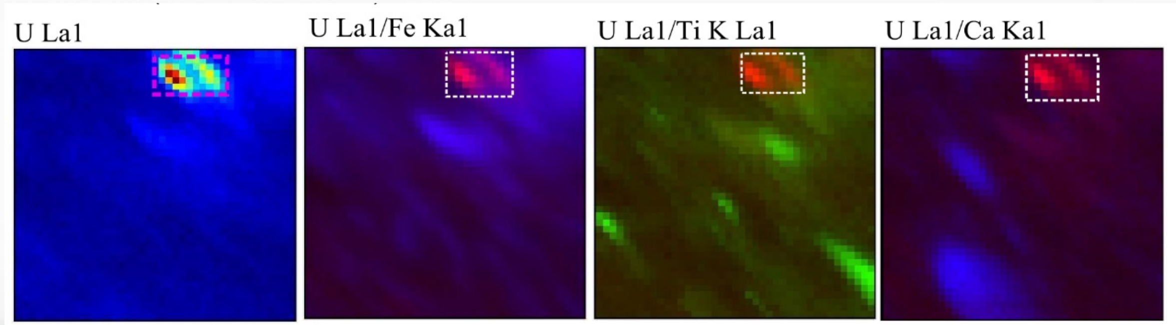


Uranium Solubility

– Dependent on oxidation state and availability of complexing ligands

Uranium Solid-Phase Speciation Results

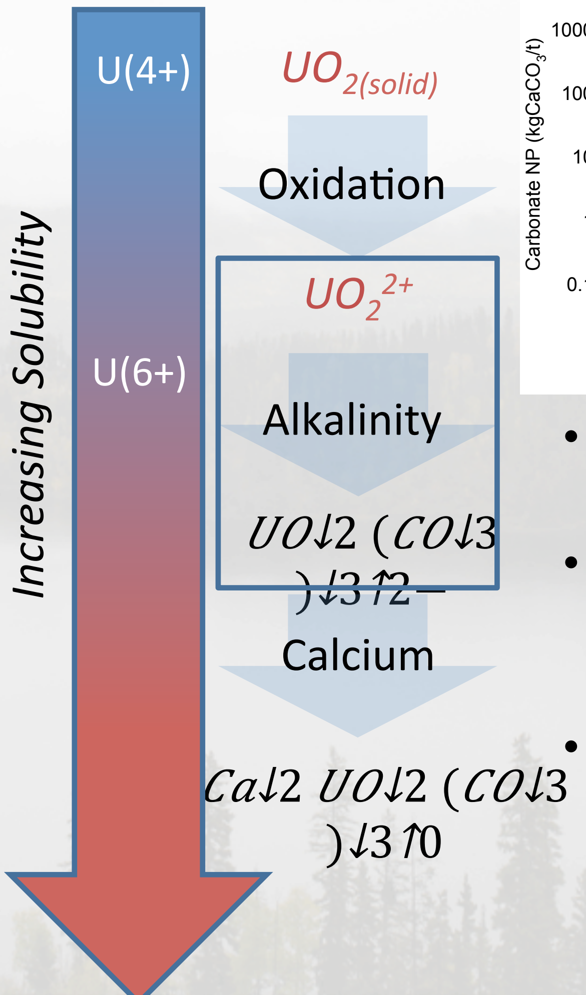


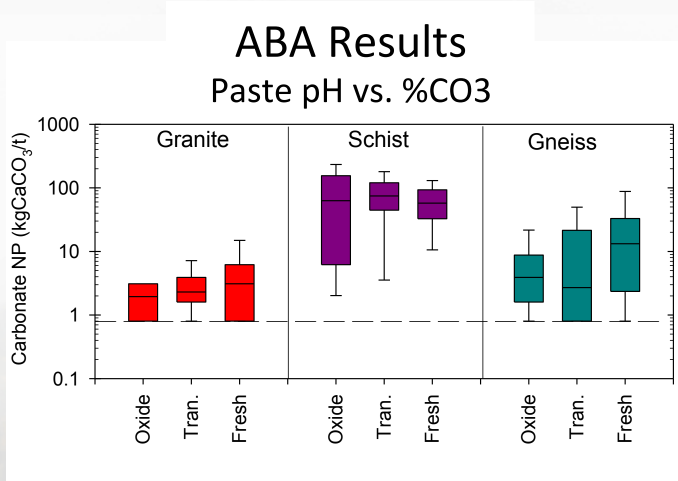


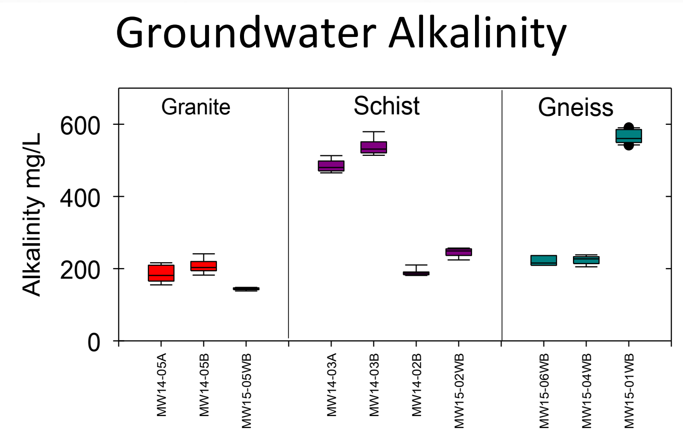
uXRF micrograph of Fresh Gneiss Waste Rock (67% U^{6+}, 33% U^{4+})

- The two dominant oxidation states of U in the environment are +4 and +6
- XANES measured relative abundance of U(6+) and U(4+)
  - Oxide Zone: 90% - 100% U(6+)
  - Transition Zone: 17% - 49% U(6+)
  - Fresh Zone: 27% - 67% U(6+)
- Results show that even though the abundance is low in bedrock, U is present in the relatively soluble U(6+) oxidation state throughout the deposit.

