cmic-footprints.ca

NSERC-CMIC FOOTPRINTS

# Exploration footprint of the McArthur River and Millennium unconformity uranium deposits: *Highlights and challenges*

**Kevin Ansdell**, University of Saskatchewan
**Kurt Kyser**, Queen's University
**Ken Wasyliuk**, University of Saskatchewan
**and the NSERC-CMIC Mineral Exploration Research Network**

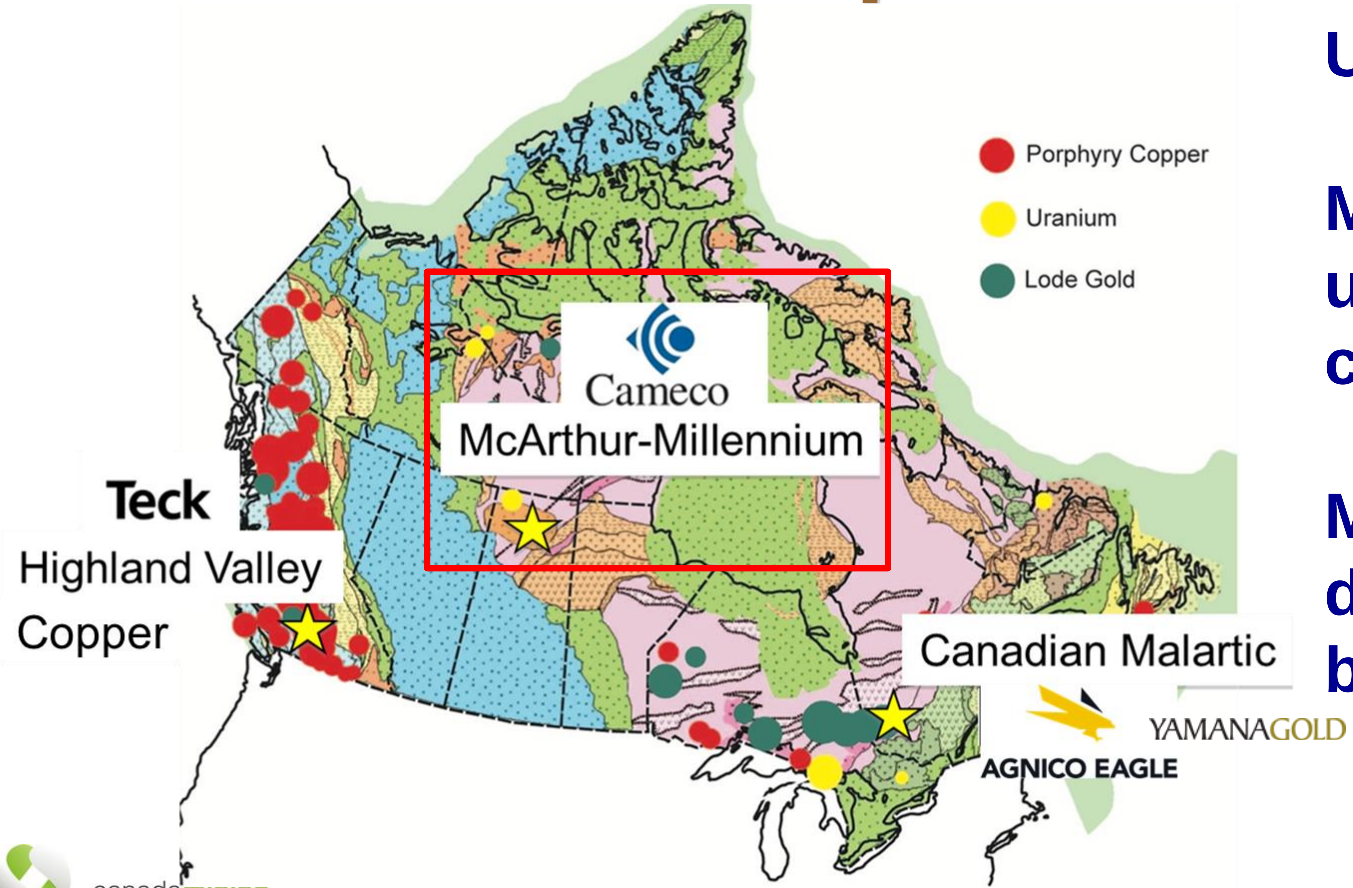
University of Saskatchewan

Cameco

Queen's University

# Location of Footprint Sites






## U site – 2 deposits:

**McArthur River – unconformity-contact**

**Millennium – dominantly basement-hosted**

# Background Geology

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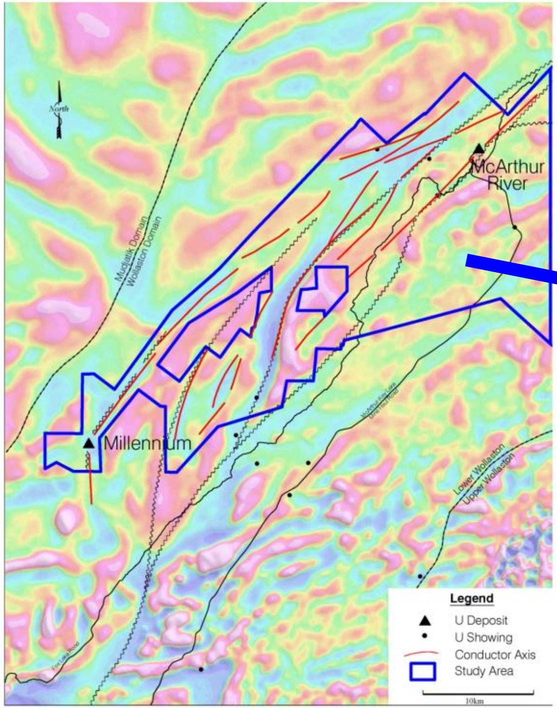
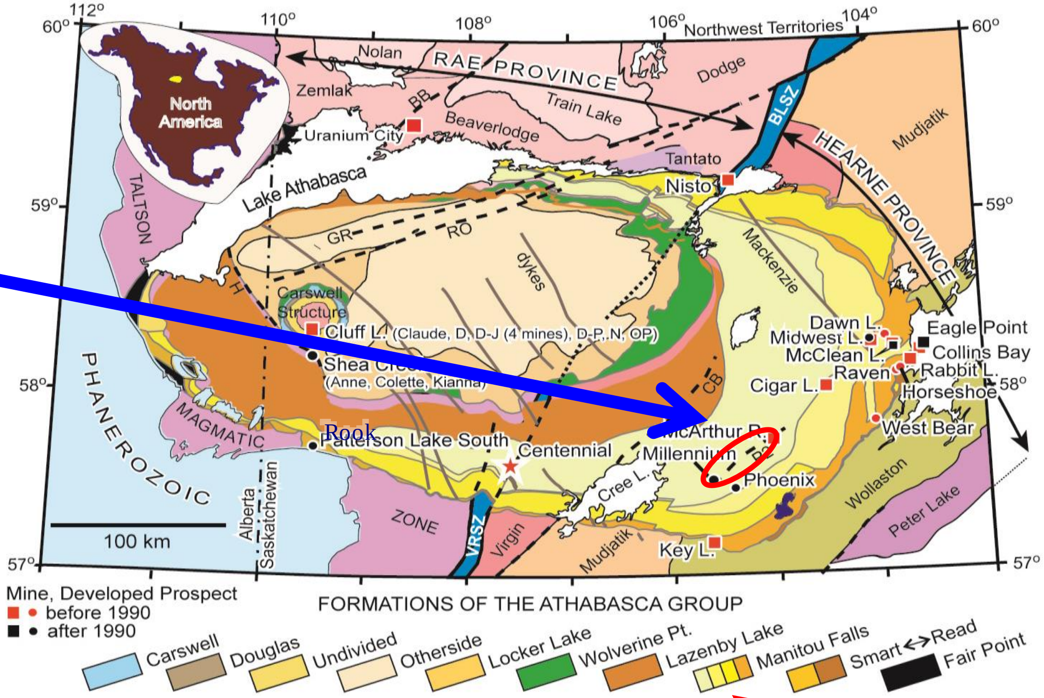



10 km




MFa, MFb, MFc, MFd

- **Relatively mature exploration with “accepted” model**

*modified after Jefferson et al (2007)*

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# Geology- Alteration Model

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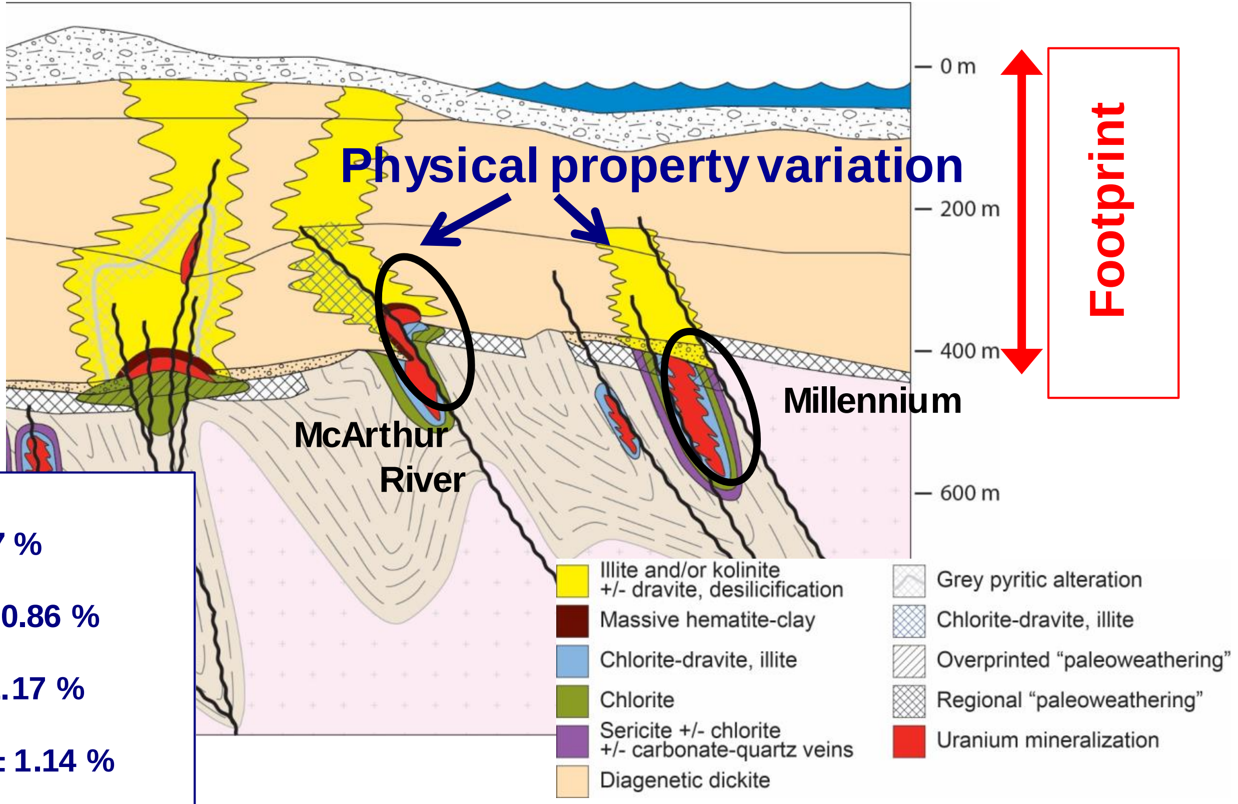
**Dominated by Qz, and so alteration is subtle**

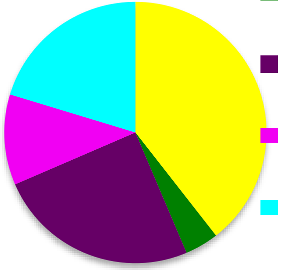
**Linked with "structures" "fractures"- extend to surface?**

**Alteration = Geochemical variations = how to image using geophysics**




*modified after Cameco SEG Short Course (2015)*

**Average non-Quartz Mineral Proportions**



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# Exploration Knowledge

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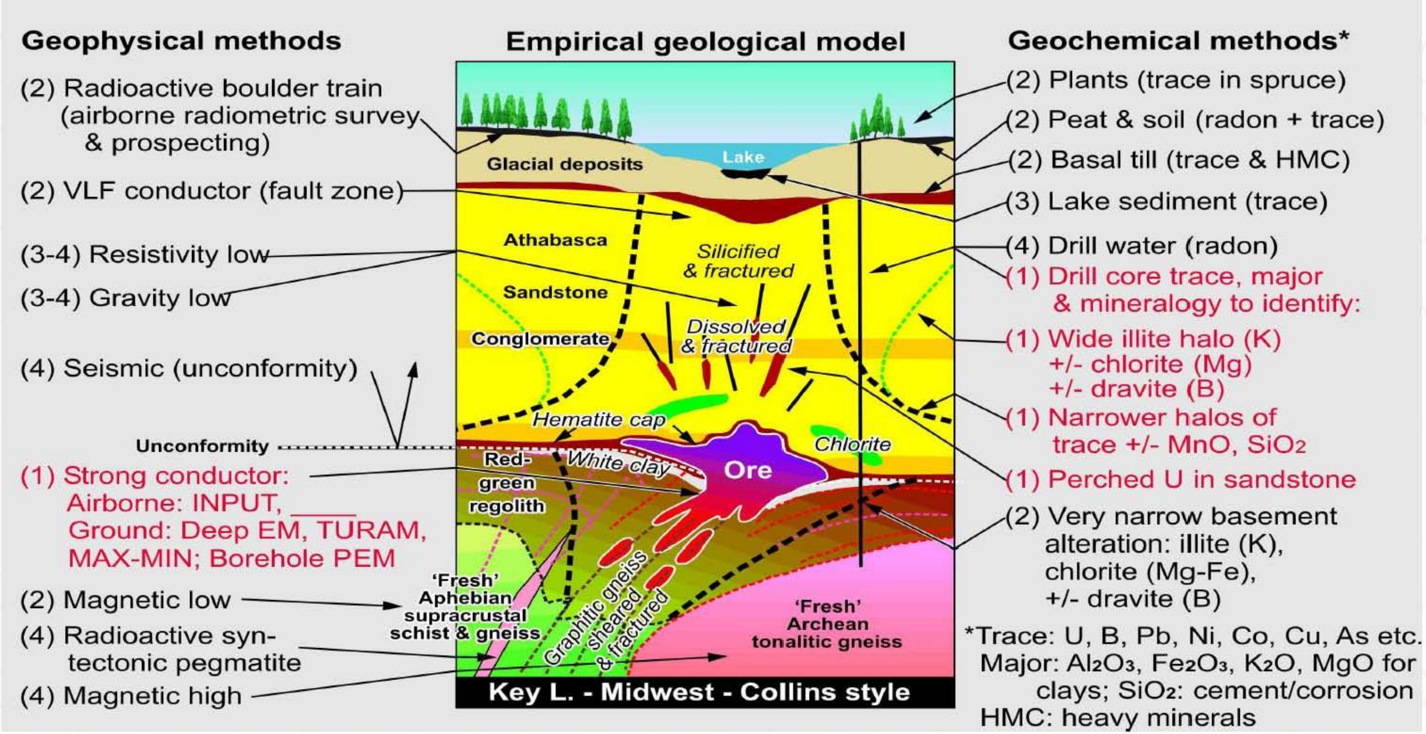
**Many techniques utilized over many years – can a statistically recognizable pattern of integrated data sets be developed?**




