

# The paragenesis of alteration associated with the P2 fault in the basement rocks of the Athabasca Basin

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### Introduction

The P2 reverse fault (Figure 1) is a major structure within the Athabasca Basin, Saskatchewan, and is spatially associated with the McArthur River deposit, the world's largest high-grade uranium mine. The McArthur River deposit is classified as an unconformitytype deposit as the mineralization is located at the unconformity (~500 m depth) between the Athabasca sandstone and basement rocks. The P2 is constrained to graphite-bearing paragneiss of the basement and is refracted within the overlying sandstone as a series of splays. The Paleoproterozoic age basement rocks (Wollaston Supergroup) are variable in composition and lithology, and have a long geologic history: upper-amphibolite metamorphism, retrograde metamorphism, paleo-weathering, diagenetic effects from the deposition of the overlying sandstones and multiple episodes of hydrothermal alteration. Mineralization at McArthur River is bound by the P2 and Vertical Quartzite (VQ) transcurrent faults; therefore, the P2 is a potential fluid pathway for uraniferous fluids. The area under the McArthur River ore body shows evidence for extensive fluid/rock interaction as it is intensely hydrothermally altered and brecciated.

### Objectives

I) To identify the mineralogy of the basement rocks during each geologic event.

II) To establish the paragenetic sequence of alteration minerals associated with the P2 and VQ faults.

III)To characterize alteration mineral chemistry within the basement expression of the P2 thrust fault proximal to i) economic grade uranium mineralization (McArthur River deposit), ii) mineralization perched within the overlying sandstone (P2 Main deposit), iii) subeconomic grade mineralization, iv) no mineralization and v) the VQ fault.

