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Application of Field Portable Spectrometers in Exploration Studies

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J.B. Percival, J.M. Peter, J. Powell

Geological Survey of Canada

EXPLORATION

- Current trend in exploration is to have instant information on materials of interest
  - outcrop, hand samples, drill core, cuttings
- Field instrumentation has become portable, affordable, robust, quantitative
  - provides rapid geochemical and/or mineralogical analyses
- Elemental analyses can be obtained using X-ray fluorescence (XRF), laser-induced breakdown spectrometry (LIBS)
- Mineralogical analyses can be obtained using X-ray diffraction (XRD) and infrared (IR) spectroscopy

Collecting VNIR-SWIR spectra from power-washed rhyolite outcrop using FieldSpec Pro contact probe, Izok Lake area, Nunavut.

Spectral Measurements on Drillcore & Outcrop

Measuring outcrop using FieldSpec Pro contact probe (calibrated halogen light source), Izok Lake area, Nunavut

Two case Studies

Measuring drillcore in Athabasca Basin using TerraSpec Halo

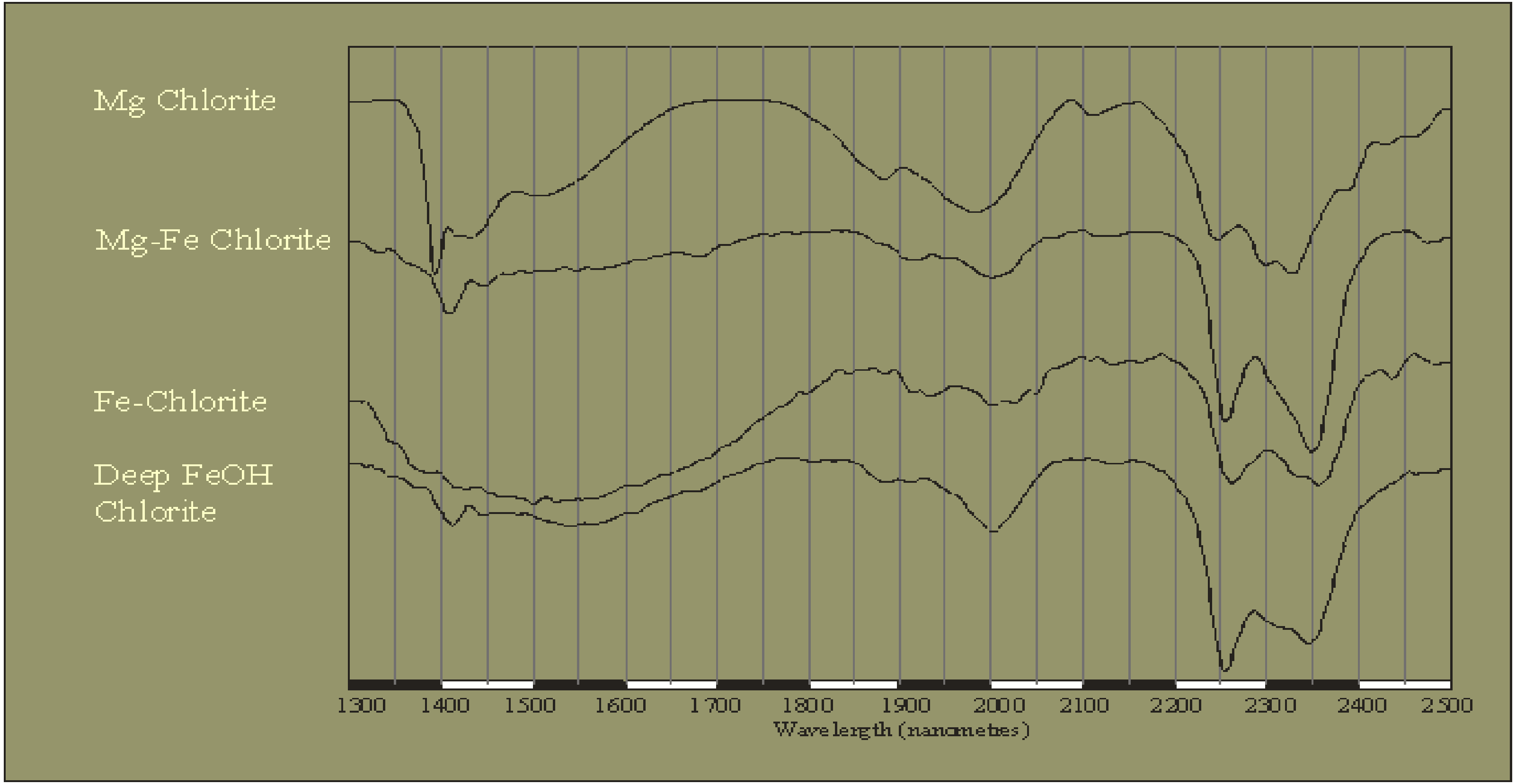
MINERALOGICAL INDICATORS

- For certain deposit types mineralogy may be a stronger indicator of proximity to mineralization
  - Volcanogenic Massive Sulfide
    - **Fe-chlorite, sericite [muscovite], phengite, Fe-carbonates, quartz**
  - Low Sulfidation Epithermal Gold
    - **Calcite, adularia, illite, smectite, barite**
  - High Sulfidation Epithermal Gold
    - **Pyrophyllite, alunite, dickite, diaspore, barite, illite, quartz**
  - Iron-Oxide Copper-Gold
    - **Biotite, sericite, amphibole, chlorite, carbonate minerals, albite, K-feldspar, magnetite**
  - Sediment-hosted Lead-Zinc (SEDEX)
    - **Siderite, ankerite, ferroan dolomite, muscovite, phengite, chlorite, smectite, apatite, tourmaline, barite, albite**
  - Mississippi Valley-Type
    - **Calcite, illite, kaolinite, quartz**
  - Porphyry Systems
    - **Epidote, chlorite, alunite**
  - Unconformity-Type Uranium
    - **Dickite, kaolinite, illite, sudoite, Fe-chlorite, dravite, Mg-foitite, APS minerals**