**Legacy data**

– drilling since the mid-1980's

– whole rock geochemical data - >10,000 samples

- rock, mineralogy, structure

**New data**

– 230 samples, McArthur River area

*from Jefferson et al (2007)*

# Outline of Highlights

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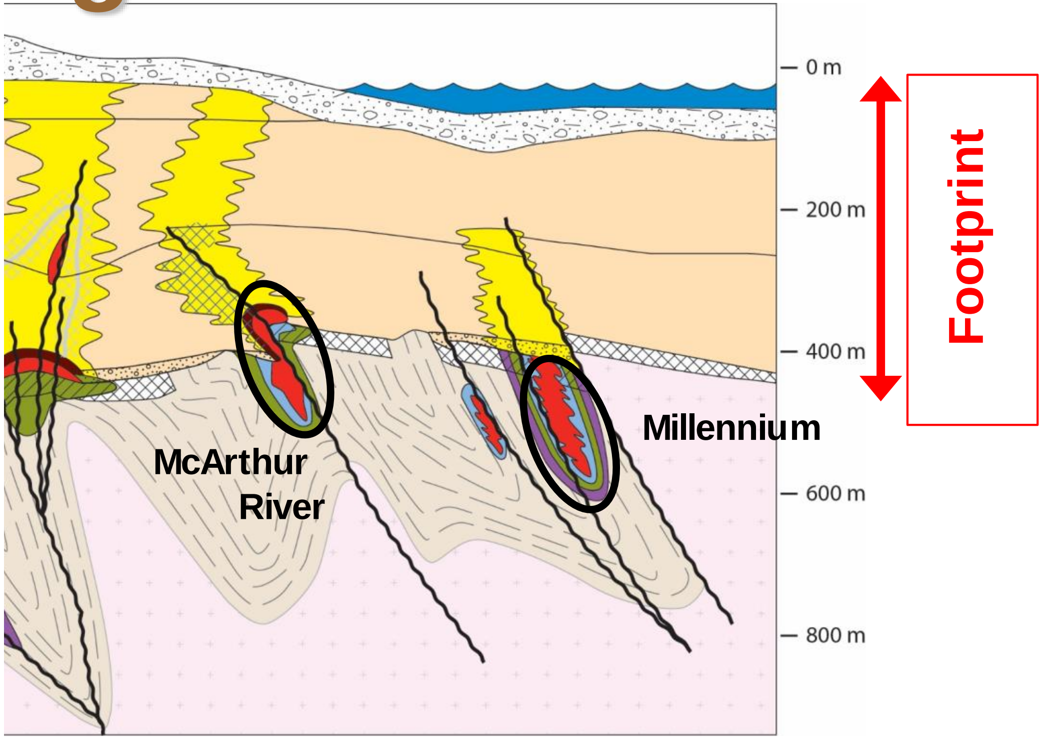
**Geochemistry in sandstone**
**Pathfinders and minerals**
**Fractures**
**Surficial mapping**
***Geophysics:***
**Overburden stripping**
**Seismic footprint**
**Consistent Common Earth Model?**




*modified after Cameco SEG Short Course (2015)*

# U Site Research Team

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- ***Site Leaders and Research Associates***
  - **Kevin Ansdell**, *Saskatchewan*
  - **Kurt Kyser**, *Queen's*
  - **Ken Wasyliuk**, *Saskatchewan*
  - **Mohamed Gouiza**, *Saskatchewan*
- ***PhD students***
  - **Mehrdad Darijani**, *Memorial*
  - **Dong Shi**, *Toronto*
- ***MSc students***
  - **Mary Devine**, *Ottawa*
  - **Shannon Guffey**, *Memorial*
  - **Nick Joyce**, *Queen's*
  - **Shawn Scott**, *Waterloo*
  - **Marissa Valentino**, *Queen's*
- ***BSc students***
  - **Yaozhu Li**, *Waterloo*
- ***Researchers and collaborators***
  - **Martina Bertelli**, *Western*
  - **Steve Beyer,** *Queen's*
  - **Michel Chouteau**, *Poly. Montréal*
  - **Najib El Goumi**, *GSC*
  - **Randy Enkin**, *GSC*
  - **Colin Farquharson**, *Memorial*
  - **Leonardo Feltrin**, *Western*
  - **Keiko Hattori,** *Ottawa*
  - **Julia King**, *Consultant*
  - **Dan Layton-Matthews**, *Queen's*
  - **Matt Leybourne**, *Queen's*
  - **John McGaughey,** *Mira*
  - **Bernd Milkereit**, *Toronto*
  - **Reza Mir**, *Laurentian*
  - **William Morris**, *McMaster*
  - **Steve Piercey**, *Memorial*
  - **Benoit Rivard**, *Alberta*
  - **Martin Ross**, *Waterloo*
  - **Pejman Shamsipour**, *Poly. Mtl.*
  - **Richard Smith**, *Laurentian*
  - **Marc Vallée**, *Memorial*
- ***Subject matter experts***
  - **Tom Kotzer,** *Cameco*
  - **Clare O'Dowd,** *Cameco*
  - **Garnet Wood,** *Cameco*
  - **Gerard Zaluski,** *Cameco*
  - **Dave Quirt**, *Orano*
  - **Rob Hearst,** *Orano*
  - **Patrick Ledru**, *Orano*
  - **Dale Verran**, *Denison Mines*
  - **Larry Petrie**, *Denison Mines*
- ***And numerous others!!***

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# Geology Model Development

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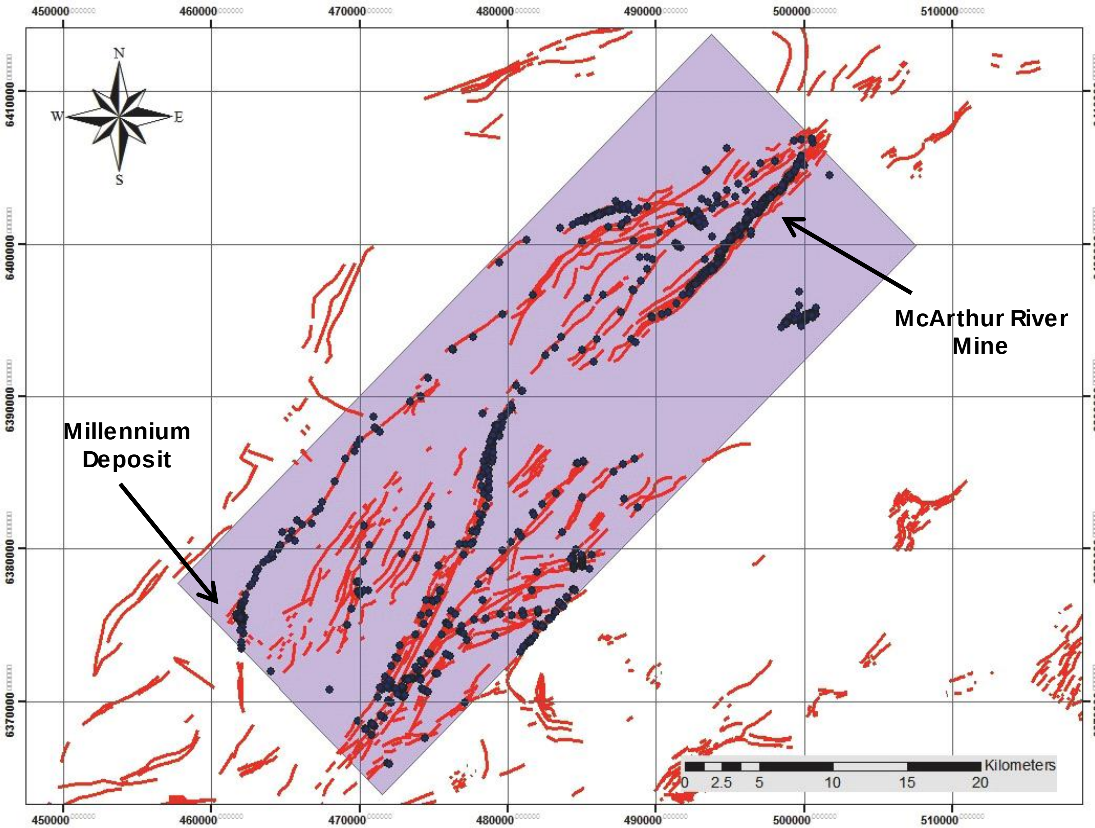
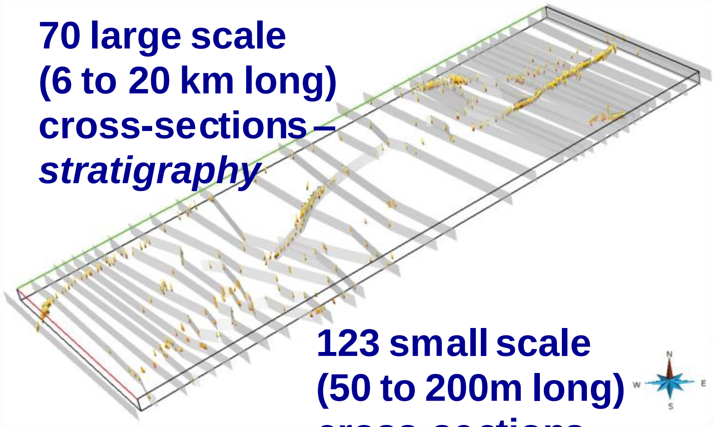



**Drilling along conductors (structures) constrains the distribution of drill holes and concentration of data (1440 holes provided by Cameco)**



**70 large scale (6 to 20 km long) cross-sections – *stratigraphy***

**123 small scale (50 to 200m long) cross-sections – *structure***

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Gouiza 2014 GAC-MAC



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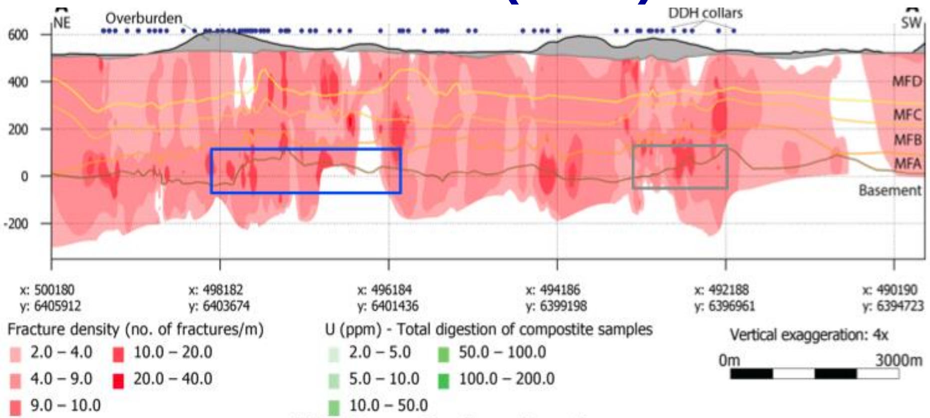
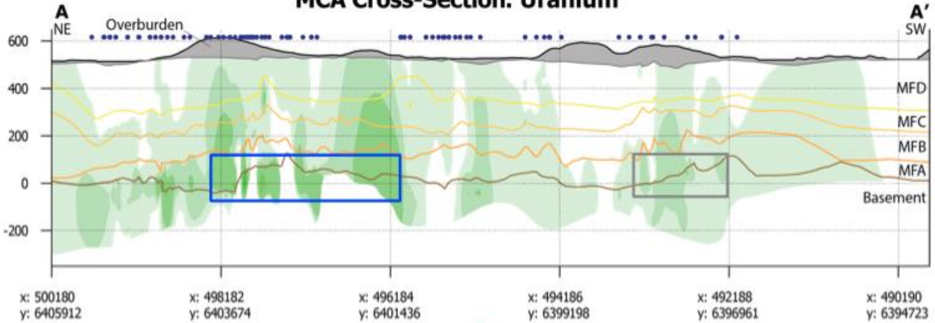
# Fracture Intensity in Sandstone

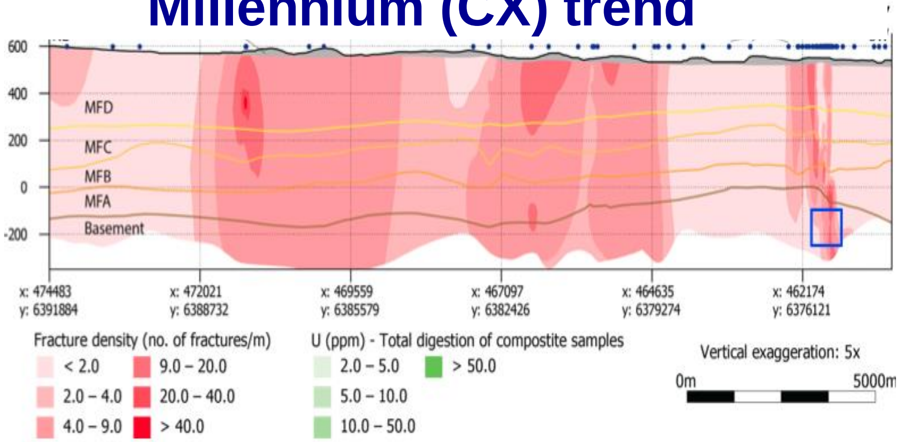
## McArthur River (MCA) trend



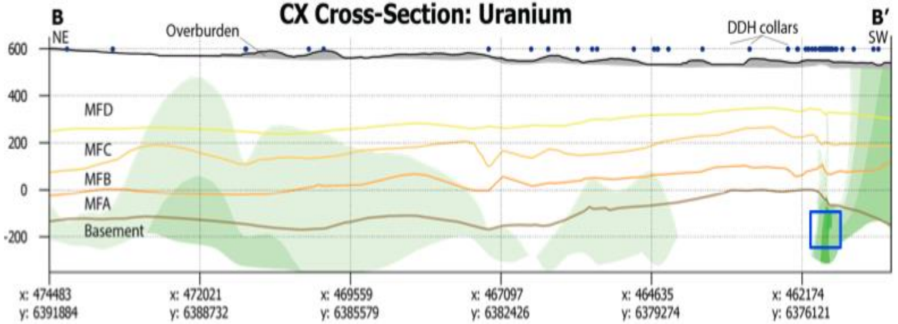

MCA Cross-Section: Uranium




## Millennium (CX) trend




CX Cross-Section: Uranium

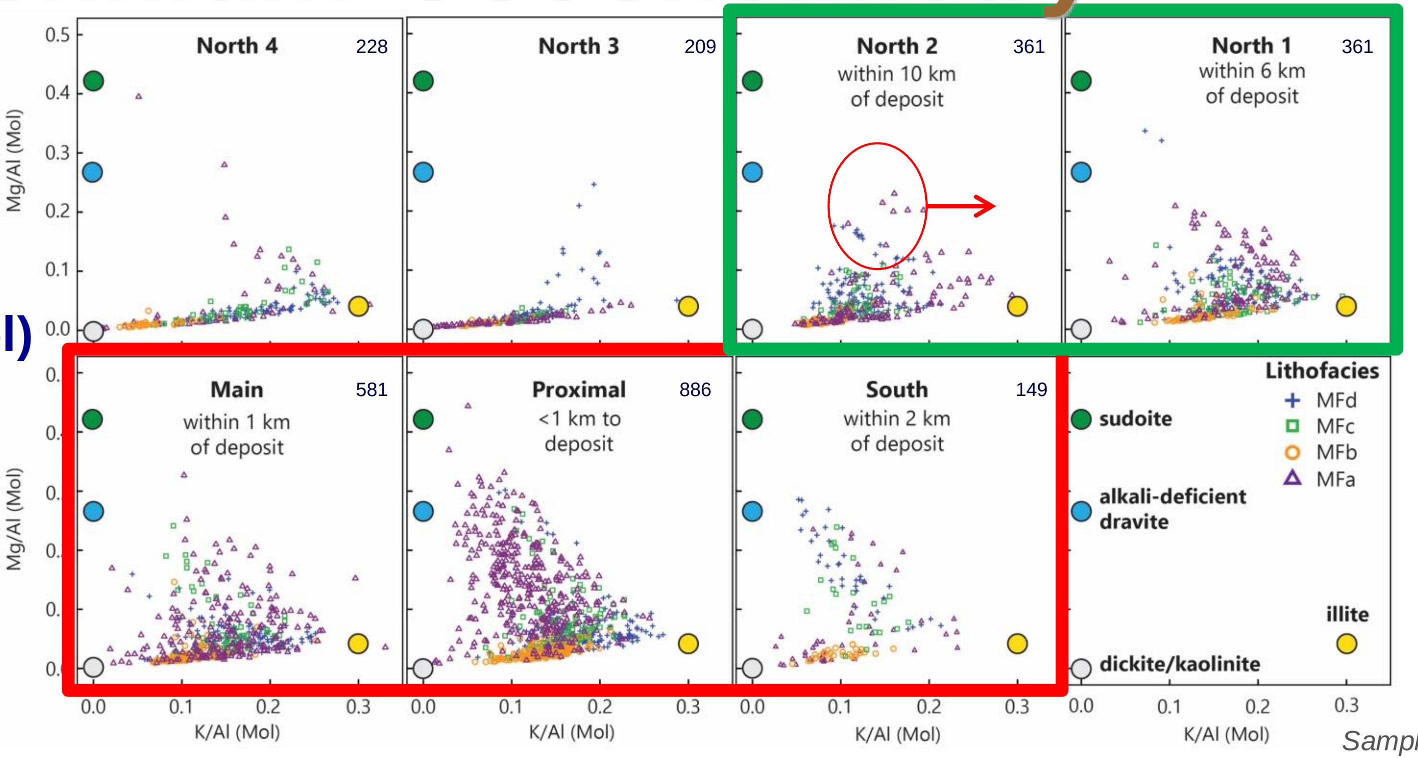



***Positive correlation between fracture intensity and uranium concentration***

Gouiza 2014 GAC-MAC

# Millennium Geochemistry

Mg/Al (mol)