# Sampling

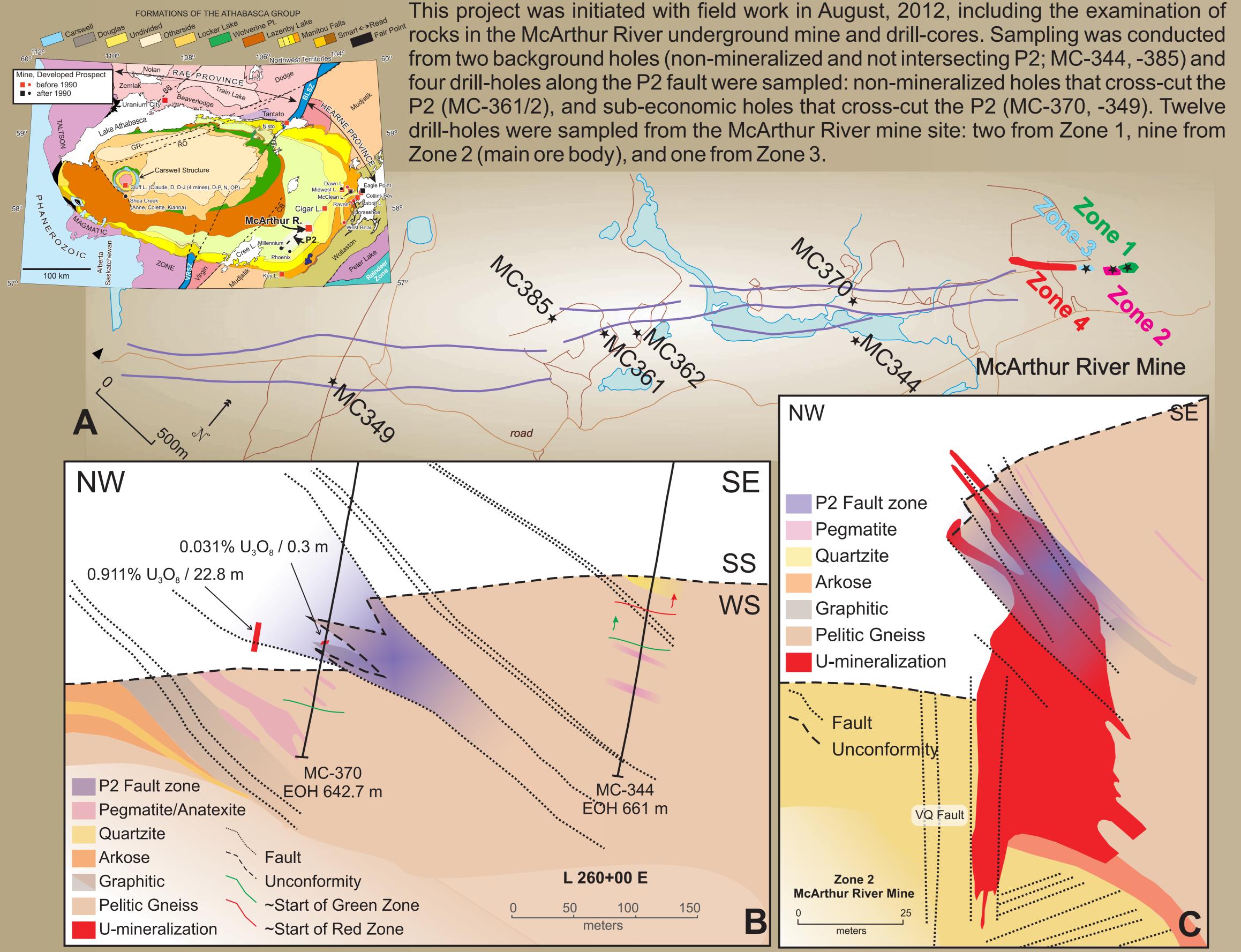


Figure 1: A) A plan-view map showing the P2 surface expression (purple), respective sample drill collars and the McArthur River mine site. A regional map (adapted from Jefferson et al., 2007) of the Athabasca Basin is in the upper left corner and shows highgrade uranium deposits and major structural features including the P2 reverse fault (highlighted in white). **B&C)** Cross sections (NW-SE) of B) exploration line 260E showing sampled drill core MC-370 and MC-344 and C) a typical cross-section of Zone 2 from McArthur River Mine. The P2 fault zone is highlighted in purple in both sections.

### Paragenetic sequence

"Fresh Zone" Prograde, upper amphibolite facies Gneiss (garnetbiotite, cordierite), pegmatite & quartzite Sulfide formation "Green Zone" → Retrograde Chloritization of mafic minerals (biotite, cordierite & garnet) Illitization of

**Uplift & erosion** 

Formation of Hematization of garnet, biotite and • other Fe-bearing Kaolinization of Al-Athabasca sandstone

"Green Zone"

chloritization

"Red Zone"

Figure 2: Interpretation of alteration paragenesis based on field

Enhancement of at unconformity Illitization, deposition

of alteration "Bleached Zone" White clay overprints Red Zone kaolinization (?) and dickite formation by diagenetic fluids

**E** Remobilization **c** consumption (?) o graphite, sulfide

> **Uranium** mineralization

> > `clinochlore

# Methodology

Thin section petrography

-Non-mineralized background holes MC-370 and MC-385 (do not cross-cut P2), sub-economic mineralized drill-hole MC-370 (cuts P2 zone), and mineralized drill-holes H729 (Zone 1) & H201 (Zone 2).

Terraspec short-wave infrared spectroscopy (SWIR)

Scanning electron microscopy

-Quantitative electron dispersive spectra (EDS) and back scatter electron imaging (BSE) to help identify

# Metamorphism

The basement rocks at McArthur River are upper-amphibolite facies paragneiss (garnet-biotite-metapelite, cordierite-metapelite, calc-silicate or arkosic psammite), pegmatite & quartzite. Prograde metamorphism produced the pink garnet & biotite that distinguishes the Fresh Zone. The Green Zone overlies the Fresh Zone and was produced by retrogression and promoted by weathering: coarse-grain crystalline chlorite (>100 µm). chloritization of garnet, biotite & cordierite, and replacement of feldspar