SWIR Spectral Characteristics

- **Chlorites**
  - Fe vs Mg content
  - 2 Main Diagnostic Absorptions:
    - 1) 2235-2255 nm (FeOH)
    - 2) 2320-2360 nm (MgOH)
- **White Micas**
  - Main Diagnostic Absorptions
    - 1) 2180-2228nm (AlOH) varies with composition:
      - Na-rich paragonititic sericite ($NaAl_2[(OH)_2|AlSi_3O_{10}]$) at 2180 nm
      - Normal potassic ("muscovitic") sericite ($KAl_2(AlSi_3O_{10})(F,OH)_2$, or $(KF)_2(Al_2O_3)_3(SiO_2)_6(H_2O)$) at 2200 nm
      - Phengitic (Fe-Mg-substituted) ($K(AlFeMg)_2(OH)_2(SiAl)_4O_{10}$) sericite at 2228 nm
    - 2) 2344 nm (AlOH)
    - 3) 2440 nm (AlOH)
- **Carbonates**
  - strong diagnostic carbonate absorption feature between 2300-2350 nm

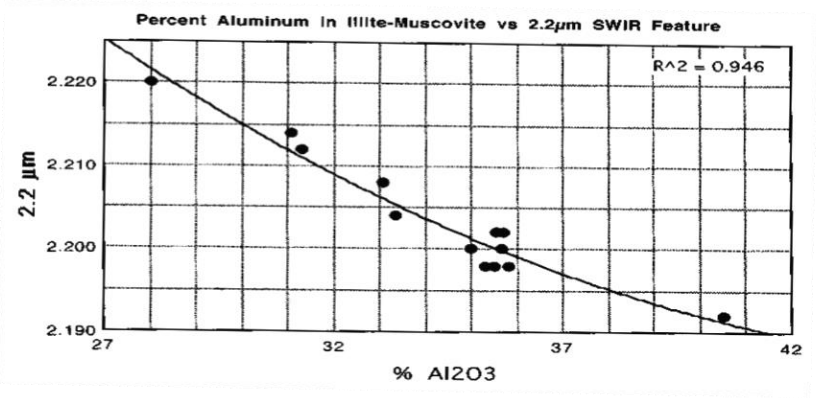
Chlorite Spectra



(Pontual et al., 1997)

White Mica Spectral Characteristics

(cited in Hauff, 2005)



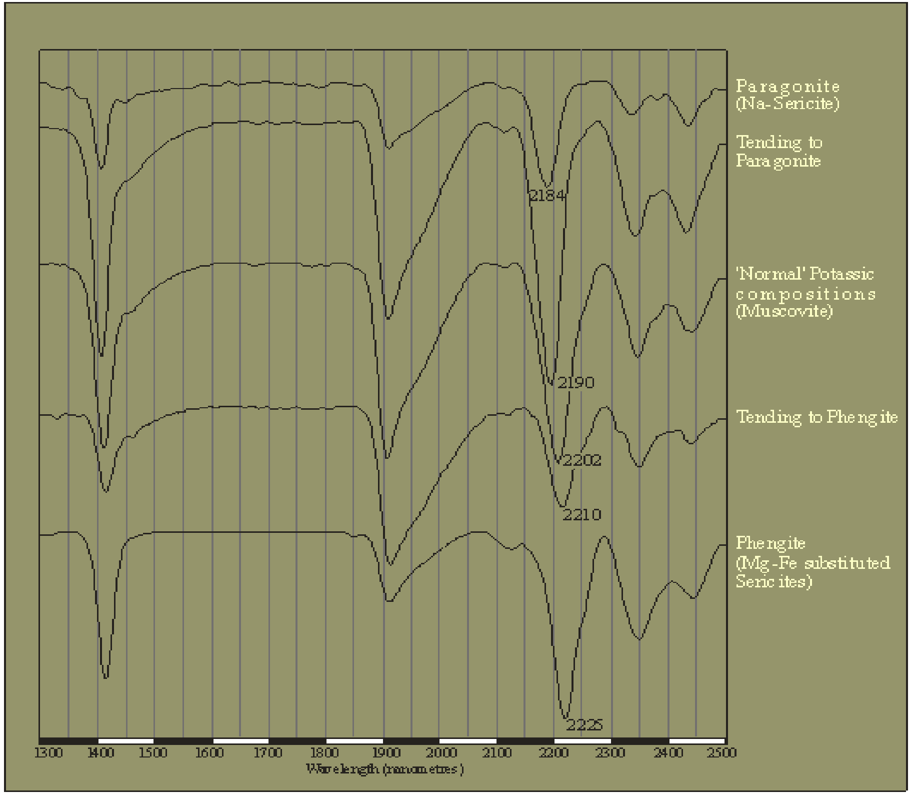
Shift in wavelength of ≈2200 nm absorption tracks Al content

Lower the wavelength, the higher the Al content

High-Al white mica = sodic (paragonitic)

Low-Al white mica = Mg-Fe substituted (phengitic)

Tschermak Substitution: octahedral Mg and Fe substitute for Al concurrently with tetrahedral Si for Al



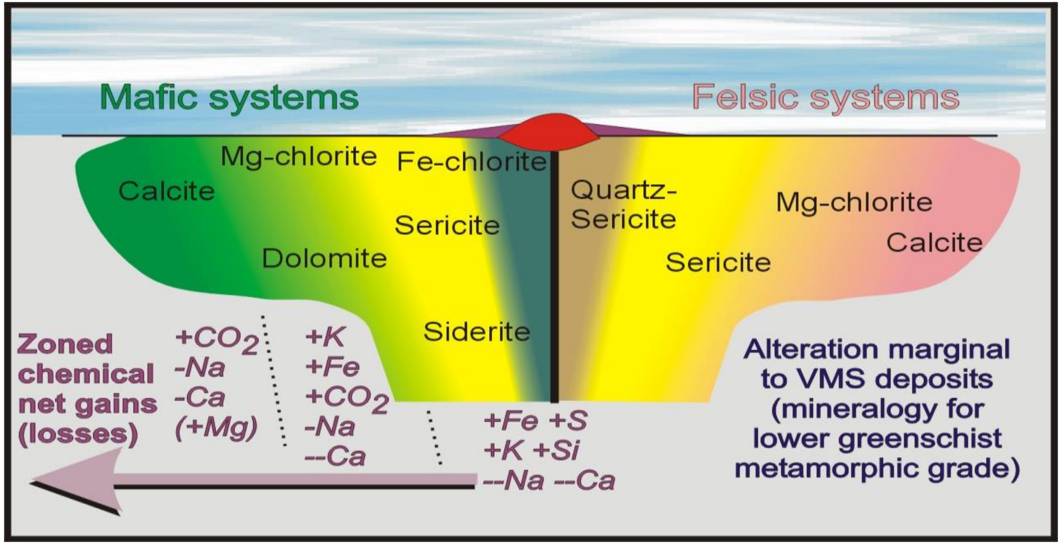
(Pontual et al. , 1997)