Uranium Solubility: Alkalinity Availability

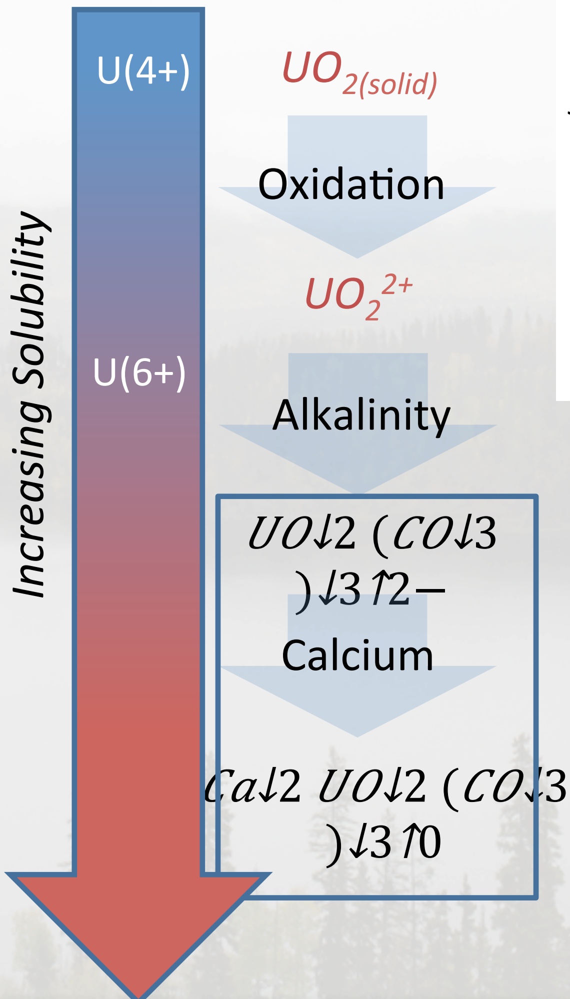


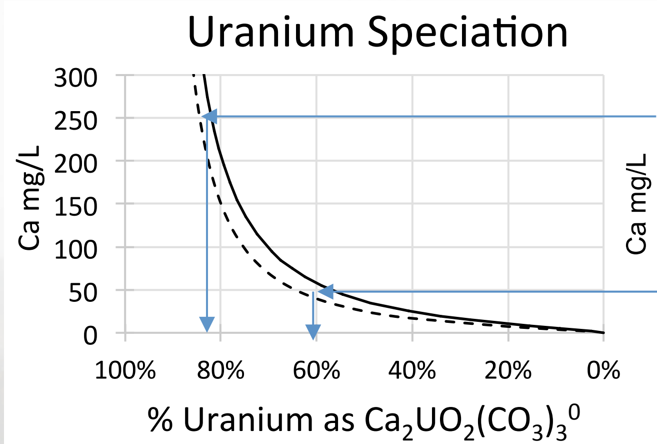


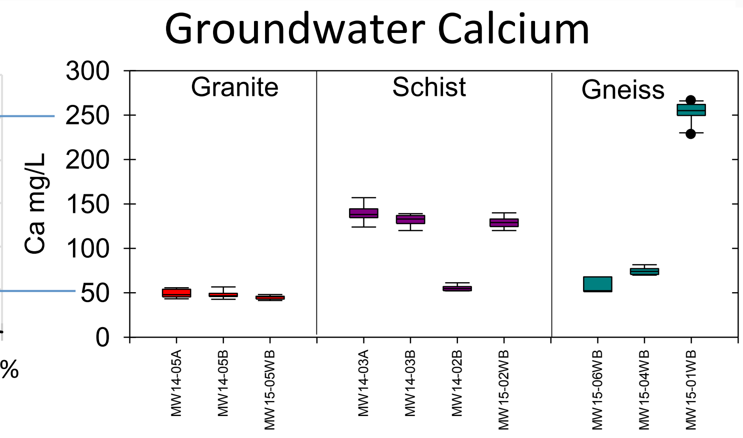


- In neutral pH environments the solubility of U(6+) is dependent on CO_3 availability.
- In-situ weathering has lead to the depletion of sulphur minerals and the oxidation of reduced mineral phases, but has not removed carbonate content.
- Elevated alkalinity in ambient groundwater supports U(6+) leaching and mobility.