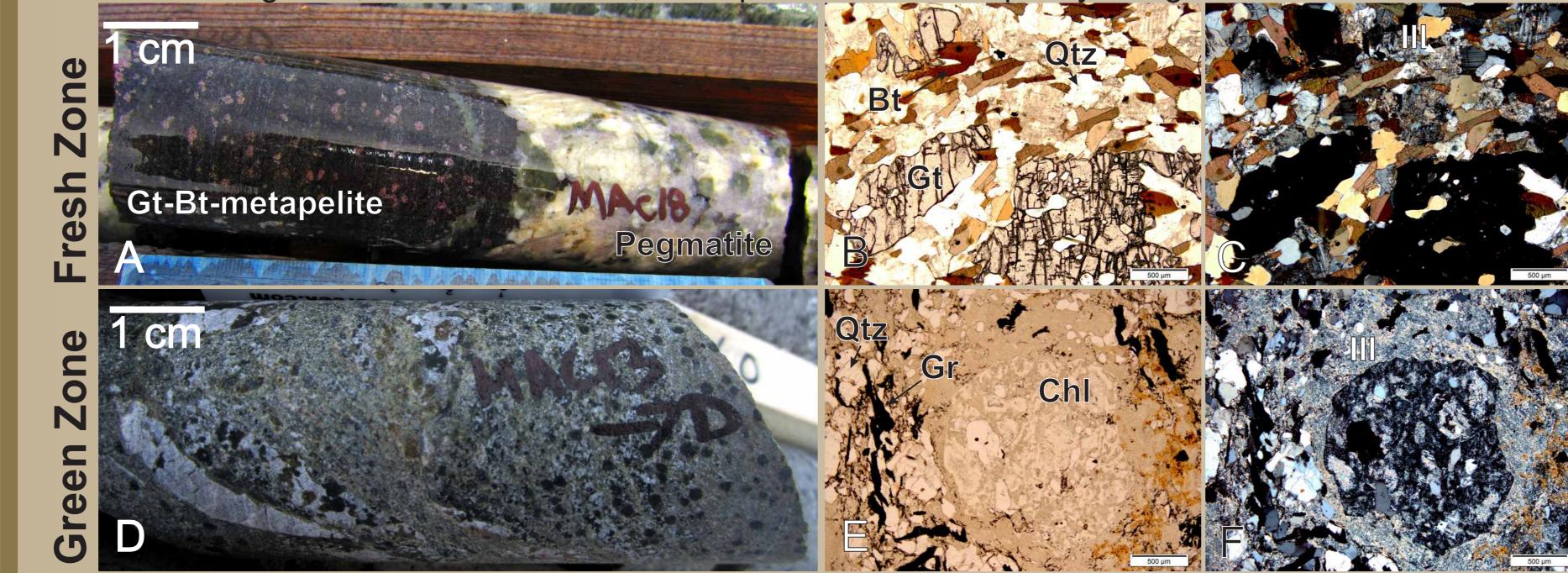


Figure 3: Drill-core and thin section (PPL & XPL) photos showing biotite-garnet gneiss (+quartz and feldspar) the Fresh Zone (top row) and Green Zone (bottom row). The Fresh Zone is characterized by pink garnet (A), freshslightly chloritized biotite (B) and feldspar that is slightly replaced by fine-grained illite (C). Minor graphite and pyrite are also observed within the Fresh Zone and aligned along the metamorphic fabric. Samples from the Green Zone (D, E & F) show chloritized garnet and feldspar that is replaced by fine-grained illite (F).

Drillcore	Sample	Phase	Na <sub>2</sub> O	MgO	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	K <sub>2</sub> O	TiO <sub>2</sub>	ΣFeO	
H729	MAC35	Feldspar	1.3		18.4	65.2	15.0			
MC344	MAC13	Illitized Feldspar		2.8	34.2	50.7	9.2		3.2	多
MC344	MAC13	Biotite Inclusion in Qtz		10.7	18.6	38.3	9.8	3.0	19.5	31
H729	MAC35	Chlorite		13.4	25.1	28.7			32.8	100 μm
Table 1: Anhydrous-based composition of representative metamorp										

phic minerals. Also shown: BSE image of chlorite and an Al-Fe-Mg ternary (octahedral site cations) comparing chlorite (this study) to representative Athabasca sudoite and clinochlore (Zhang, 2001). Note chlorite formed during retrogression contains high-Fe.

# Paleo-weathering

The Red Zone developed during the weathering of the basement rocks and is Green zone by the hematitization of Febearing minerals and the Green Zone.

Figure 4: Drill-core and photos show hematization

Diagenesis

Previous researchers have interpreted the Bleached Zone to have formed during weathering. However, the Bleached Zone occurs above and below the unconformity as fine grained whiteyellow clay alteration that overprints the Red Zone. Thin sections of samples from the Bleached Zone are dominated by primary quartz, secondary fine-grained kaolinite and two generations of illite: early, fine-grained illite and late, coarse-grained illite. SWIR spectral analyses suggest a mixture of kaolinite, illite and dickite, and the spectra are reproduced in all samples along the P2 independent of mineralization. The evidence indicates that the formation of illite and kaolinite was most likely a regional event. Therefore, the Bleached Zone was probably formed by Kbearing diagenetic fluids during the deposition of the Athabasca Group.