Hydrothermal Alteration Mapping: Volcanogenic Massive Sulfides

- Typically far larger hydrothermal alteration zone than mineralization footprint

- Proximal alteration characterized by Fe-chlorite, sericite, Fe carbonates and quartz

- Distal alteration characterized by Mg-chlorite, in addition to Fe, Ca, and Ca-Mg carbonates

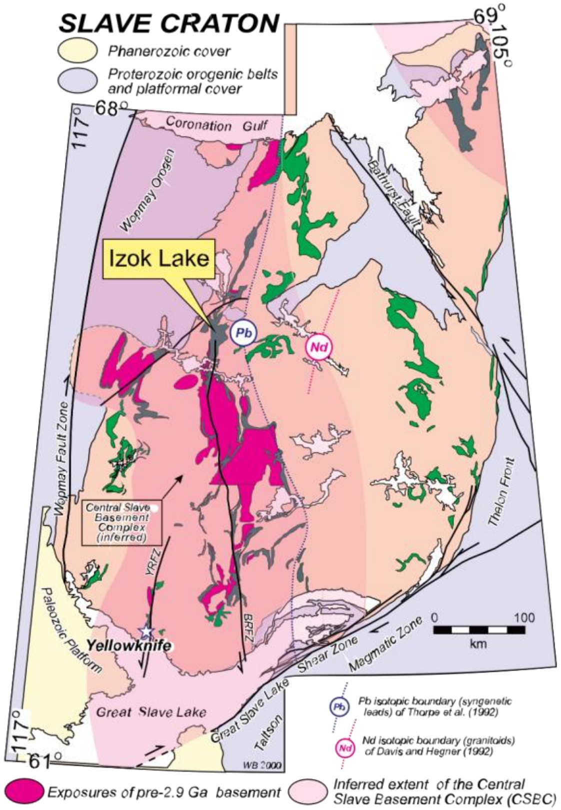


Simplified alteration zonation (Richard Herrington; after Franklin et al., 1981)

Izok Lake, Nunavut

Geological map of the Slave craton (province; modified after Bleeker and Hall, 2007) showing the location of the Izok Zn-Cu-Pb-Ag VMS deposit (65°37.5'N; 112°48.0'W), in the Kitikmeot region of Nunavut.

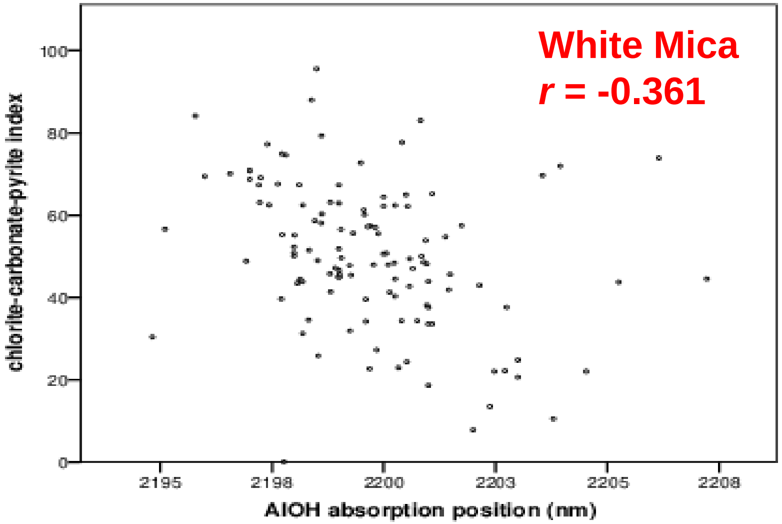
Resources: 5 Mt grading
13% Zn
2.3% Cu
1.4% Pb
73 g/t Ag