Uranium Solubility: Modelled Speciation







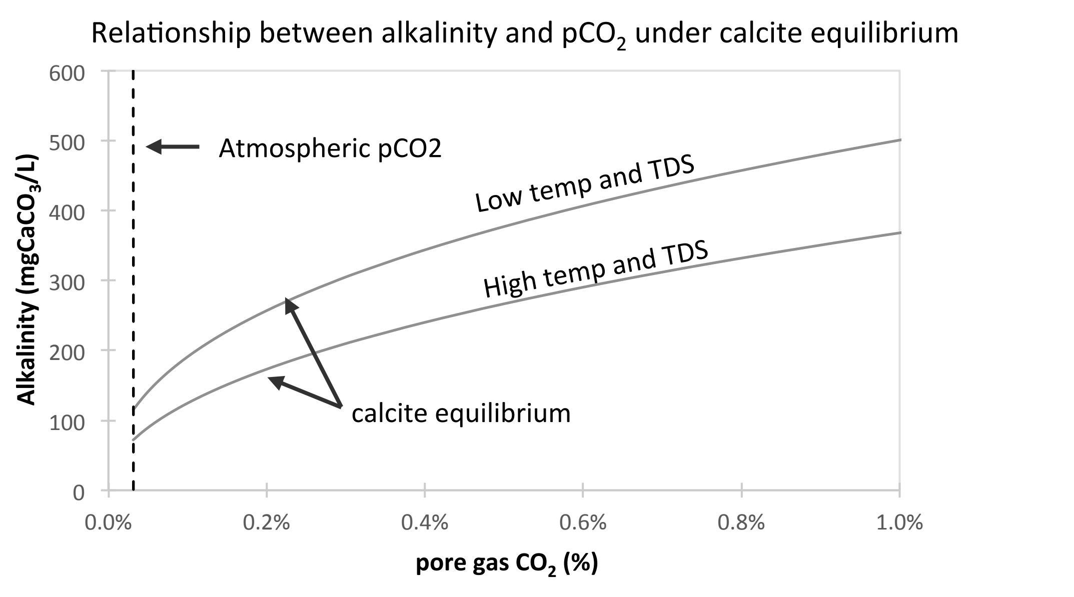
- Mobility of $UO_2(CO_3)_3^{2-}$ can still be limited by sorption to mineral surfaces.
- Formation of $Ca_2UO_2(CO_3)_3^0$ ternary complex further enhances solubility.
  - Calcium is the dominant cation in most groundwater
- Groundwater chemistry supports a majority of U as ternary Ca-U-CO_3 complex.
- Species should be equally soluble in surface water and groundwater environments