K/Al (mol)

*Samples (n) in top right of each plot*

**Gradual increase in Mg/Al with respect to deposit location.**

Guffey 2017 MSc Memorial U.
Guffey 2018 GEEA in press

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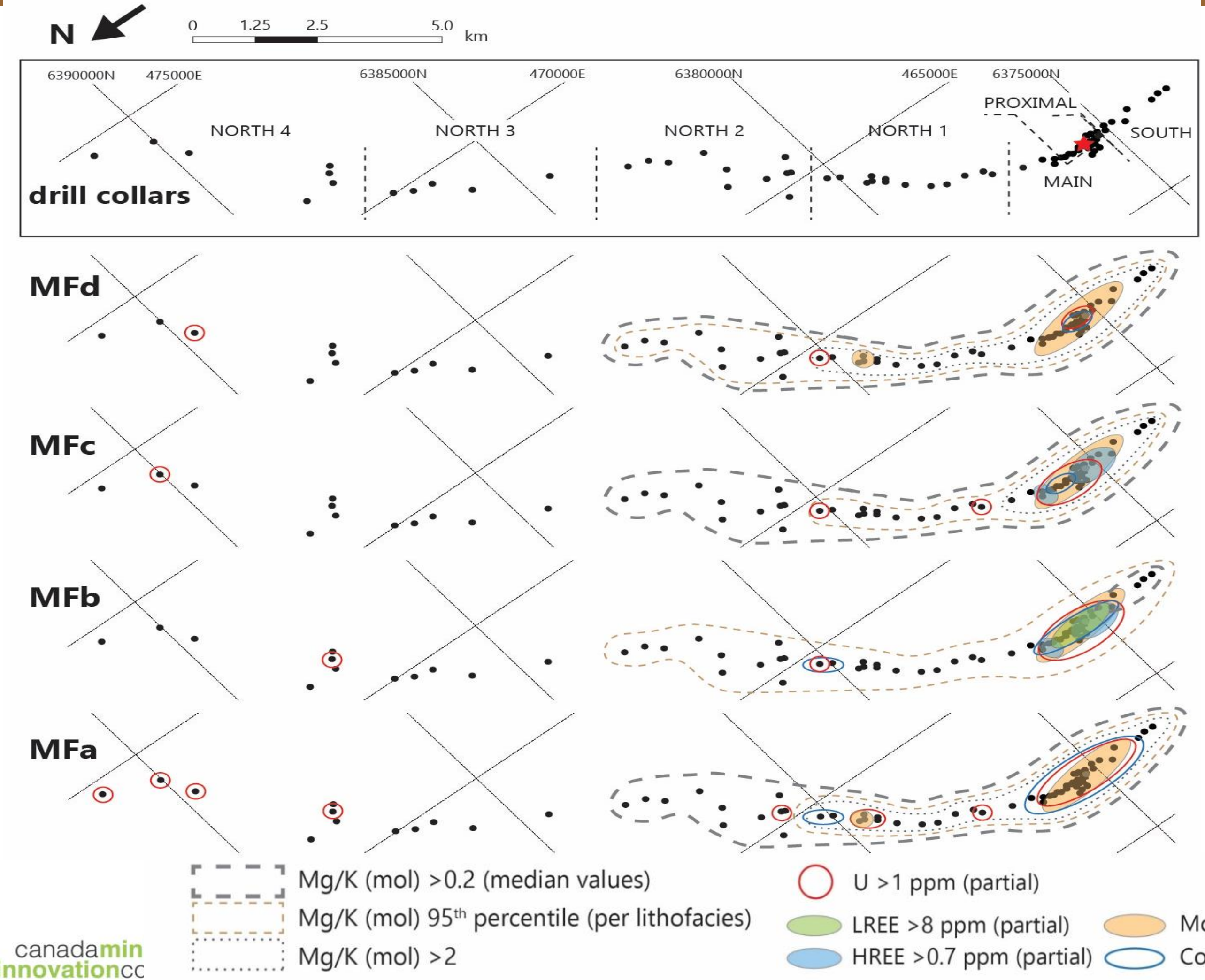


# Millennium Plan view

## Mg/K (mol) variations observed >10km along structure

## "Chimneys" of certain elements (e.g. Mo) above deposit

Guffey 2017 MSc Memorial U.
Guffey 2018 GEEA in press

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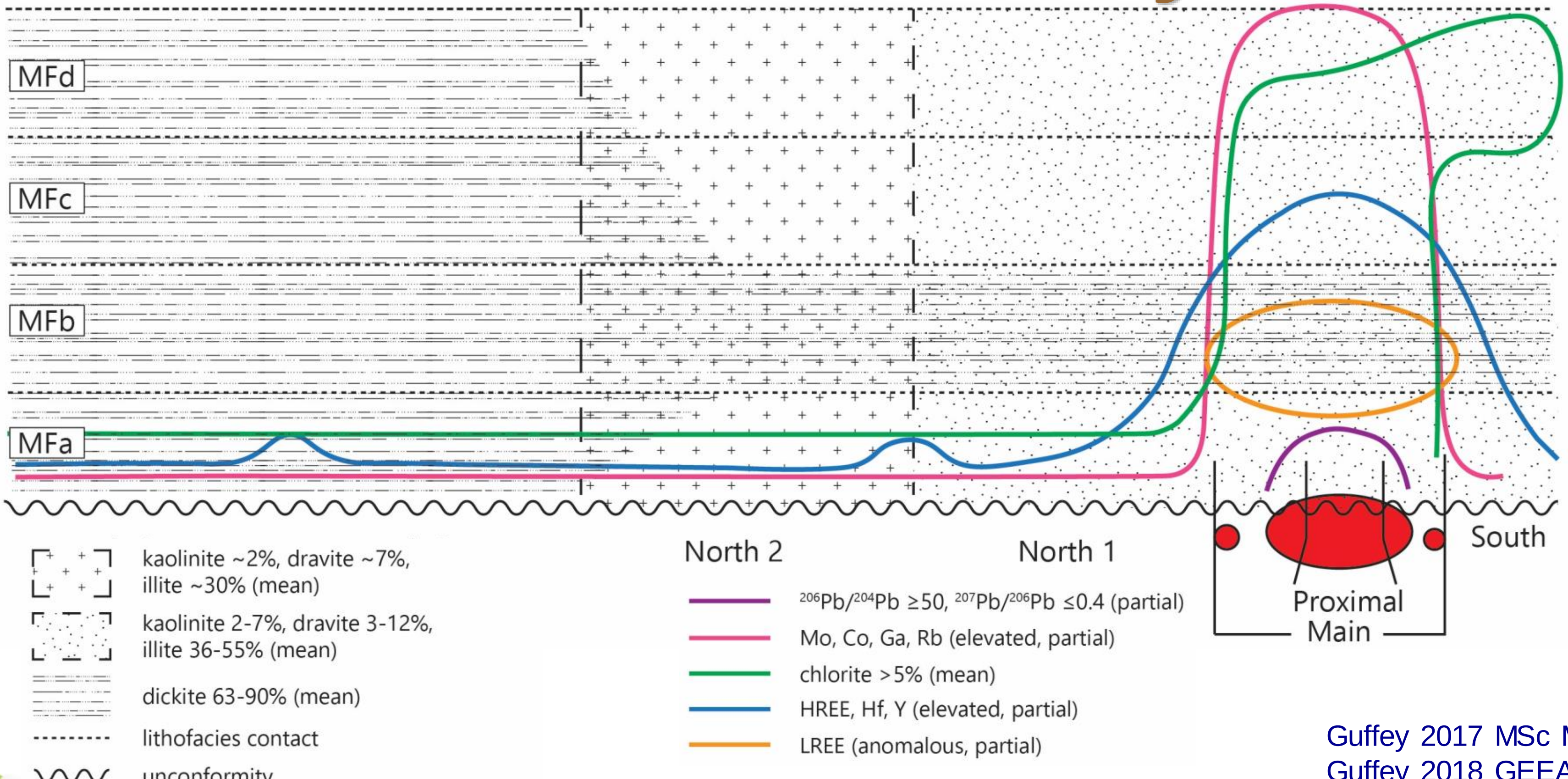
# Millennium Geochemistry




*Not to scale: looking east*

Guffey 2017 MSc Memorial U.
Guffey 2018 GEEA in press

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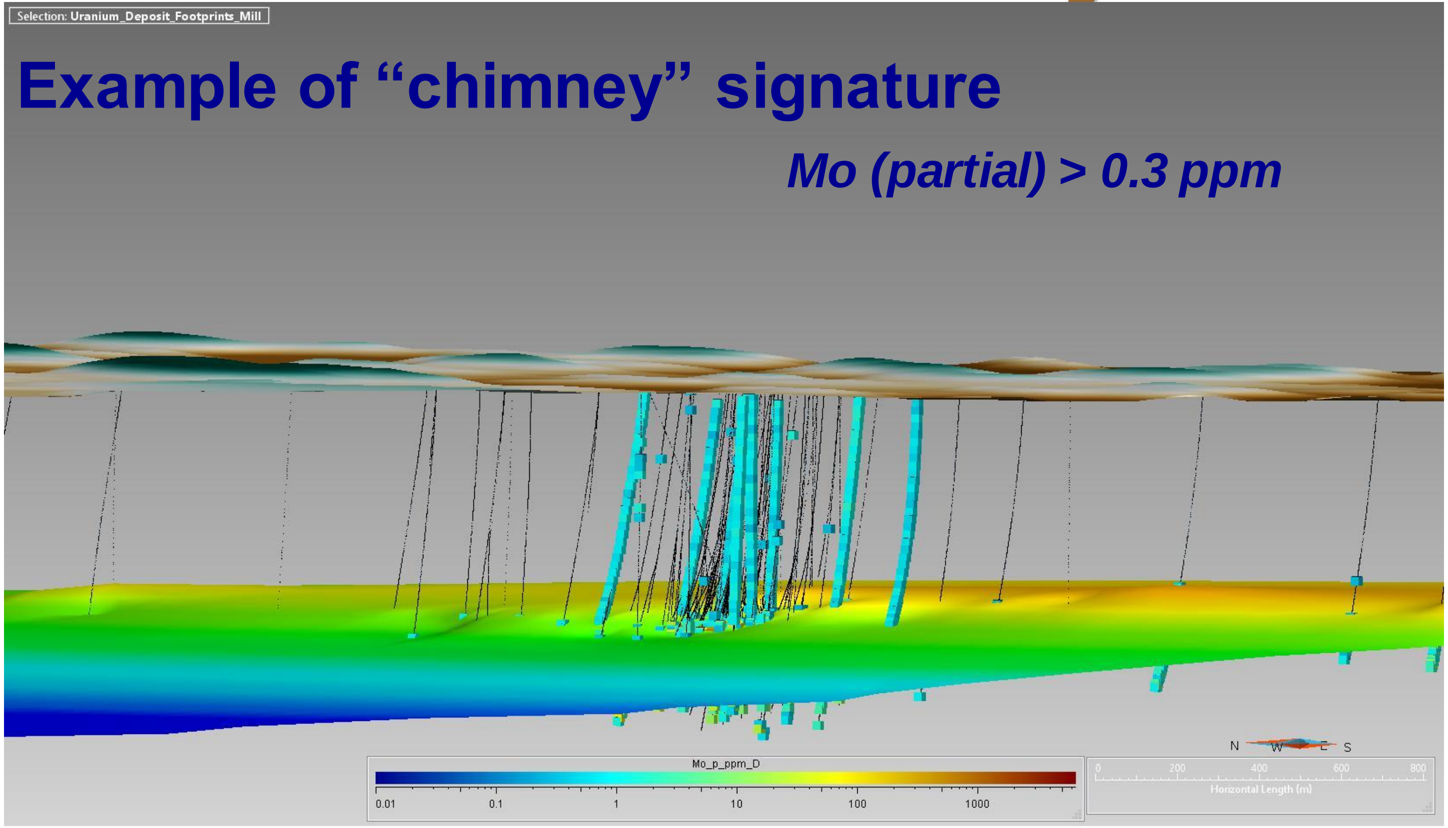
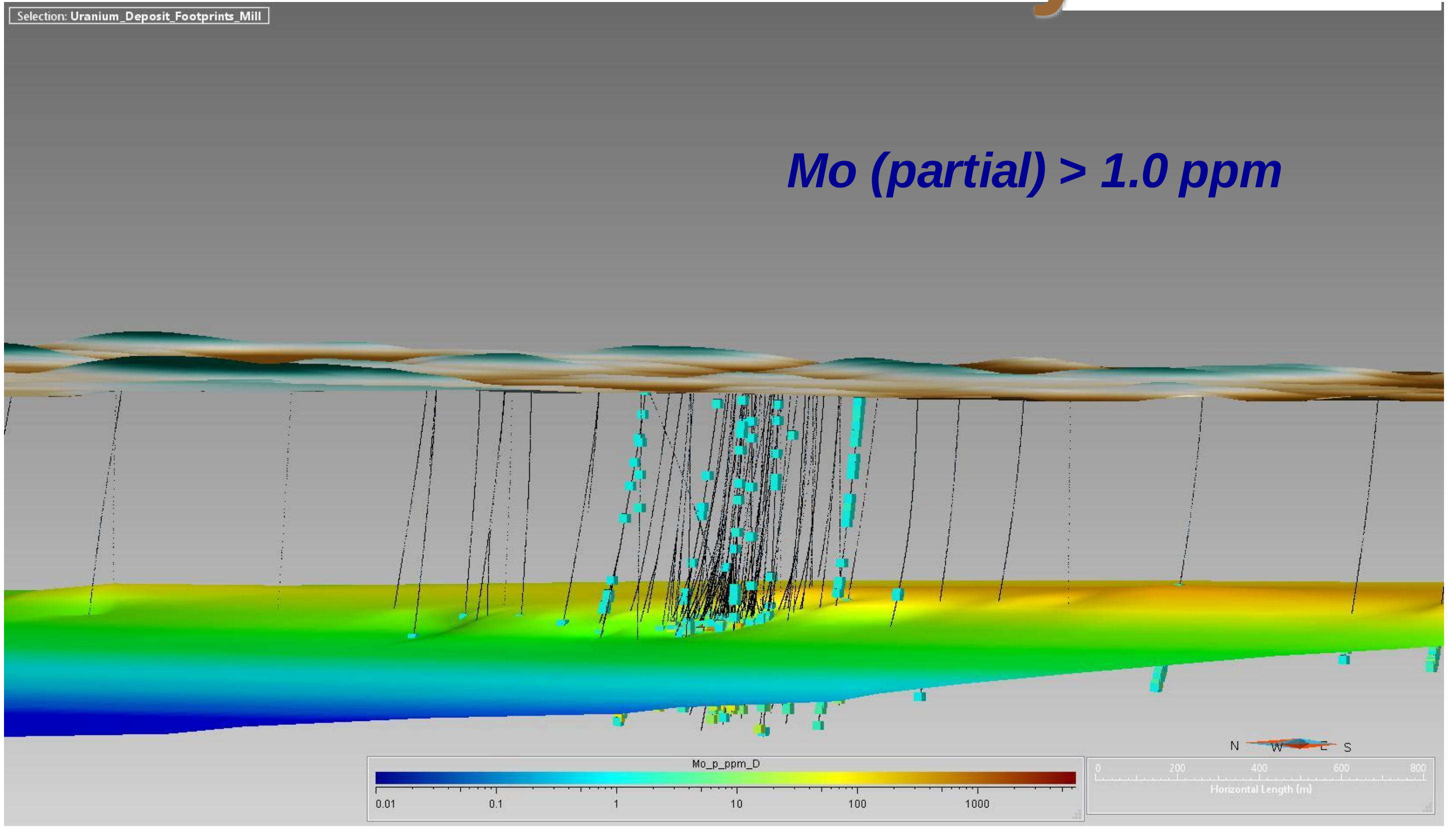
# Millennium Geochemistry