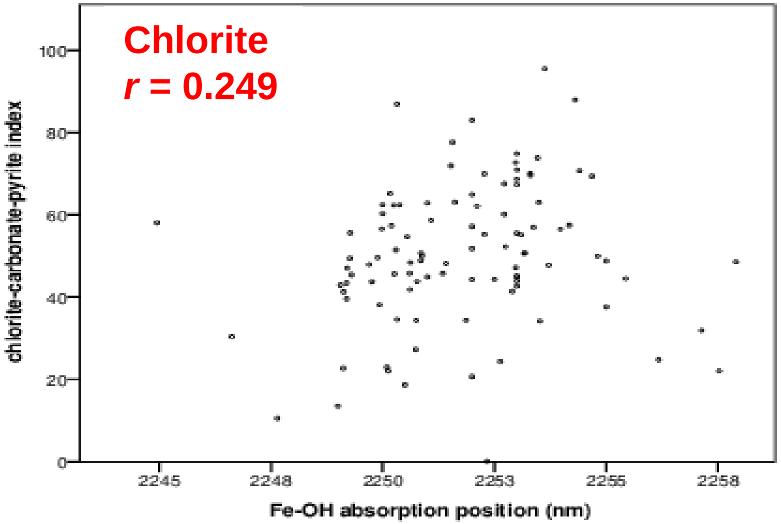


Izok Lake Drill Core Spectrometry Results

$$CCPI = \frac{100(FeO + MgO)}{FeO + MgO + K_2O + Na_2O}$$

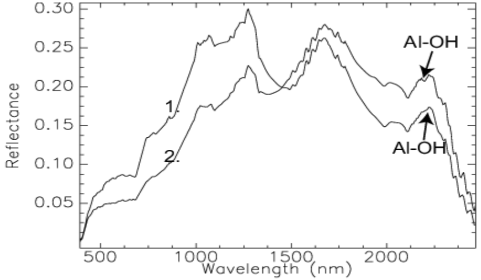
Laakso et al., 2016

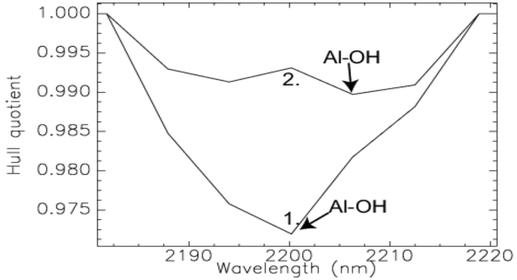




- White micas range from sodic to phengitic; shift toward shorter wavelengths in white micas with increasing alteration intensity in the drill core spectrometry (Cu stringer 2204 nm; the lower the wavelength, the higher the Al content)
- Shift toward longer wavelengths in chlorite with increasing alteration intensity (higher CCPI) (based on ground and drill core spectrometry; 2253 nm in Cu-stringer, 2250 nm background; the longer the wavelength, the higher the Fe content)

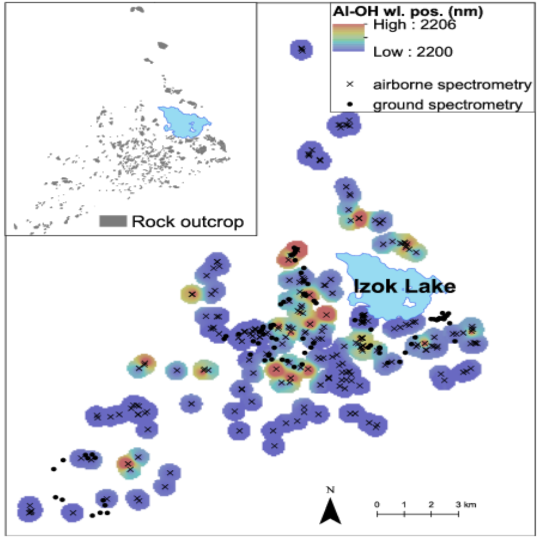
Izok Lake VMS Airborne Hyperspectral Data Comparison with Ground Data

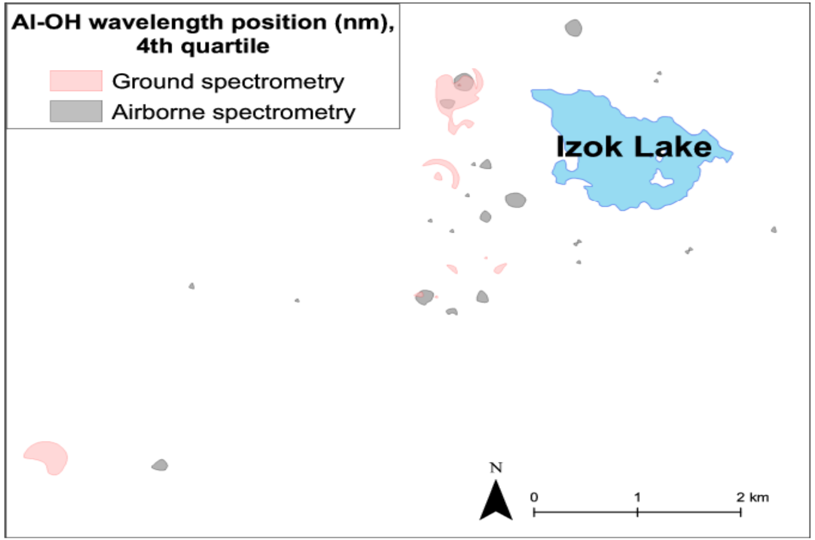




4th quart. plot displays values at the highest 75-100% of the ground and airborne spectrometry. These are areas of relatively high Al-OH wavelengths

Ground: 2207-2211 nm
Airborne: 2205-2206nm





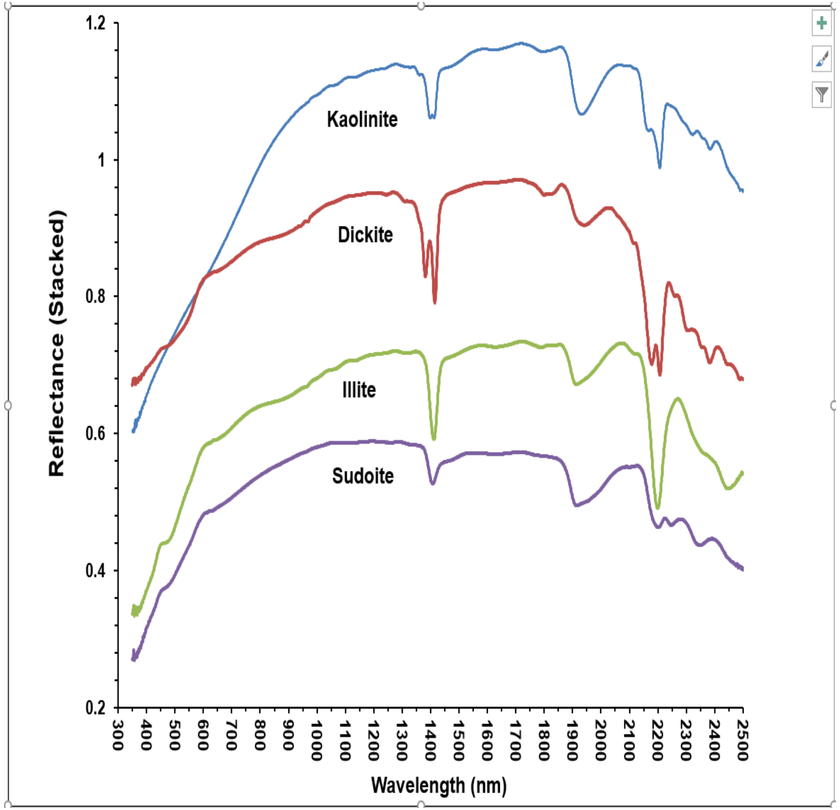
(Laakso et al., 2015, 2016)

Unconformity-type Uranium Deposits

- Infrared spectroscopy has been used extensively for exploration in the Athabasca Basin in northern Saskatchewan, Canada for over 3 decades