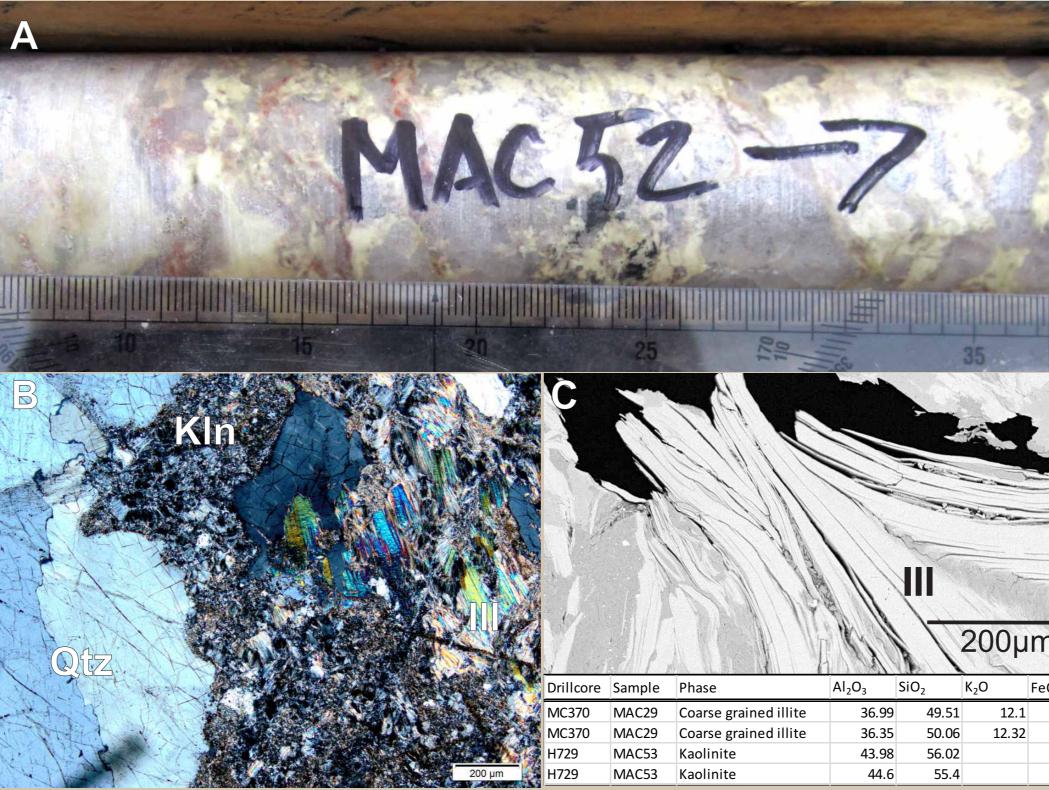
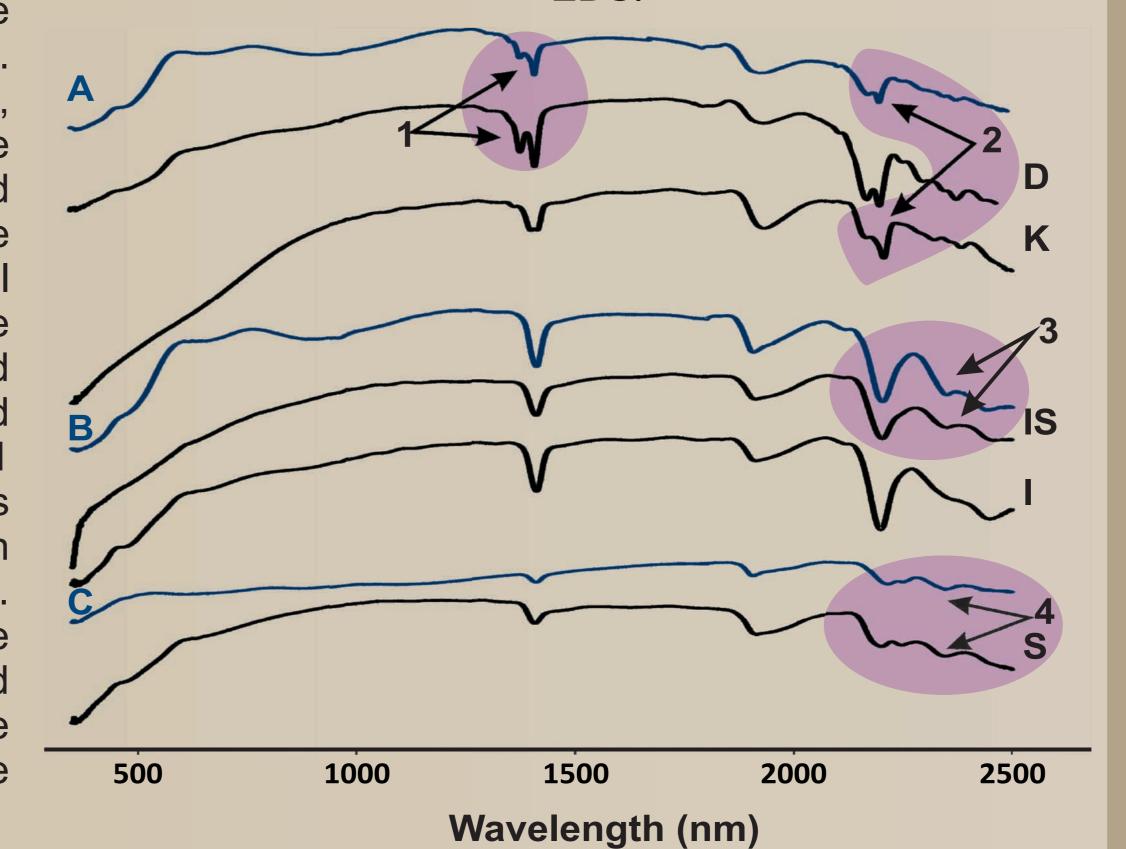