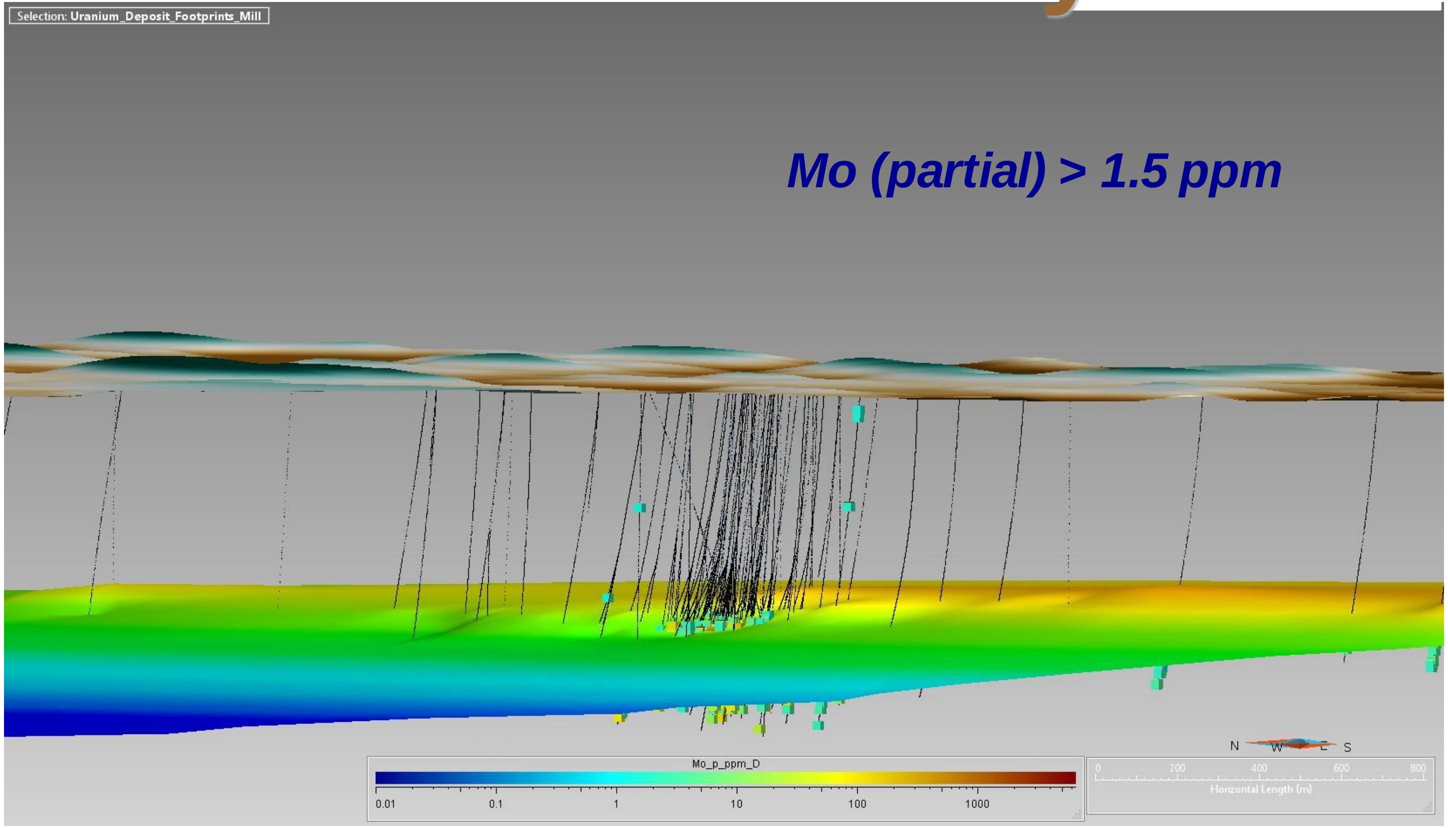

*from Common Earth Model*

# Millennium Geochemistry




*from Common Earth Model*

# Millennium Geochemistry




*from Common Earth Model*

# EDA: Millennium Volume

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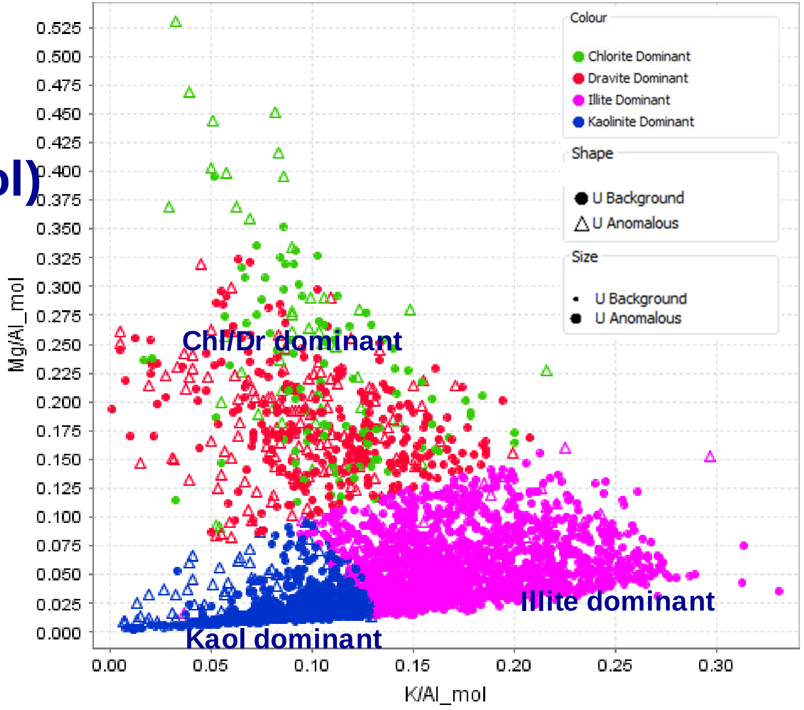
## Four main groups were identified:

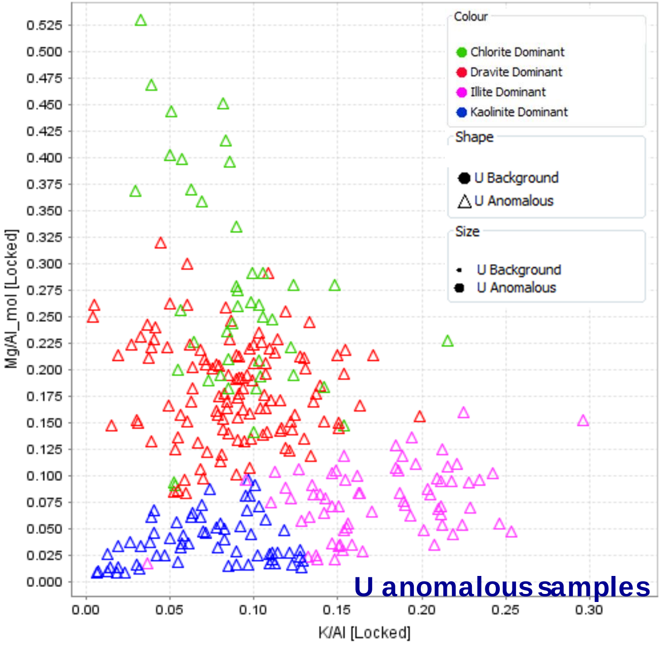
## Illite, kaolinite, chlorite, dravite

Mg/Al (mol)




K/Al (mol)

## ~30% of chl/dr groups are anomalous with respect to U

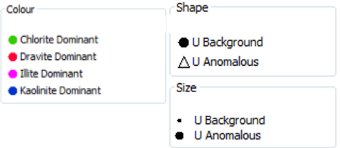


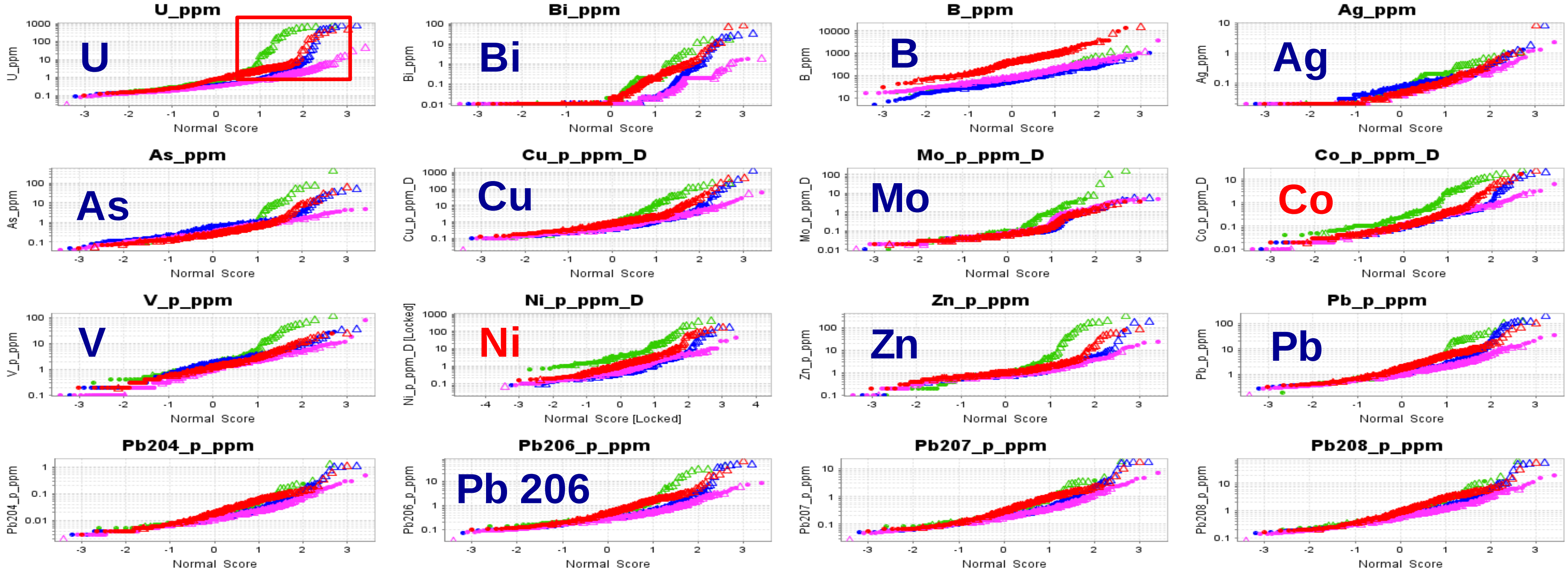

## 90th percentile – 1.34 ppm U

# Minerals and Key Elements

- Uranium enrichments in all the groups, although predominantly in the chlorite group. Similar behaviour for Bi, As, Cu, V, Zn, Pb Mo, and $^{206}Pb$.

- The chlorite group is characterized by an overall enrichment in Co and Ni.



# Pathfinder Mass Balance

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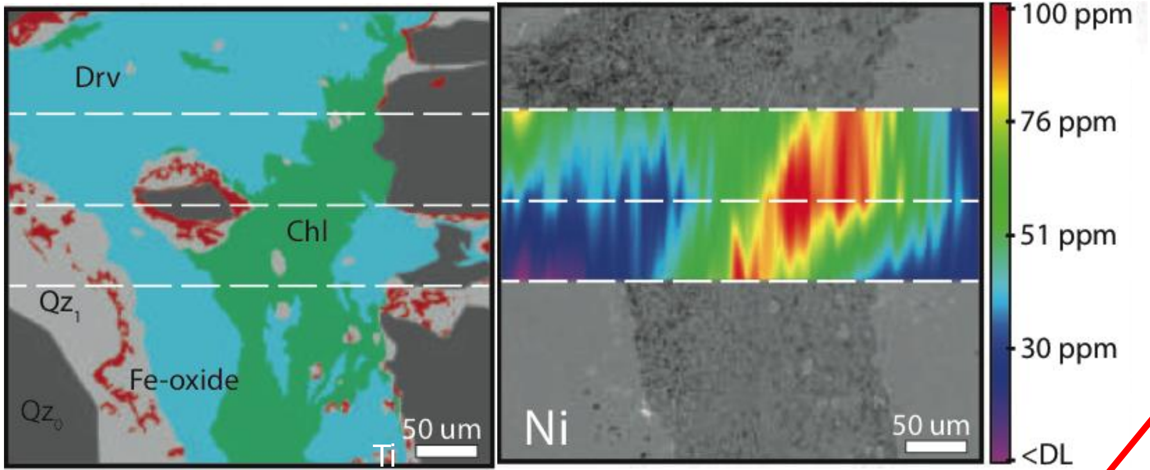
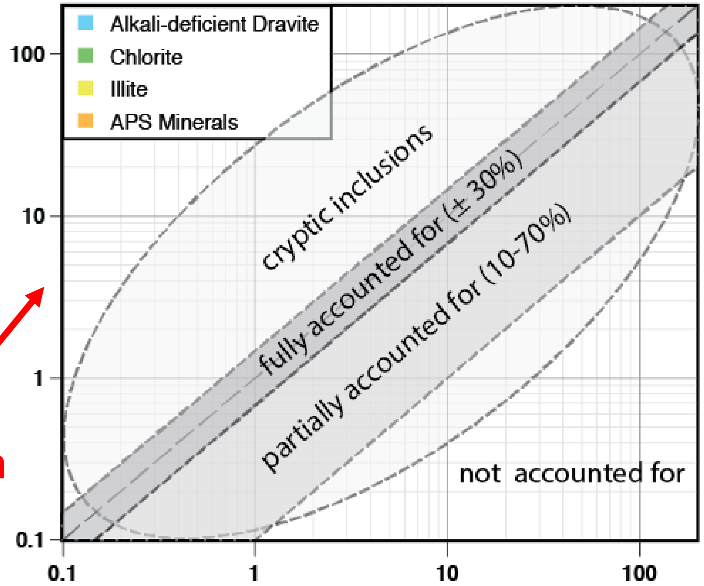



*APS aluminophosphate sulfate*




**LA-ICP-MS chemical mapping of interstitial assemblages, detrital grains, and cements provides new insights into the distribution and inventory of pathfinder elements**

**Concentration of element in mineral (Norm mineralogy, LA-ICPMS of mineral)**

**Concentration of element in whole-rock analysis (ppm)**

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Joyce 2017 GAC-MAC

# Pathfinder Mass Balance

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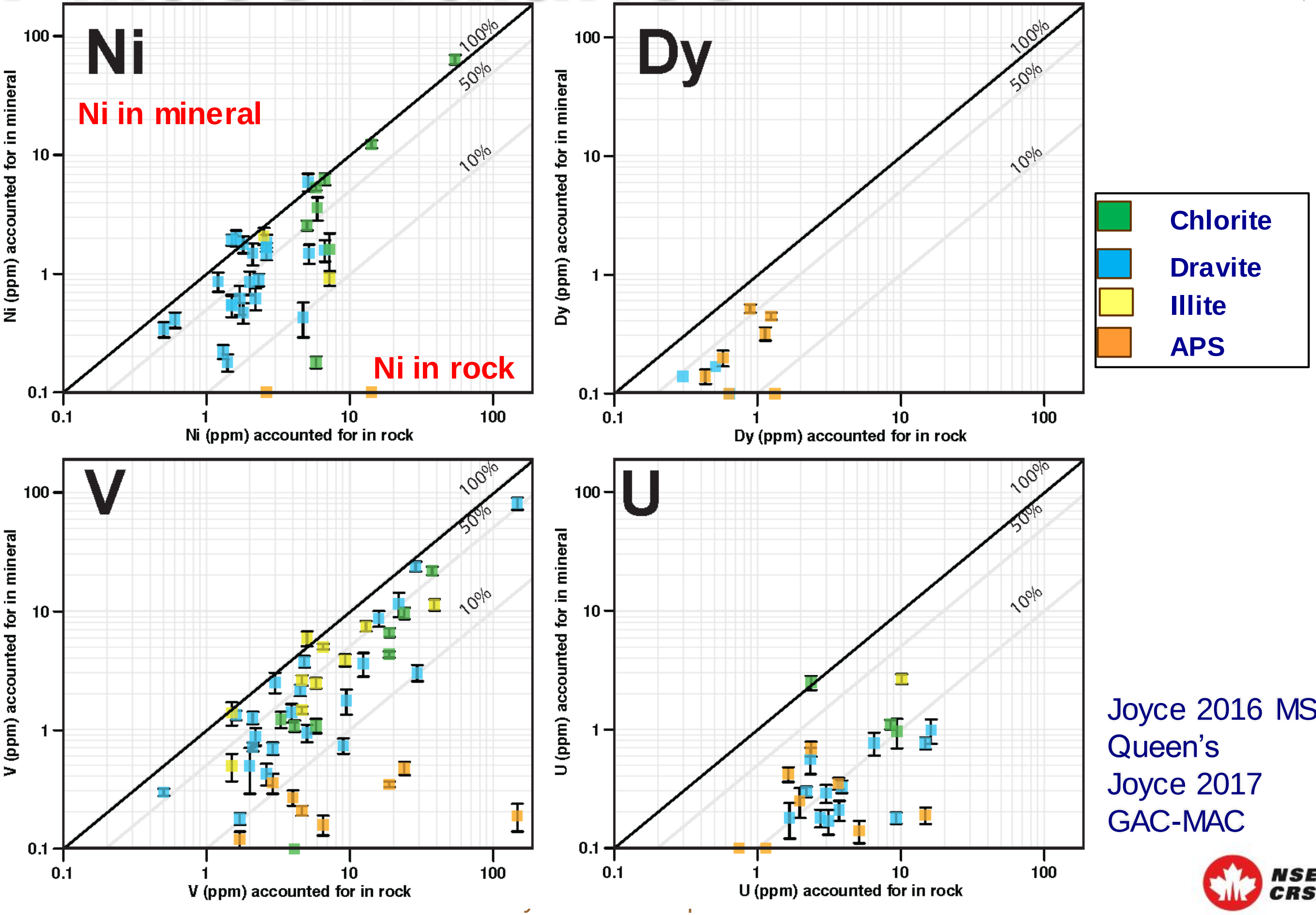
## Examples:

- Ni is accounted for in Chlorite and increases in concentration with proximity to ore
- REE, and significant U are accounted for in APS minerals, Apatite, and Monazite
- U, and V are not fully accounted for in the minerals analyzed; in or adsorbed to the surfaces of Fe oxides

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# Overview - Alteration

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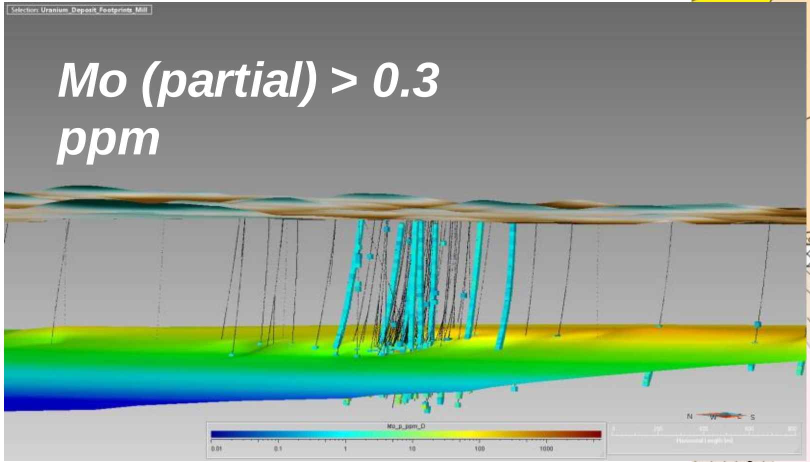


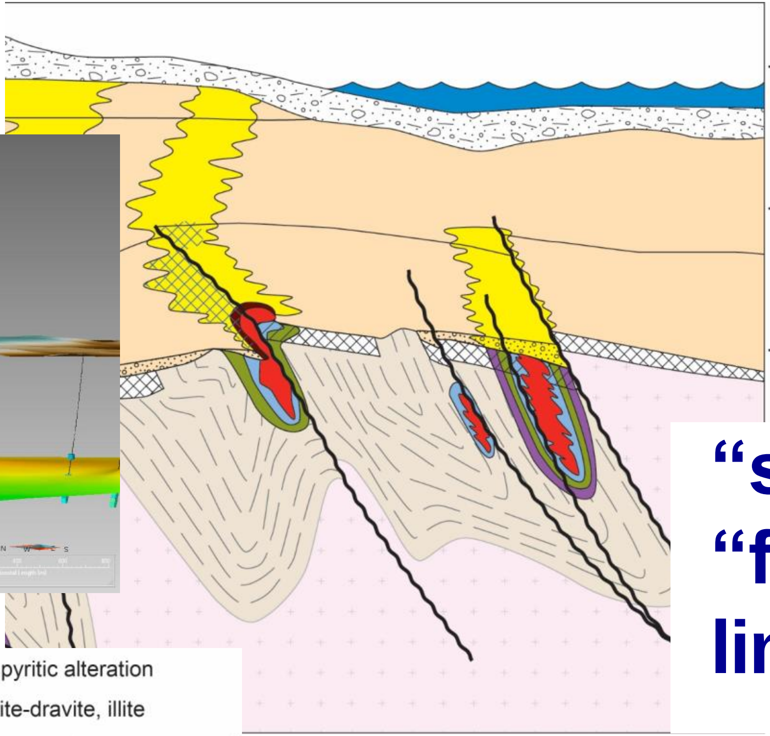


**"structures" "fractures" link to surface**

**Is there a Footprint signature at the surface?**

# Fractures: McArthur River

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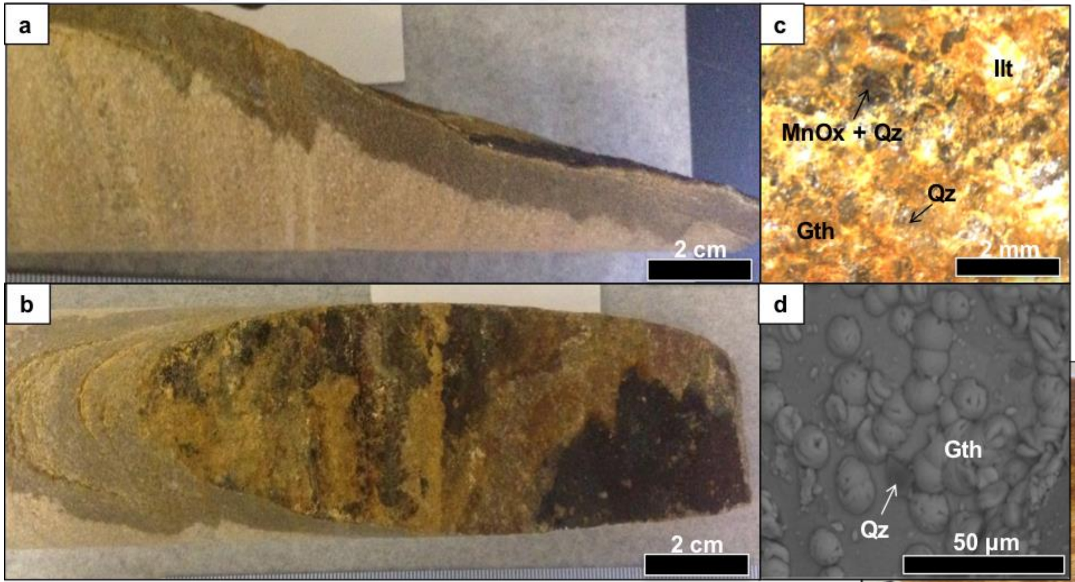
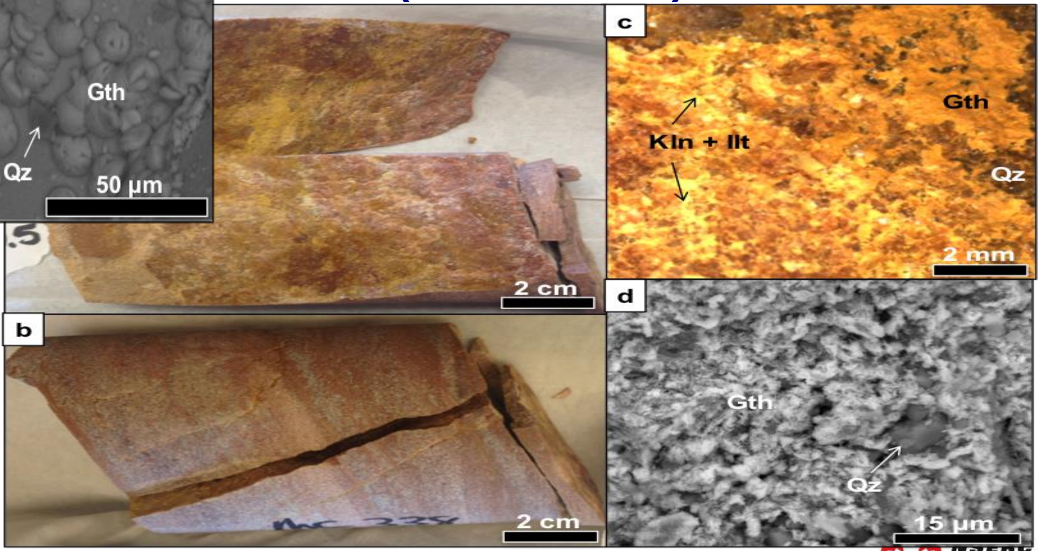



**Brown fracture coating (MC-344-379.3)**

***fracture face and orientation, optical and SEM mineralogy***

**White and yellow fracture coating (MC-338-504.5)**




## Fractures classified on colour, mineralogy, chemistry

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Valentino 2017 MSc Queen's
Valentino 2017 PDAC

# Fractures: Stable isotopes

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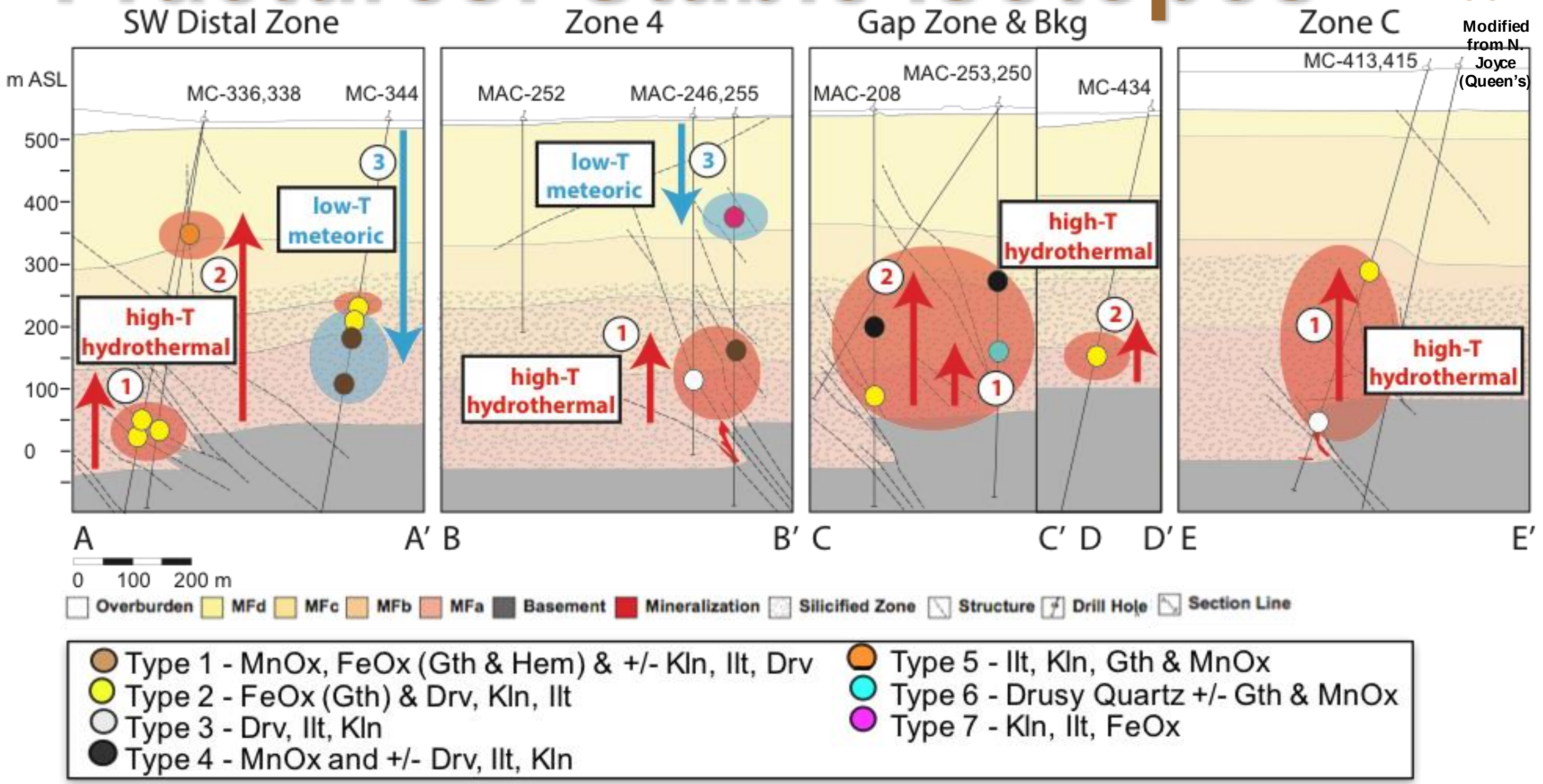


Modified from N. Joyce (Queen's)

**Record of high-T (~200 °C), and low-T (25-50 °C) fluids preserved in fracture coatings**

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# Continuous Leach-ICP-MS

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**Black & orange fracture-coating (MC-338-121; Ilt, Kln, FeOx, MnOx)**

*Multipliers were used to bring elements to a common scale*

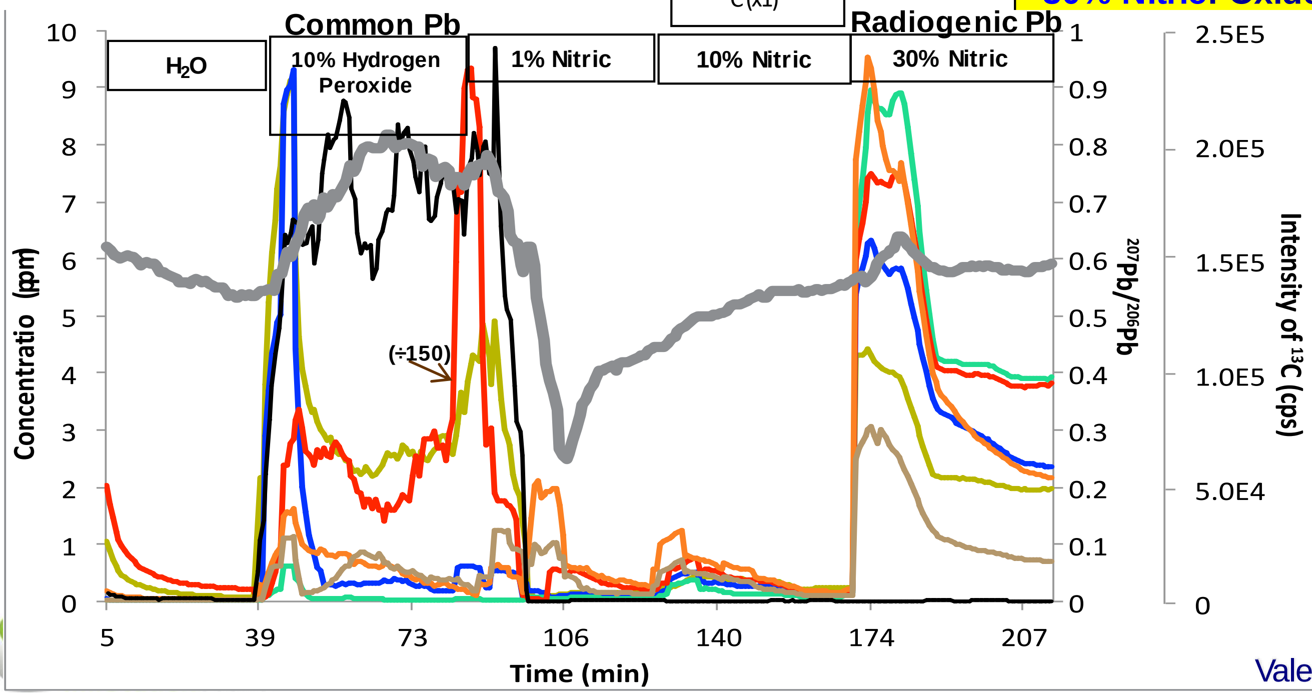
**What is released with each leaching solution?**

**Water:** Weakly held fine sediment

**10% Hydrogen Peroxide:** Dominantly organics ($^{13}C$)

**1% Nitric:** Surfaces - Similar to WAL

**30% Nitric:** Oxides/Silicates/Sulphides - Similar to AR




**organic control on common Pb because associated trace and major elements (e.g. Mn) appear to be adsorbed onto organics (leached with 10% hydrogen peroxide)**

**clay and Fe oxide association with radiogenic Pb (Brown (White & Yellow) fractures) as Pb, U, Al, and Fe are released during 30% nitric leach phase**