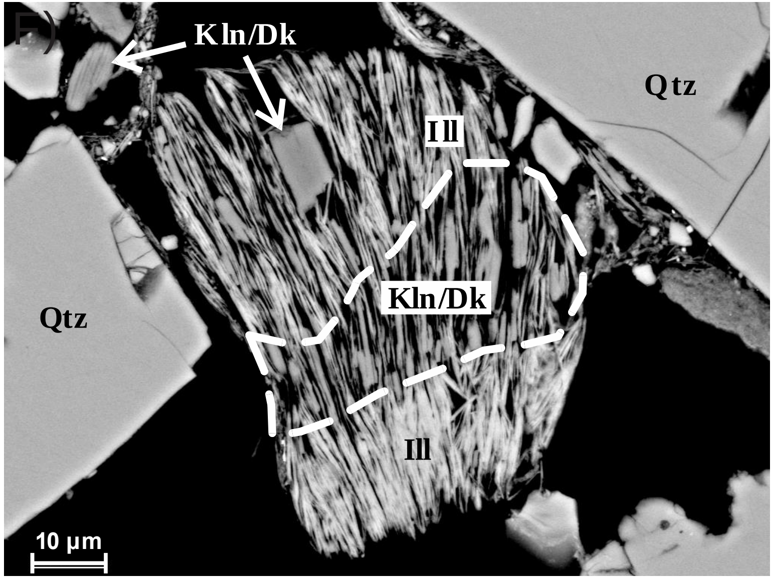
- Uranium companies use the field portable instruments (PIMA, ASD, etc.) during drilling operations to identify the key minerals that vector to ore

- Collection of infrared spectra from archived drillcore at the Saskatchewan Geological Survey has provided key mineralogical information related to the deposits and their genesis, and to regions distal to deposits for basinal history



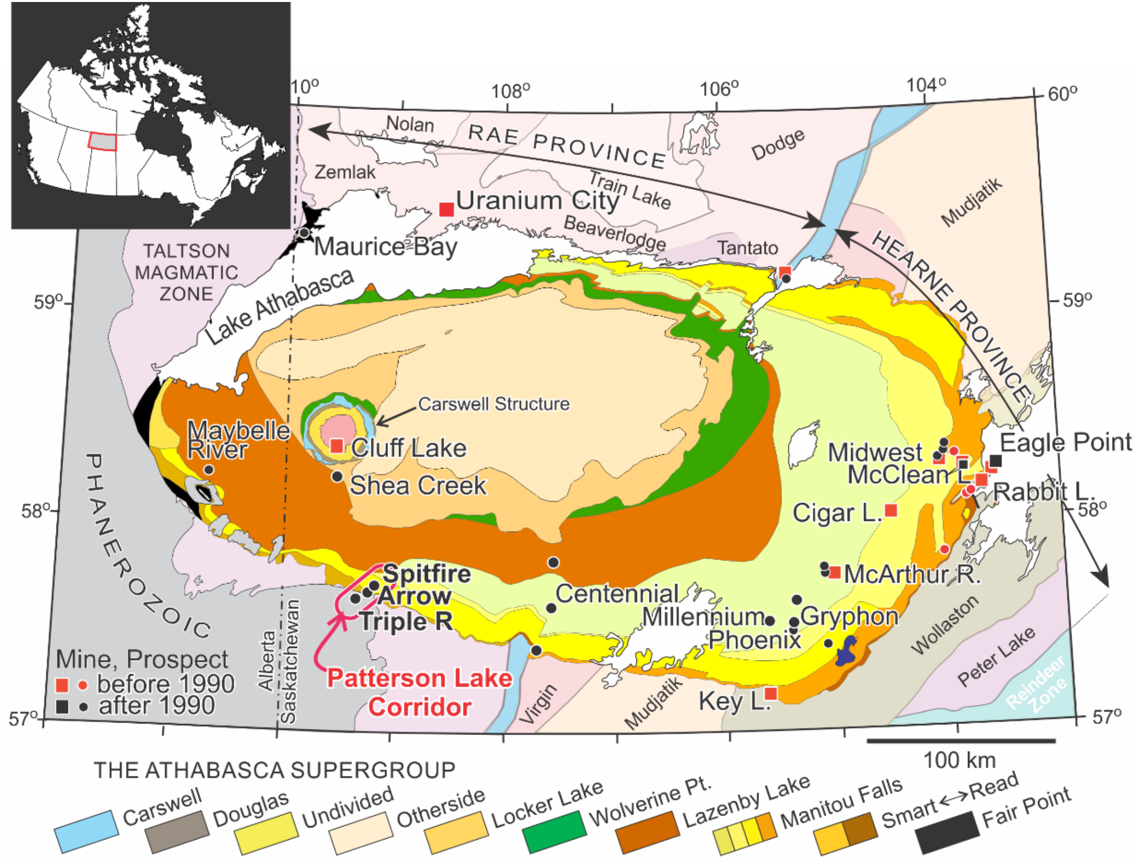
Mineral Changes

- Minerals of interest
  - **Dickite, kaolinite, illite, sudoite, Fe-chlorite, dravite, Mg-foitite, APS minerals**
- Mineral changes from diagenetic dickite to hydrothermal illite occur in the eastern side of the basin
- Mineral changes in the western side are less extensive and subtle in comparison
- This shift in clay patterns between east and west side of basin
  - **Does this represent different source rocks, different fluids, different depths of formation, or influence from major tectonic zones?**