Uranium Solubility: Summary

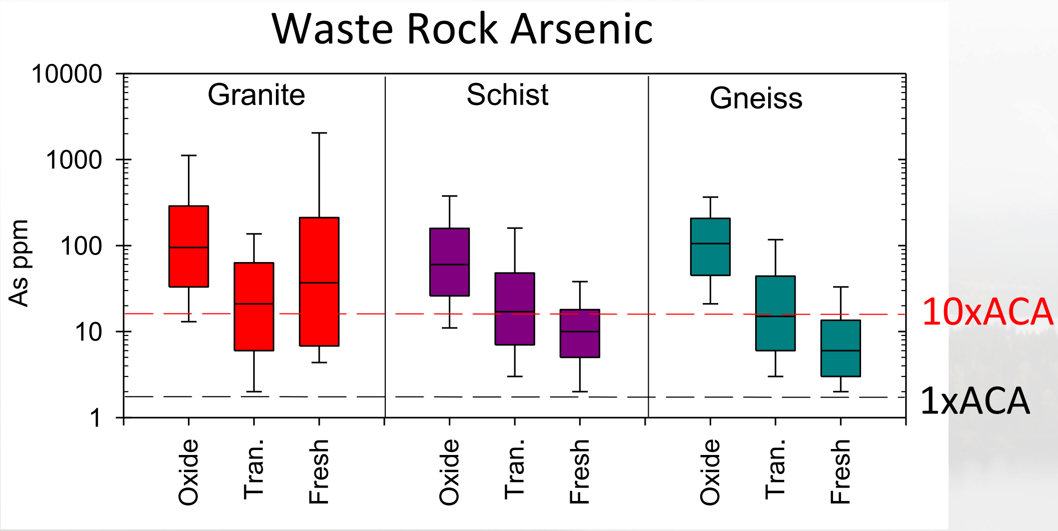
- Elevated uranium concentrations in the baseline environment can be attributed to:
  - Enrichment of uranium in gneiss and granite host rock
  - Occurrence of uranium in oxidized [U(6+)] state
  - Alkaline and calcium rich groundwater and surface water which supports release and mobility of U(6+)

Implications for U Prediction and Management

- Uranium release and mobility will be enhanced in mine waste environments with high alkalinity and calcium in pore water.
- In carbonate buffered waste rock dumps, alkalinity is in large part determined by the partial pressure of CO_2 in pore gas. Uranium leaching will be accelerated in environments with limited gas exchange.
- Conversely, environments where pore gas CO_2 and Ca are not able to accumulate will limit U release (e.g., pit wall rock).