**- *link to U-rich source (deposit)?***

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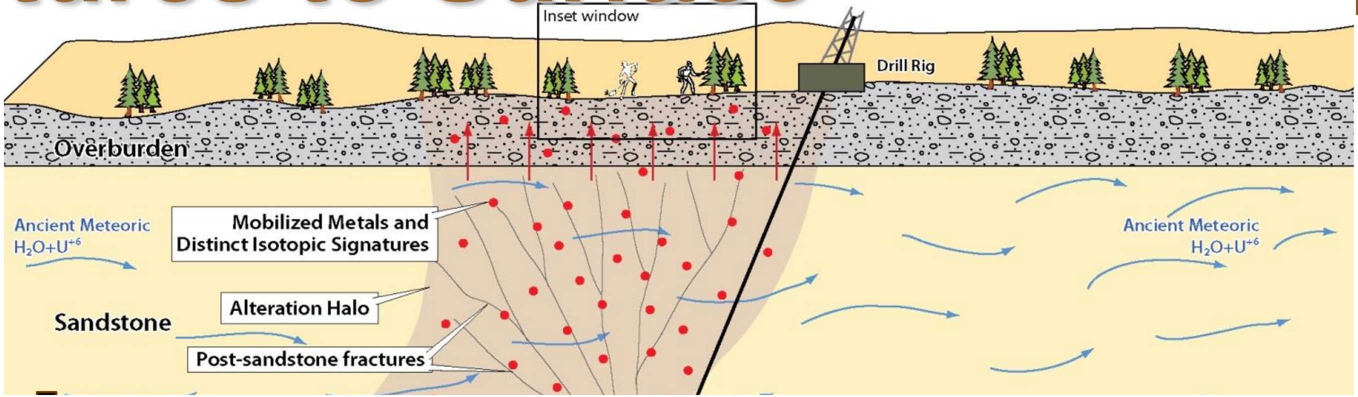
# Fractures to Surface






*modified after Kyser and Uravan Minerals*

- **White and yellow fractures (Drv, Kln, Ill, Fe oxides (Gth))**
- **likely formed from hydrothermal fluids, reflected by a near neutral pH and high $\delta^2$H values of fibrous goethite, and anomalous values of U, V, and radiogenic Pb**
- ***Primary dispersion***

**Brown fractures (Mn oxides, Fe oxides (Gth and Hem) +/- Kln, Ilt, and Drv)**

**elevated Co, Ba, Tl, Mn and low $^{207}$Pb/$^{206}$Pb values throughout the entire depth profile**
***– useful vector***

***Secondary dispersion***



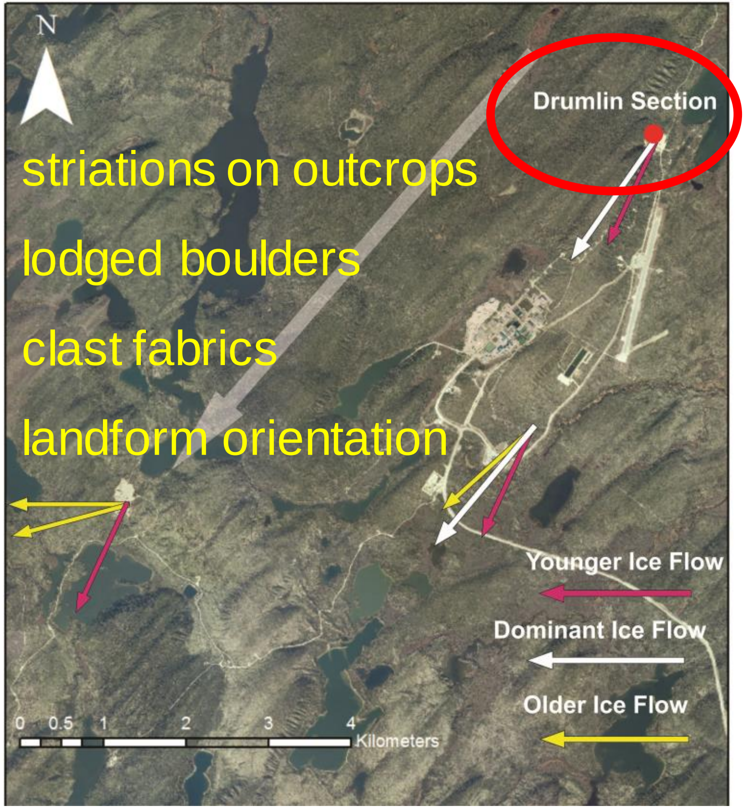


Valentino 2017 MSc Queen's

# Surficial Geology: McArthur River

**Important to understand the geological relationships in the glacial deposits to interpret results from media being sampled**

**- are anomalies from the glacial deposits, or mineral deposits at depth *– 500 m***

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# Pebble Counts and Stratigraphy

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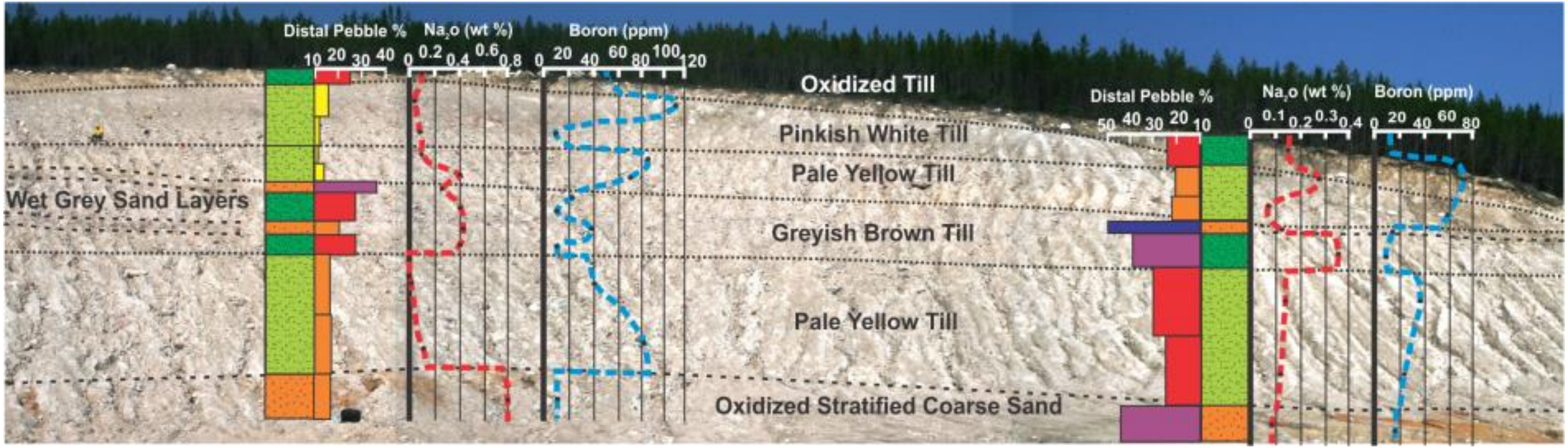


- <u>**Drumlins are stratified**</u>**. Internal stratigraphy is complex**
- **Includes one middle horizon of more 'distal' provenance (sandstone-poor, boron depleted, and $Na_2O$ enriched) between two contrasting layers of dominantly 'local' provenance (sandstone/boron-rich and $Na_2O$ depleted) + a thin landform-conformable carapace of distal provenance**

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# Predictive Map Rationale

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- **Existing surficial maps in the eastern Athabasca Basin are based mostly on geomorphology (streamlined vs hummocky) and dominant surficial sediments (glaciofluvial vs till)**
  - No information on till lithology and provenance, and therefore prospectivity
- **Airborne radiometric datasets cover the whole Athabasca basin and if predictive mapping accurately maps sediments in the study area then it may be able to be applied elsewhere in the basin**
  - **Potentially the most cost effective method for mapping sediments**

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# Radiometrics and Pebbles

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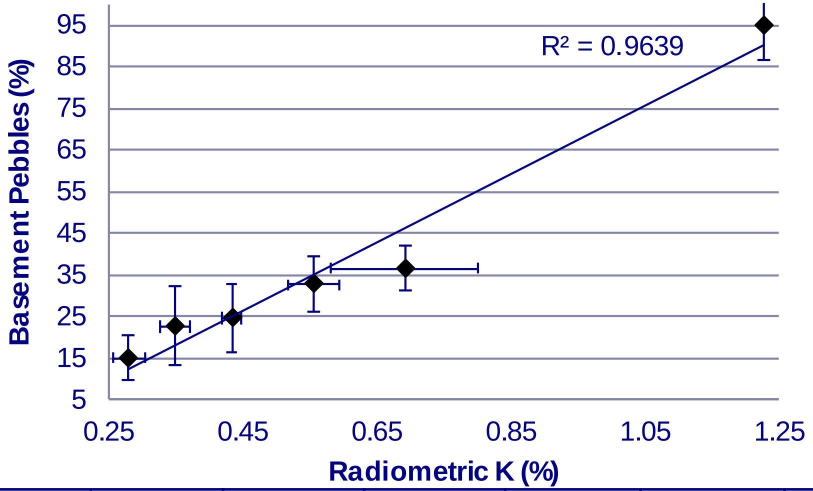


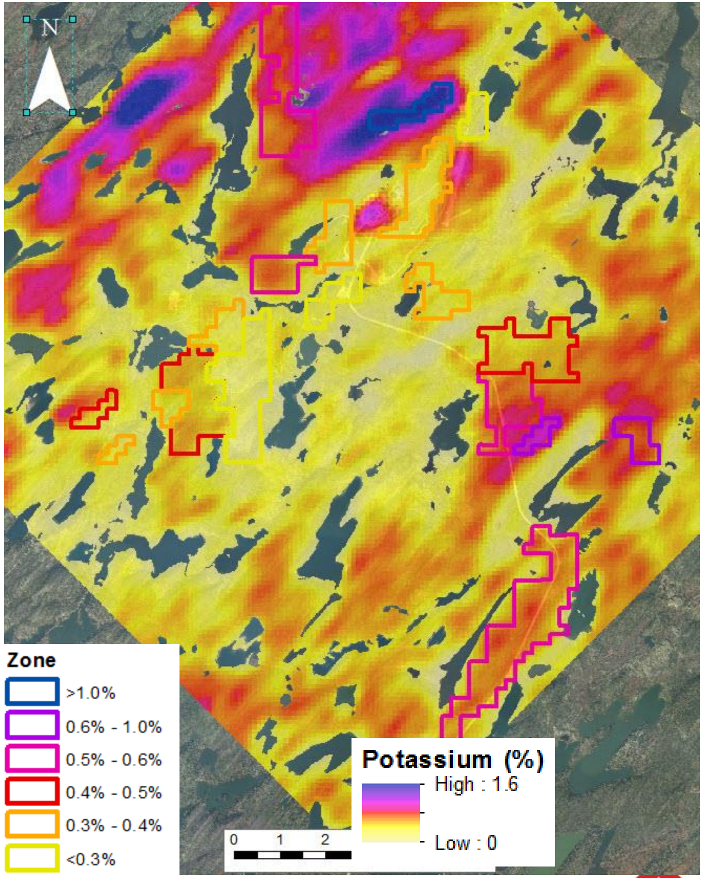


| | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 |
|---|---|---|---|---|---|---|
| Range (K%) | <0.3 | 0.3-0.4 | 0.4-0.5 | 0.5-0.6 | 0.6-1.0 | >1.0 |
| Average (K%) | 0.279 | 0.348 | 0.433 | 0.555 | 0.692 | 1.227 |
| # of Samples | 15 | 28 | 14 | 14 | 5 | 4 |

# Predictive Map

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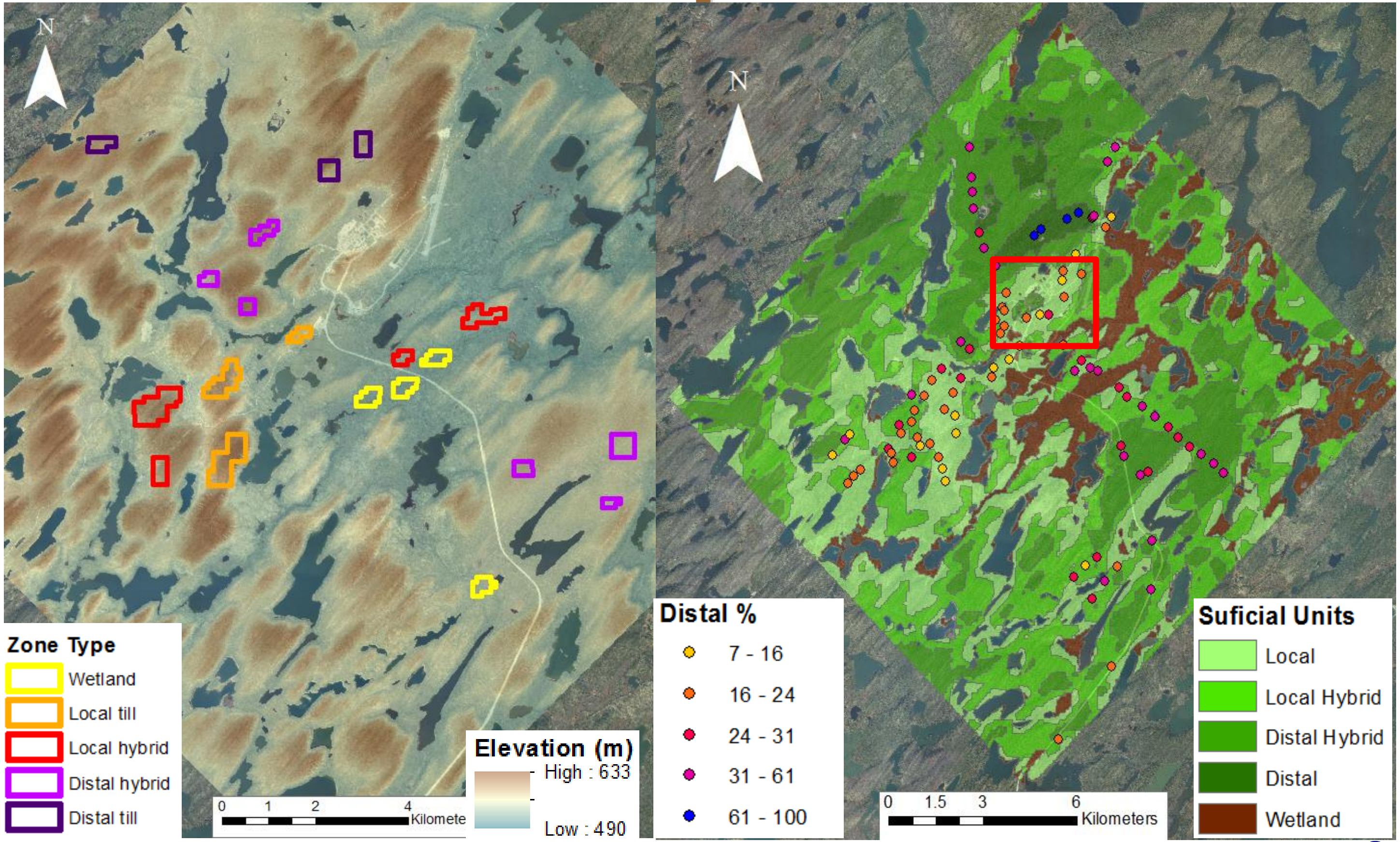


**Local best to sample**

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# Multimedia Surficial Sampling