Athabasca Basin

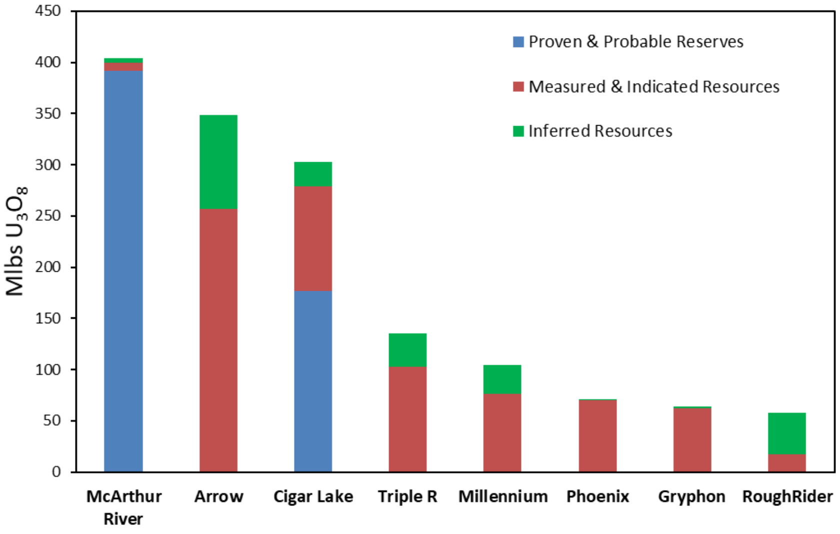
- Host to some of the world's largest high-grade, large tonnage uranium deposits
- Historic deposits in the east are associated with intersections of the crustal-scale faults with the regional unconformity
- New deeper discoveries in the southwest (Patterson Lake Corridor; PLC)

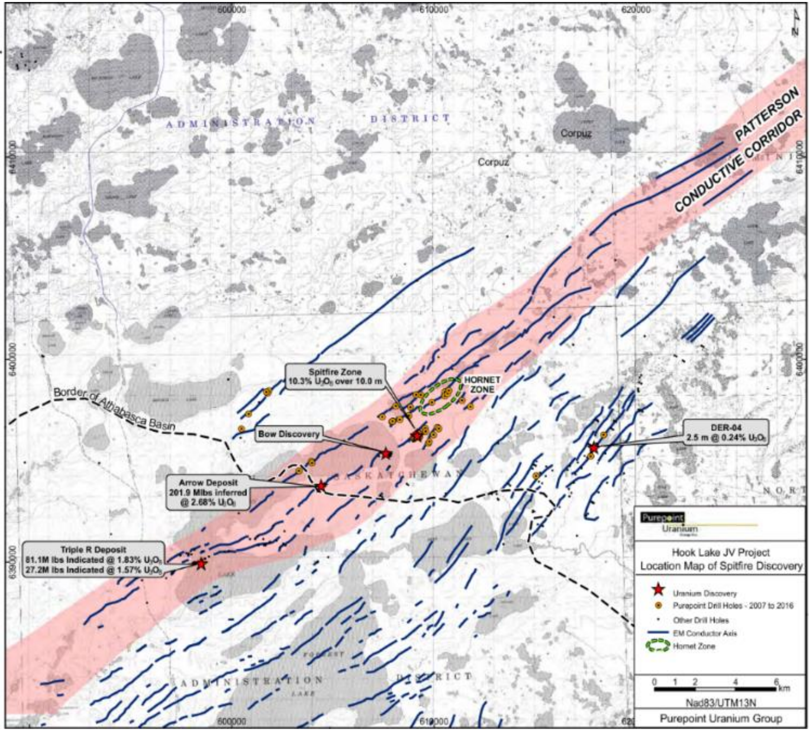


(after Jefferson et al., 2007)

Uranium Exploration in the PLC

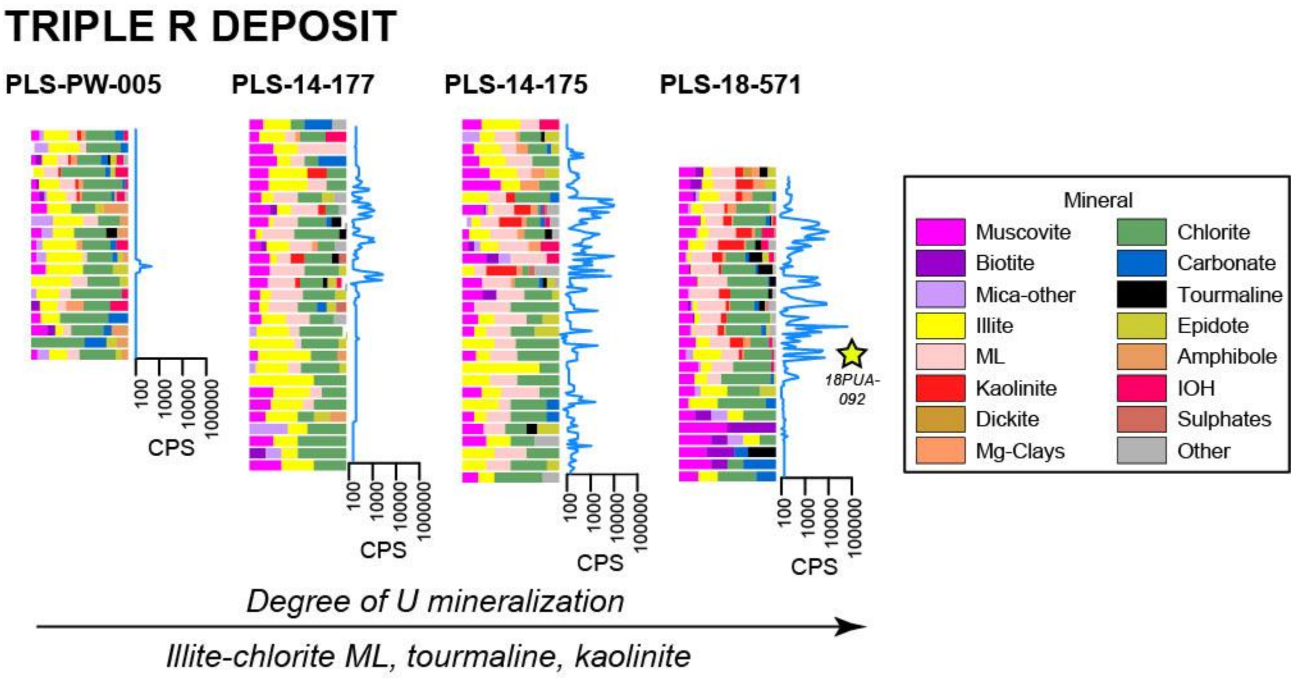
High-grade deposits (e.g., Triple R, Arrow) and occurrences (e.g., Bow, Cannon, Harpoon, South Arrow, Spitfire,) along a > 40 km long trend