Arsenic Enrichment in Bedrock



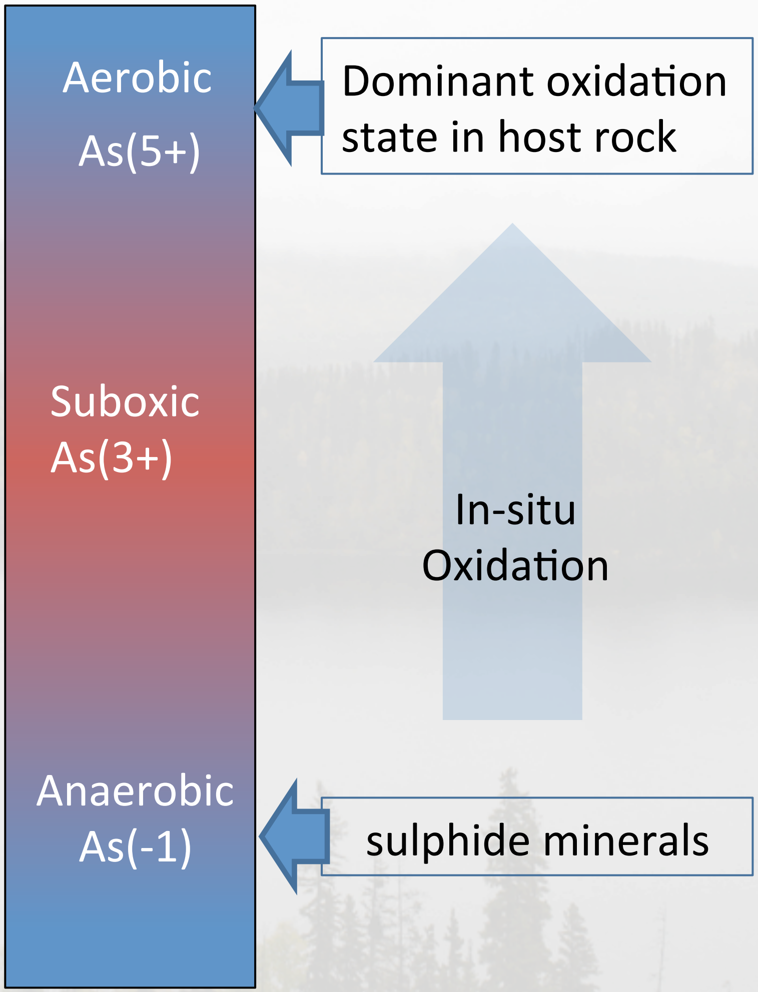
Average Continental Abundance (ACA) = 1.8 ppm

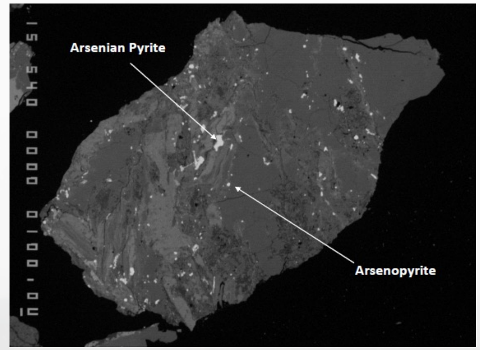
Arsenic

– Elevated in all rock types, with waste rock typically equal to or exceeding 10xACA

– Ore is significantly enriched in As (>1,000 ppm) compared to waste rock

Arsenic Solid Phase Speciation





SEM micrograph showing occurrence of arsenian pyrite and arsenopyrite within illite matrix.

- XANES analysis found As primarily present primarily As(+5) and As(-1)
  - Oxide Zone: 100% As(5+)
  - Transition Zone: 91% - 100% As(5+)
  - Fresh Zone: 20% - 59% As(5+)
- As(5+) is associated with Fe-oxide and Fe-arsenate minerals.

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Arsenic Solubility: Redox Controls

Aerobic
As(5+)

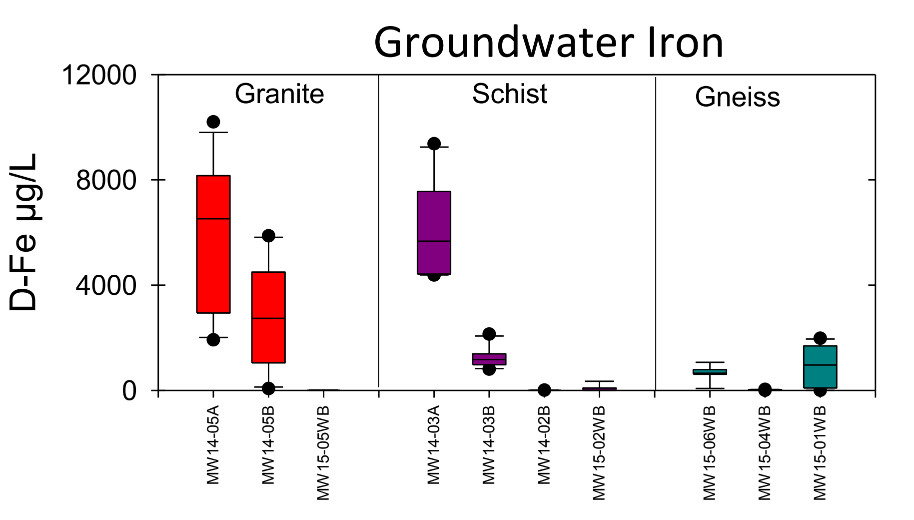
Dominant oxidation state of As in mine rock.