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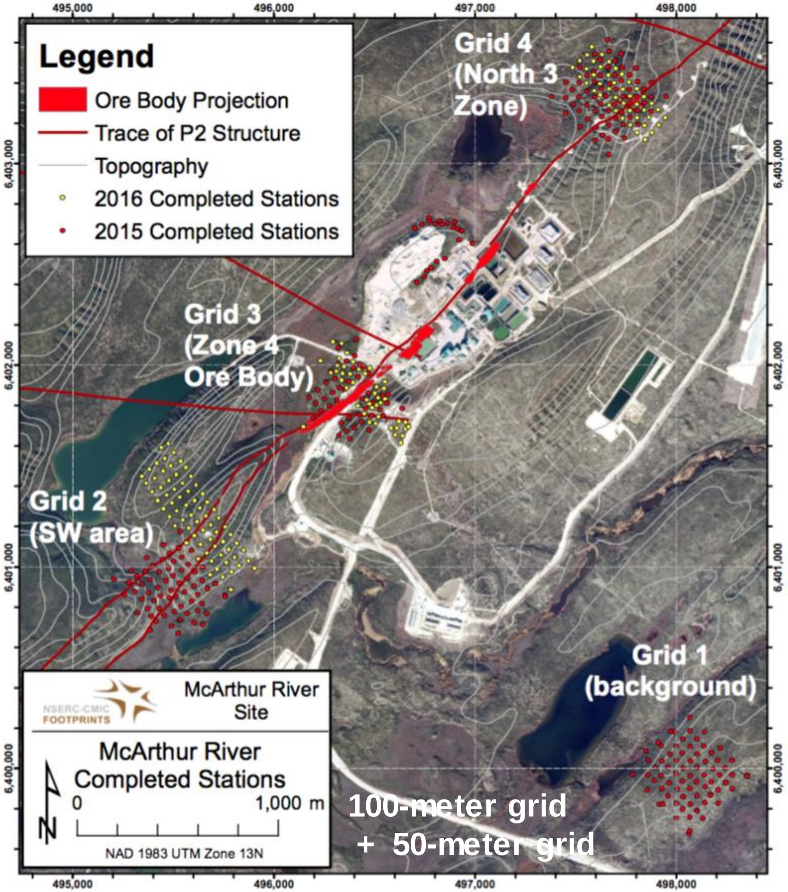
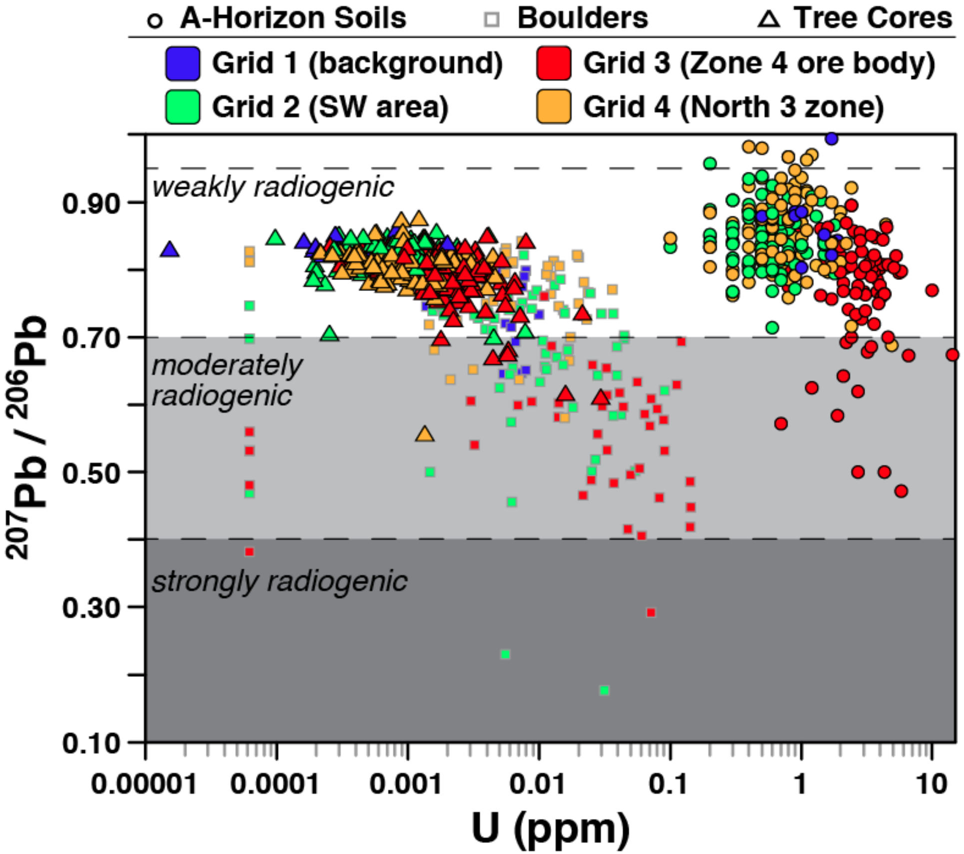



100-meter grid + 50-meter grid



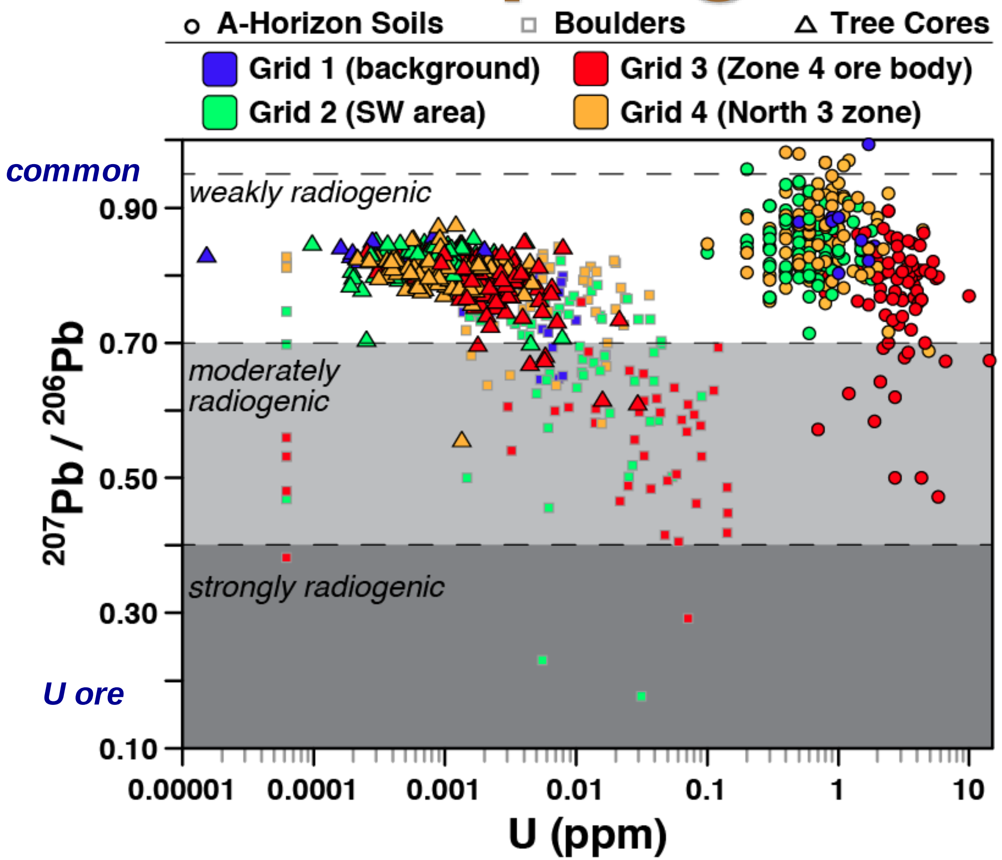



Beyer 2017 GAC-MAC

# Multimedia Surficial Sampling



- **All sample media on Grid 3 give the highest relative U concentrations and the most radiogenic Pb***
- **Higher U and rad. Pb results on Grids 2 and 3 suggest the P2 fault is a conduit for secondary dispersion even away from the high-grade ore body**
- **Higher U and rad. Pb boulders on Grid 2 may represent glacial dispersion from Grid 3**

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# Overburden Stripping

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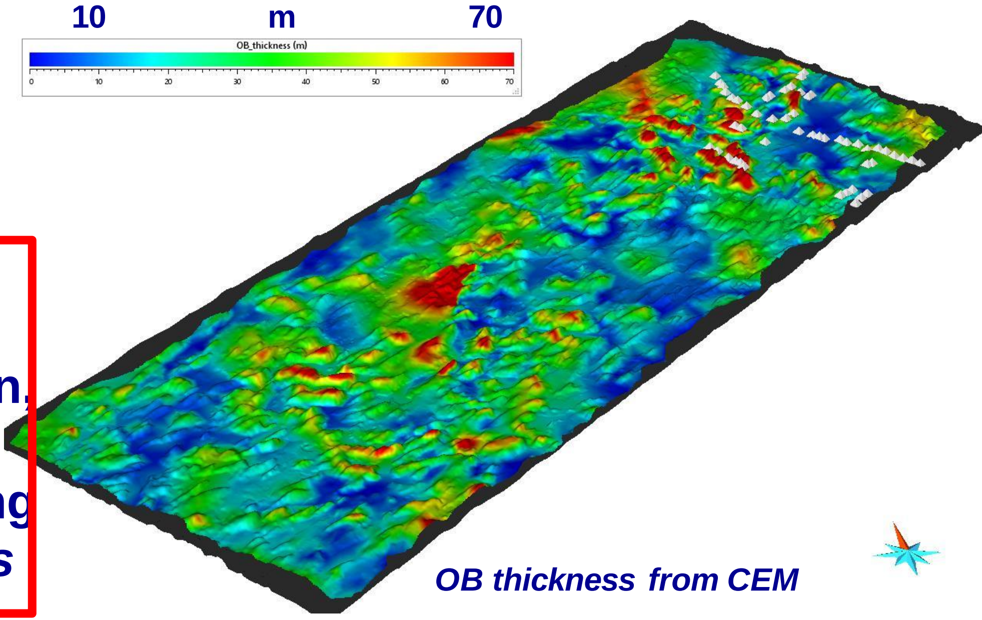
**Develop methods to separate the gravity contribution due to variable thickness glacial sediments from the gravity contribution due to alteration in the sandstones**

***Better resolution of alteration at depth***

**Modelling of synthetic data**

- **Independent, constrained and joint inversions of gravity, seismic refraction, magnetic, and EM data, and spectral analysis and frequency filtering**
- ***Most advanced inversion techniques***




*OB thickness from CEM*

# Rock Properties

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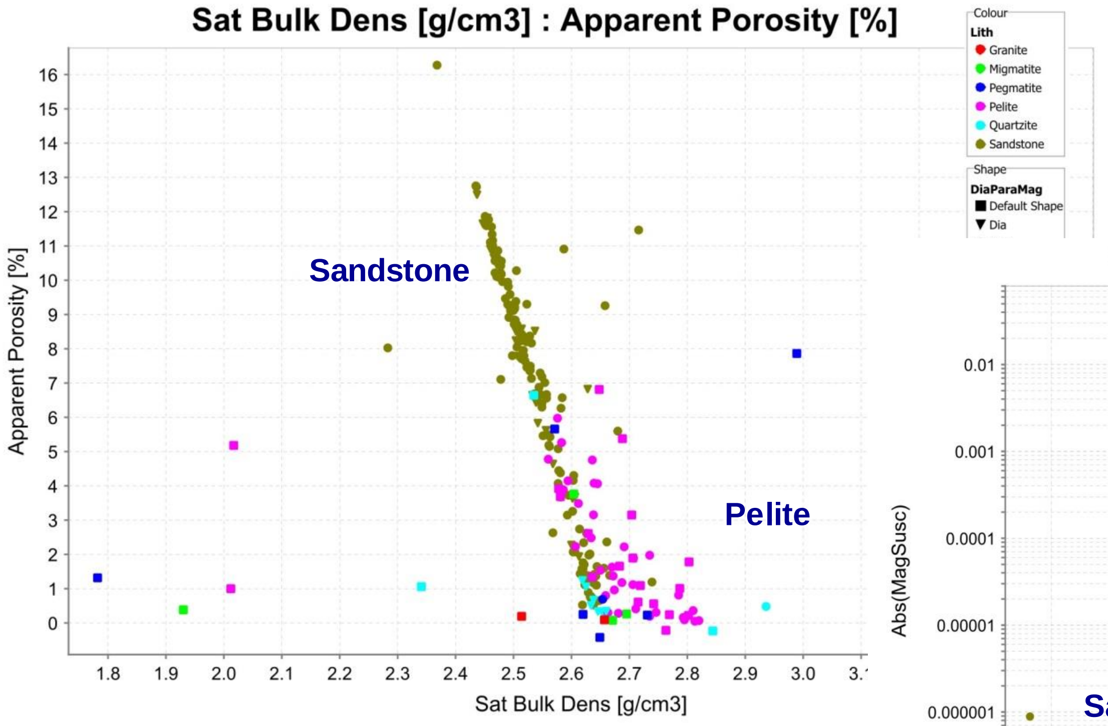
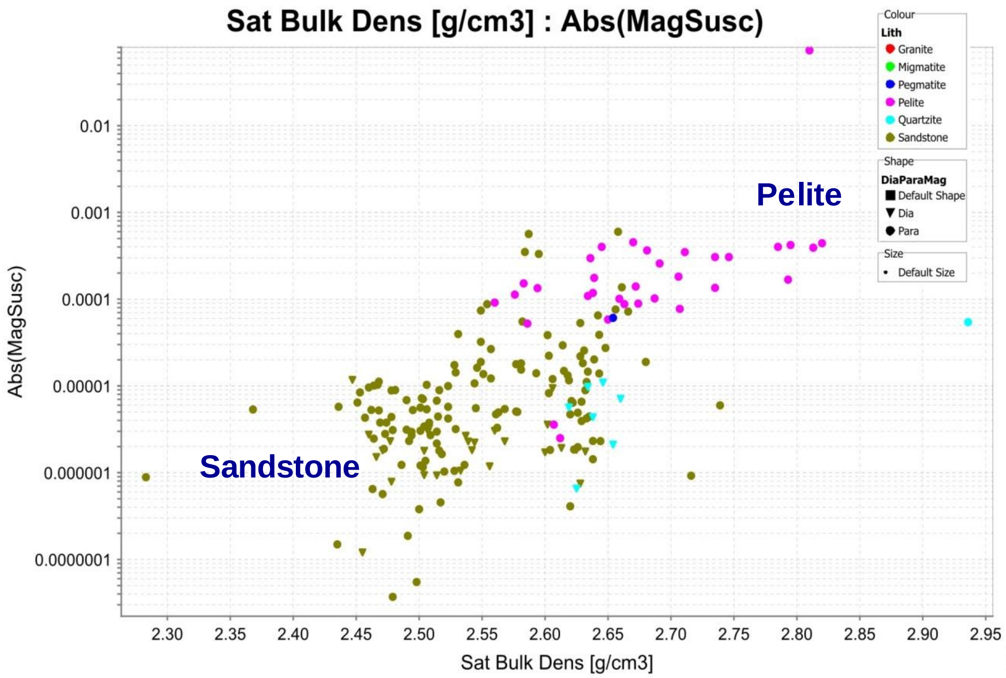



**New data collected on samples adjacent to new geochemistry samples – McA River area, and ~500 legacy data from drillholes**




Shamsipour, Chouteau, Enkin, El Goumi

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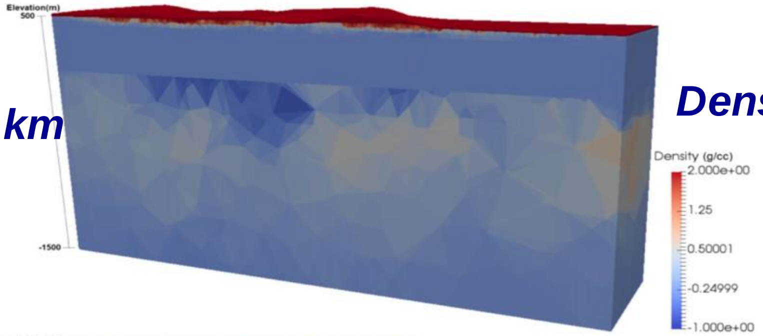
# Magnetic, Gravity and VTEM