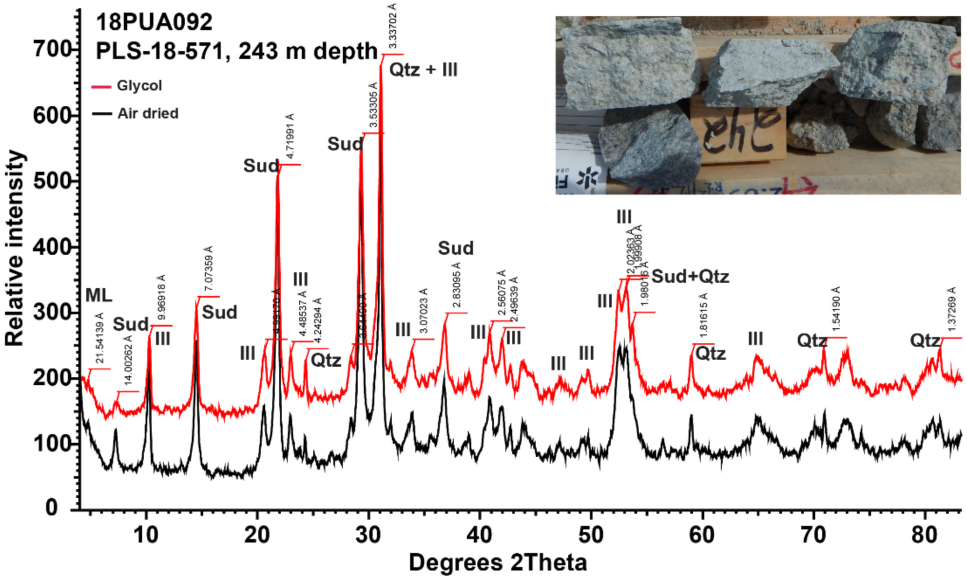
(From Purepoint Uranium Group)

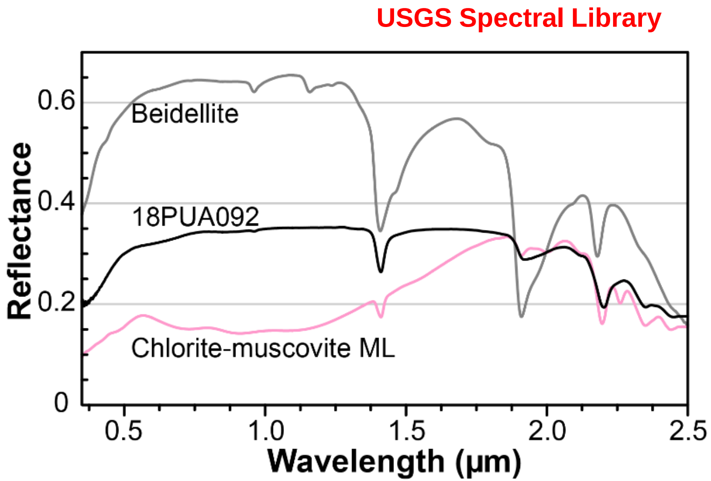
Alteration Associated with U Mineralization



- Background alteration: clay (illite + chlorite) altered orthogneiss
- U mineralization associated with increasing proportion of mixed-layer clay relative to illite and chlorite
- Tourmaline and kaolinite also associated with high grade ore

SWIR vs XRD: Beidellite (smectite gp) vs Mixed-layer Clay Mineral

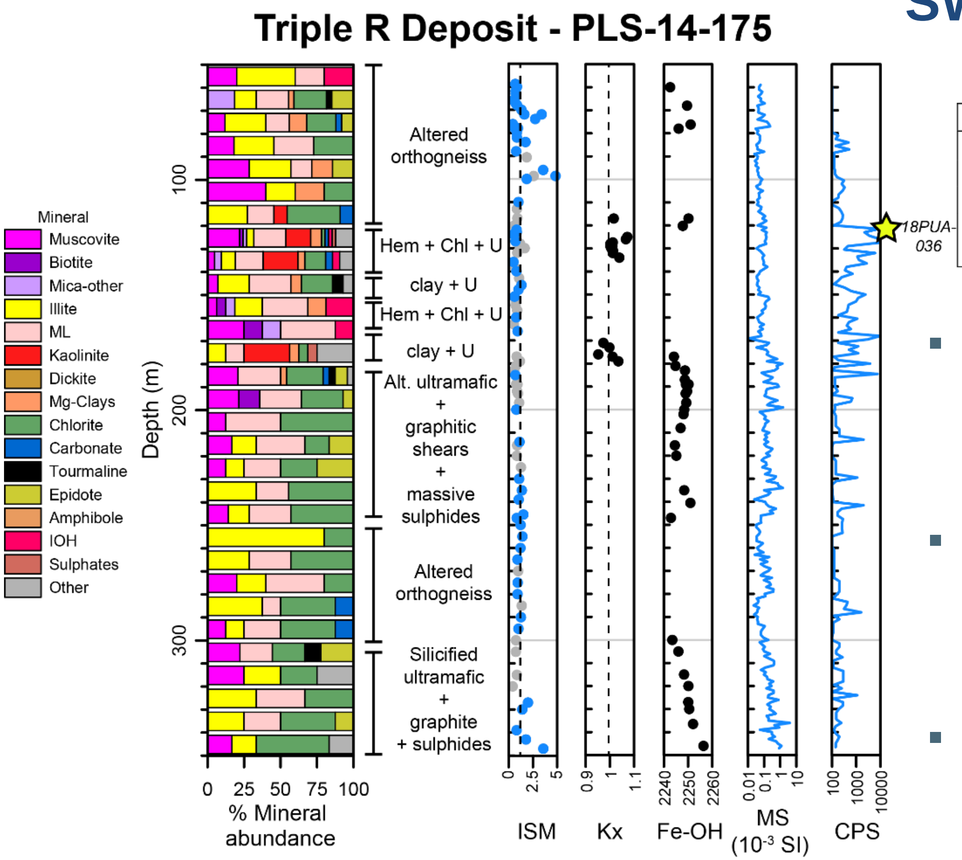




Halo identified minerals: Beidellite (ML), Mg-chlorite, K-illite

- The Halo identified *beidellite* as a common alteration mineral. XRD results determined that these smectite-group minerals are likely an *illite* + *chlorite* (*sudoite*) mixed-layer (ML) clay mineral
- It is likely that *cookeite* identified by the Halo is really *sudoite*, as *cookeite* is the only di-trioctahedral chlorite in the onboard library of reference spectra