Reduction

Suboxic
As(3+)

Elevated D-Fe in groundwater indicates suboxic conditions

Anaerobic
As(-1)

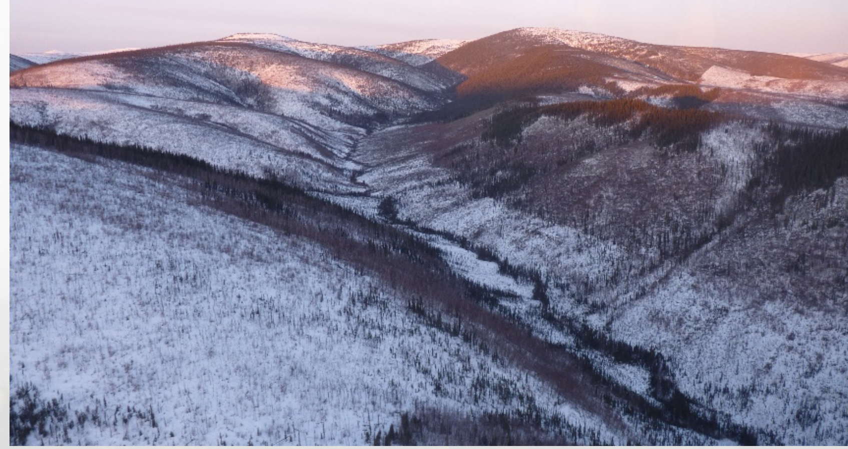


- Groundwater chemistry shows that conditions are sufficiently reducing to support reductive dissolution of Fe-oxide minerals
- Reduction of As(5+) to As(3+) occurs concomitantly with Fe reduction.
- Elevated As in groundwater is likely due to groundwater being sufficiently reducing to support As(3+) formation and stability

Arsenic Solubility: Attenuation Processes

Aerobic As(5+)	Aerobic surface water support As(5+) formation
	↑ Oxidation
Suboxic As(3+)	Elevated D-Fe in groundwater indicates suboxic conditions
Anaerobic As(-1)	

Why is arsenic absent from surface water?



- Exposure to atmospheric oxygen when will result in the oxidation of As(3+) and Fe(2+)
  – As(5+) is readily sorbed by iron oxide mineral surfaces
- Aerobic metal leaching tests show that As solubility is related to Fe content and pH.
  – Supports viability of sorption attenuation mechanism

Arsenic Solubility Summary

- Elevated arsenic concentrations in groundwater can be attributed to:
  - High degree of arsenic enrichment in ore and waste rock around the deposit.
  - Occurrence of arsenic in an oxidized state which is prone to reductive dissolution in suboxic groundwater environments.
- Low arsenic in surface water can be attributed to:
  - Oxidation of D-As and D-Fe when groundwater exposed to atmospheric oxygen.
  - Attenuation of As(5+): sorption onto Fe-oxide surfaces.

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Implications for Arsenic Prediction and Management

– Placement of material with high As leaching potential in saturated environments should be avoided.

– Storage of As-rich mine waste in unsaturated environment is preferred.

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Conclusions

- Analysis of background data can identify geochemical processes occurring at the field scale
- Geochemical characterization testing can provide data to help explain site observations, and provide data on how mining activities will modify or amplify these processes.
- Overall, data gained from field observations reduces uncertainty around prediction of metal behaviour in a future mining environment and increases confidence in water quality predictions

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