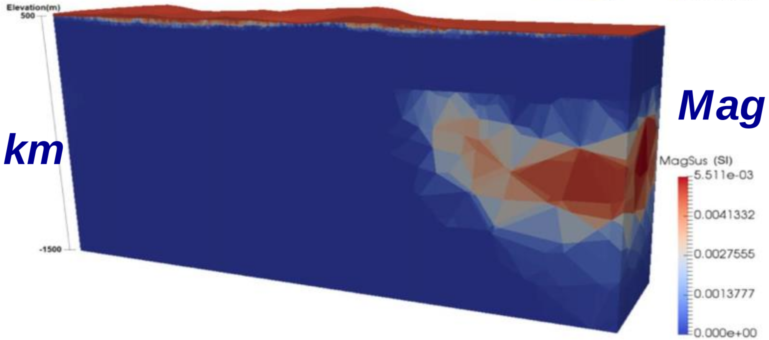
NSERC-CMIC FOOTPRINTS

2 km

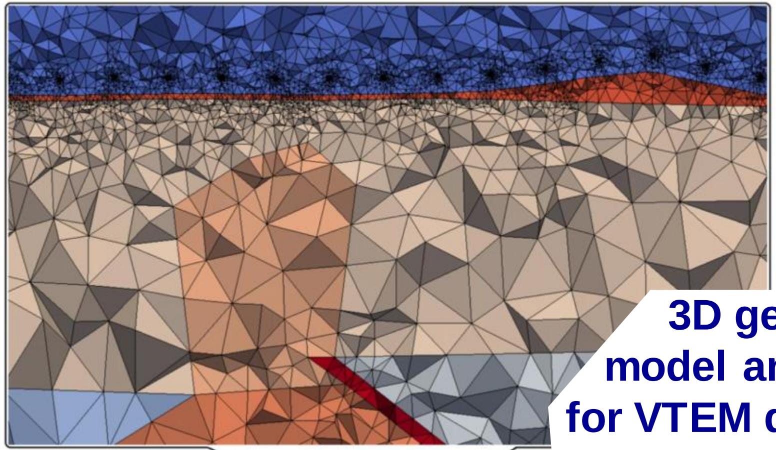



*Density*

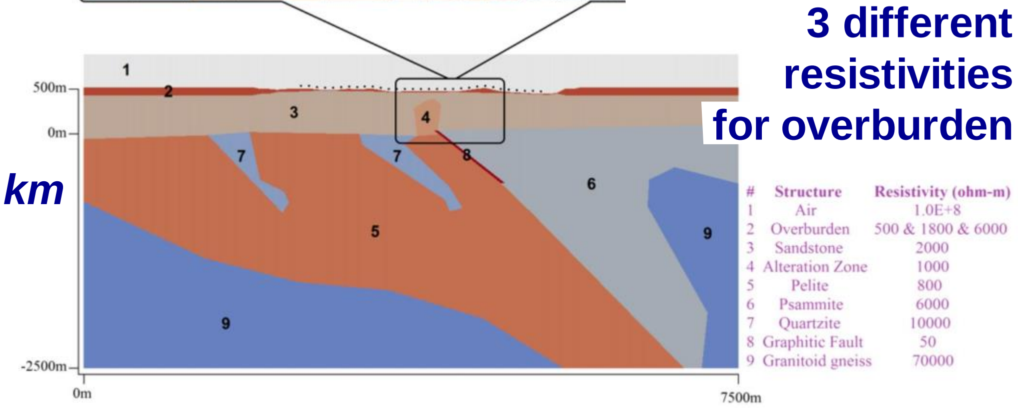
2 km




*Mag Sus*



3 km




**3D geological model and mesh for VTEM data and 3 different resistivities for overburden**

**Vertical sections of constrained joint inversion models of gravity and magnetic data (2 clusters – overburden and sandstone; coupling factor of ρ=10)**

Darijani 2018 PhD Memorial

# Summary of Modelling

NSERC-CMIC FOOTPRINTS

| | Seismic Refraction (2D) | Gravity (2D) | Gravity (3D) | Magnetics (3D) | DIGHEM (1D/3D) | VTEM (1D/3D) |
|---|---|---|---|---|---|---|
| Independent Inversion |  *with caveats* | X | X | X |  *with caveats* |  |
| Constrained Independent Inversion | - | X | X | X | - | - |
| Joint Inversion |  *with caveats* |  | X | X | - | - |
| Constrained Joint Inversion | - | - |  |  | - | - |
| Filtering and Spectral analysis | - | - | X | - | - | - |

**Models with synthetic and real data**

**Good for OB stripping**

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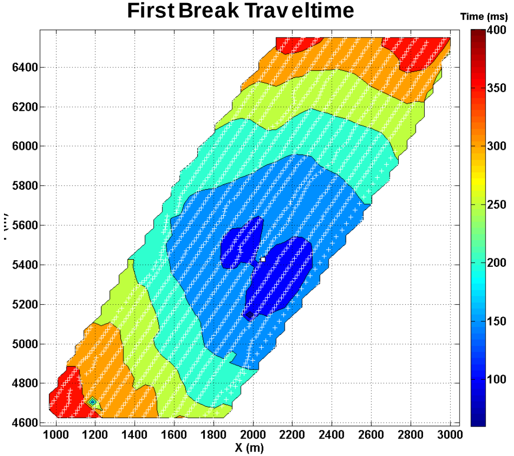
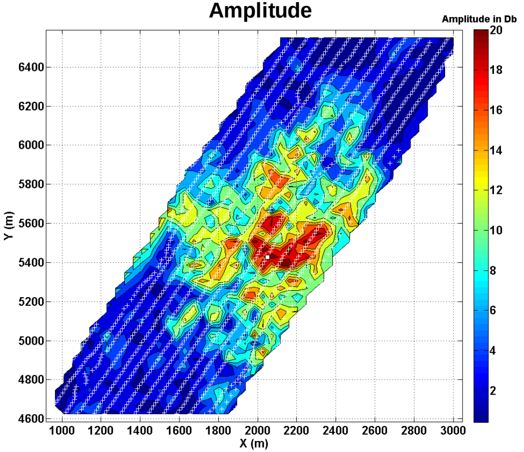
# Geophysics example: Seismic

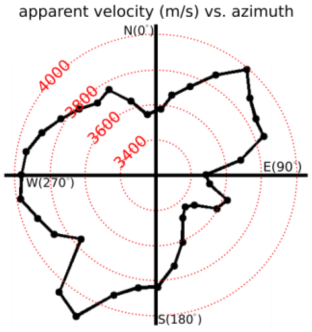
NSERC-CMIC FOOTPRINTS

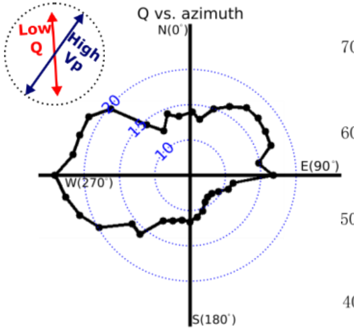
- Qp can be extracted from **first-break amplitude analysis**
- Energy decay shows directional (**anisotropic**) dependence
- **Seismic attenuation ≠** Overburden effect (Qp reflects deep lithological and petrophysical variations, and locally very low)
- **Seismic Footprint !**

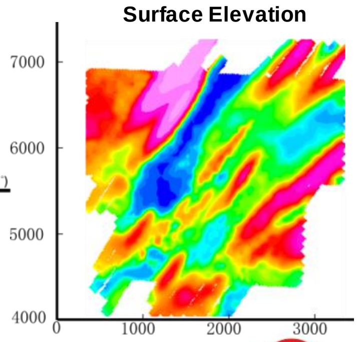
## Millennium

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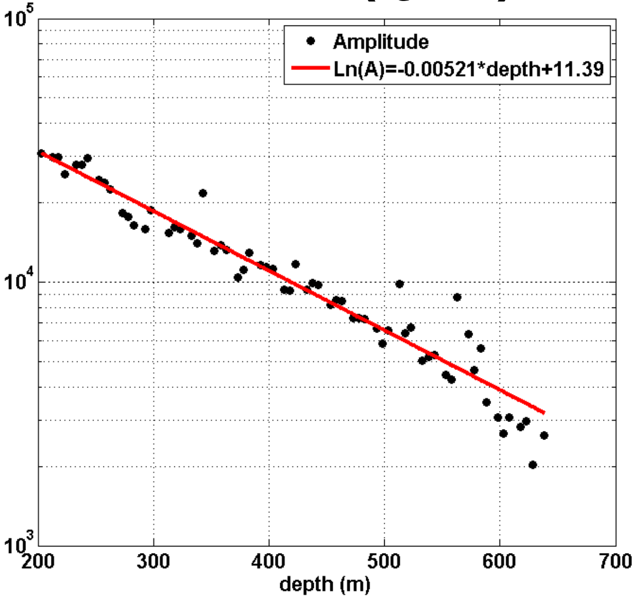
NSERC CRSNG

# Seismic: 3D Alteration Imaging



## Millennium (Q=24)




**McArthur River – Q=7.69**
**Extremely low**

**Downhole amplitude decay in 3D VSP confirms attenuation observed in surface seismic data**

***Inverted to produce 3D Q model***

***Q tomography***

## 3D model:

**Nearly vertical alteration zone**

**From near surface to unconformity**

**Limited width (thin?)**

**Limited lateral extent (fluid pathway?)**

**Long-lived, soft, porous, low Q provides geotechnical challenges**



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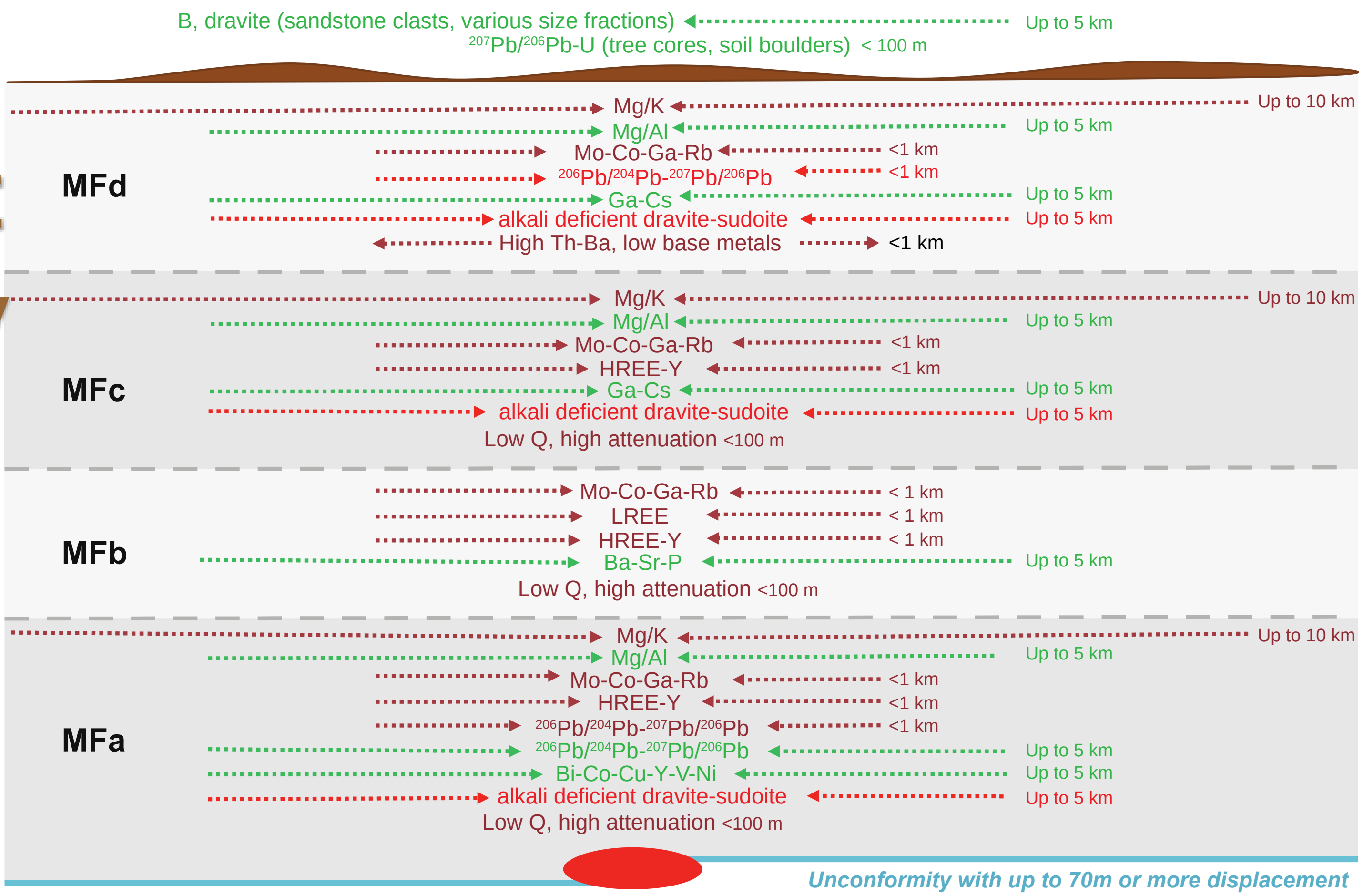
# U Site Footprint Summary




Increasing concentration

**McArthur River and Millennium**
**McArthur River only**
**Millennium only**

Signals most pronounced along structures to surface and laterally

**Dominated by geochemistry and mineralogy**

Lesher 2017
Exploration 17

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# U Site Summary

- Footprint in sandstone – focus of the project – mineralogy/geochemistry
- Molar ratios (e.g. Mg/Al) broaden footprint, and machine learning supports "chimneys" of select elements
- Fractures can provide access to the surface, but understanding surficial geology vital
- Subtle alteration in sandstones (dominated by quartz) means variation in physical properties is small
- Challenging to remove the geophysical signature of the basement, and the overburden to image this subtle alteration
- Most important product may be toolkit of methods, what can be done/what can't, for exploration at depth

# Sponsors/Collaborators

NSERC-CMIC FOOTPRINTS

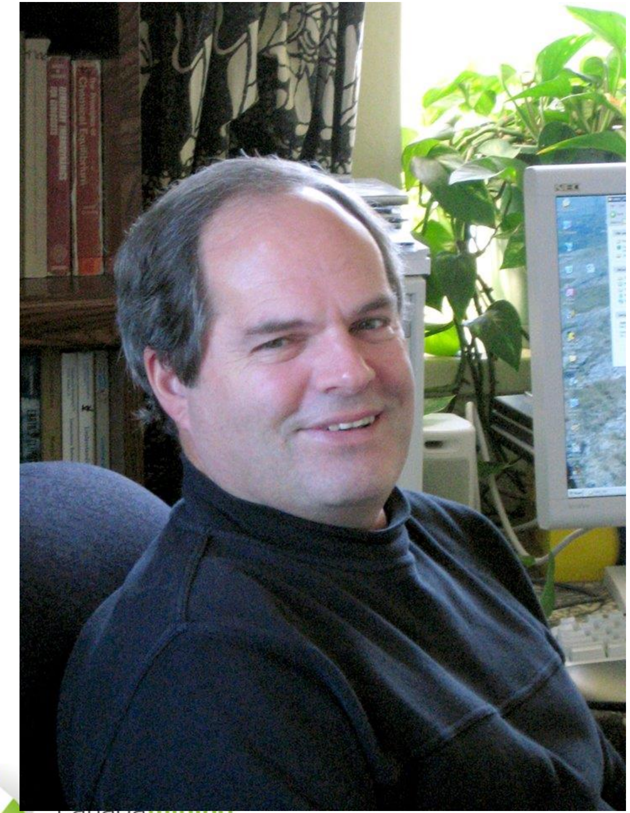
**Collaborators:** GSC TGI4 Program
MRNQ
Saskatchewan Geol Survey
BC Geological Survey

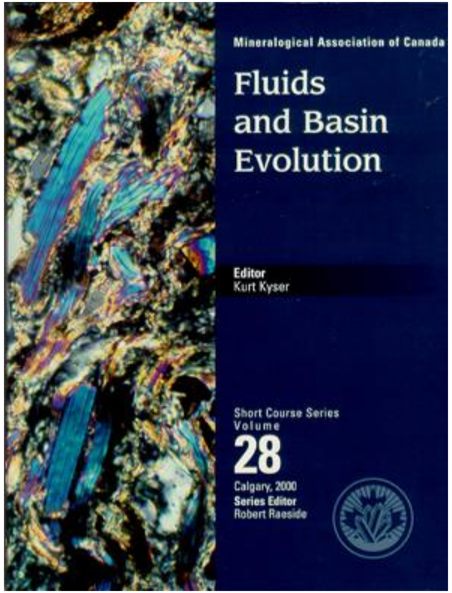
**Supporters:** Fullagar Geophysics
Rekasa Rocks
UBC Geophysical Inversion Facility

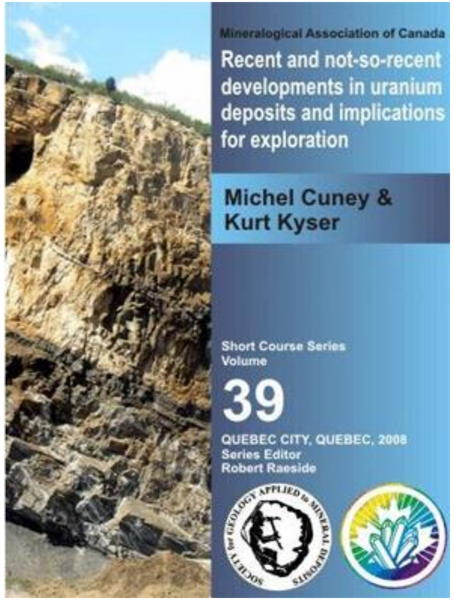
# Remembering



- Site Leaders - Kevin Ansdell and Kurt Kyser






University of Saskatchewan – 1981-1995
Queen's University and
Queen's Facility for Isotope Research
1995 - August 29, 2017