SWIR Profile: Mineralogy and Scalars



XRD data for clay alteration from main ore zone, PLS-14-175

Sample No.	Qtz	Tm	Ill	Chl	Sud	Kln	ML	Cal	At	Hem	Jrs
18PUA-036, 141 m depth											
18-PUA-036 63-10 µm	21	tr	63	10					5		1
18-PUA-036 10-6 µm	tr	41	40	17			tr		2		tr
18-PUA-036 6-2 µm		48	36	15			tr		1		
18-PUA-036 2-0.2 µm		8	72	20			tr				

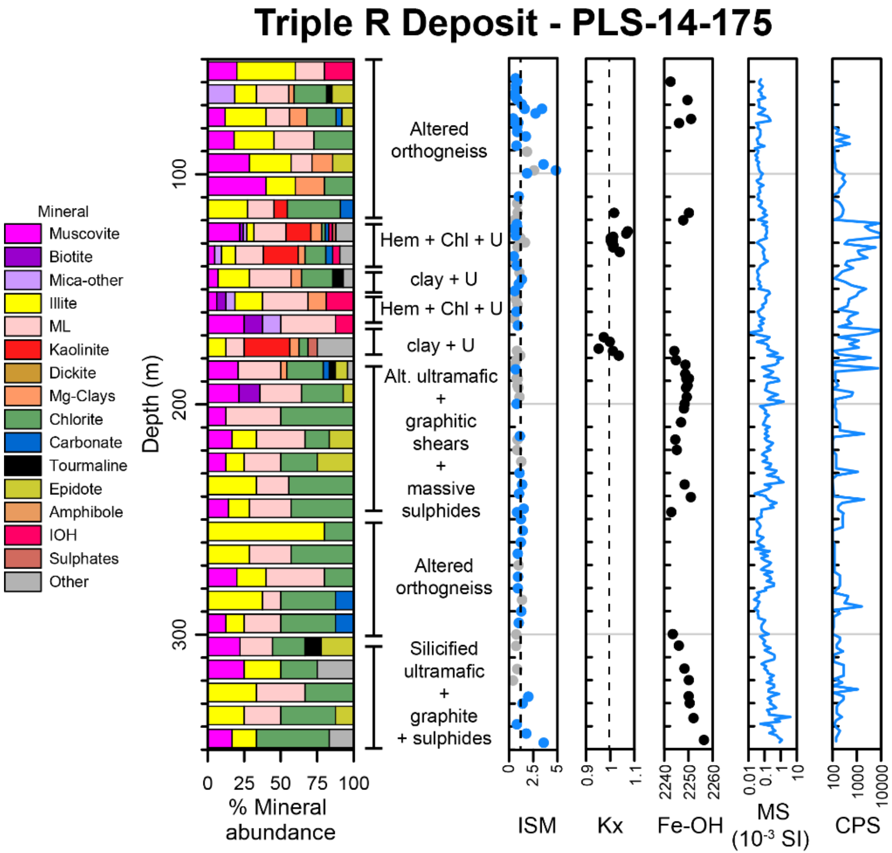
- Halo identifies very fine-grained alteration minerals (e.g., tourmaline) that may not show up in bulk fraction XRD analyses

- ISM (illite spectral maturity): <1 = poorly crystalline, hydrothermal illite; > 1 = increasingly crystalline micas

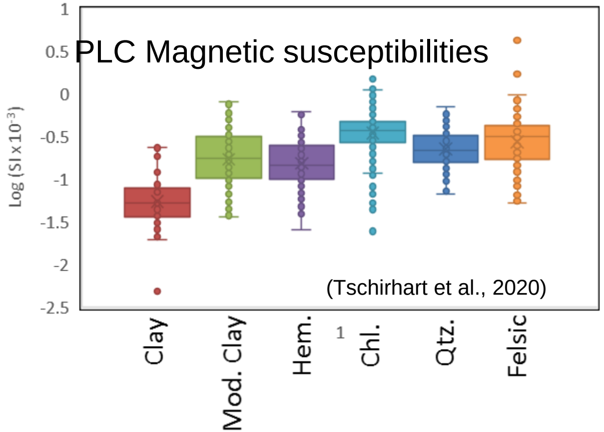
- Kx = kaolinite crystallinity: <1 = crystalline hydrothermal kaolinite; >1 = poorly crystalline, weathering related

(See also Powell et al., 2019)

Clay Alteration and Rock Properties



- Clay alteration affects physical properties of host rock (density, magnetic susceptibility, etc)



- Clay alteration of high MS mafic to ultramafic units decreases their response to values that are similar to felsic units
  - **Fe-OH scalar of the ultramafic unit indicates chlorite alteration and follows same trend as MS**
- This is an important consideration for geophysical interpretation: ***magnetic response does not map protolith!***

GSC Research

- Portable infrared spectrometers have been used in research at the GSC since 2000 in various exploration and mine camps, as well as for environmental applications.
- Both the FieldSpec Pro 3 and TerraSpec Halo are used in the lab and field as well as airborne/satellite hyperspectral data.
- Malvern Panalytical (ASD) provided a TerraSpec 4 instrument to collect spectra to develop onboard libraries
  - **Percival, et al. 2016. Spectral Library: The Kodama Clay Collection. GSC Open File 7923, doi:10.4095/297564**
  - **Percival, et al. 2019. The National Mineral Reference Collection (NMC) Digital Spectral (VIS-NIR-SWIR) Library. Part II: REE-Nb-U-Th-bearing minerals. GSC Open File 8619, doi.org/10.4095/315690**
  - available from GEOSCAN: https://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/geoscan_e.web.
- These instruments will continue to play an important role in our research.

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USGS Spectral Library: https://www.usgs.gov/energy-and-minerals/mineral-resources-program/science/usgs-high-resolution-spectral-library?qt-science_center_objects=0#qt-science_center_objects