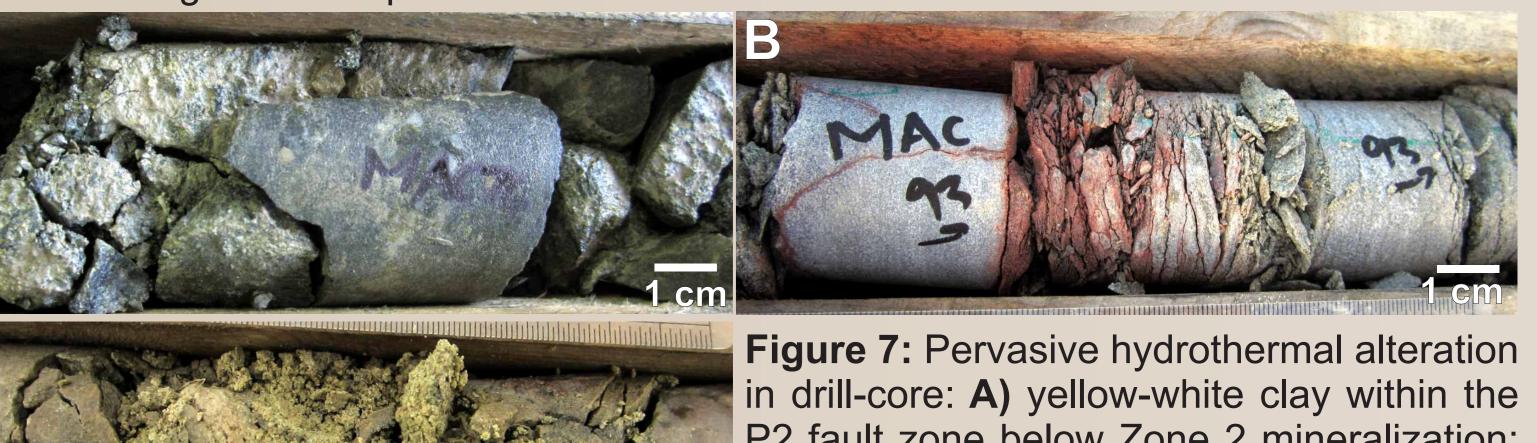
Figure 6: Spectra A, B and C are most typical for samples. Spectra D, K, IS, I and S (dickite, kaolinite, 80% illite 20% sudoite (Mg-Al chlorite), illite and sudoite, respectively) are spectra of Athabasca mineral standards obtained from the GSC. Spectrum A is interpreted to be a mixture of dickite and kaolinite (based on features and 2 outlined in purple) and is found most commonly within Bleached Zone samples. Spectra B and C are the mixtures of chlorite and illite (features 3 & 4).

Figure 5: A) A drill core sample of quartzite breccia from the Bleached Zone proximal to the VQ fault within Zone 1 (of the McArthur River section image of the quartzite sample showing quartz (Qtz) and high birefringent fine illite. Kaolinite and coarse grained illite is replacing finegrained illite. C)BSE image of coarse-grained illite and compositions of illite and kaolinite determined by SEM-



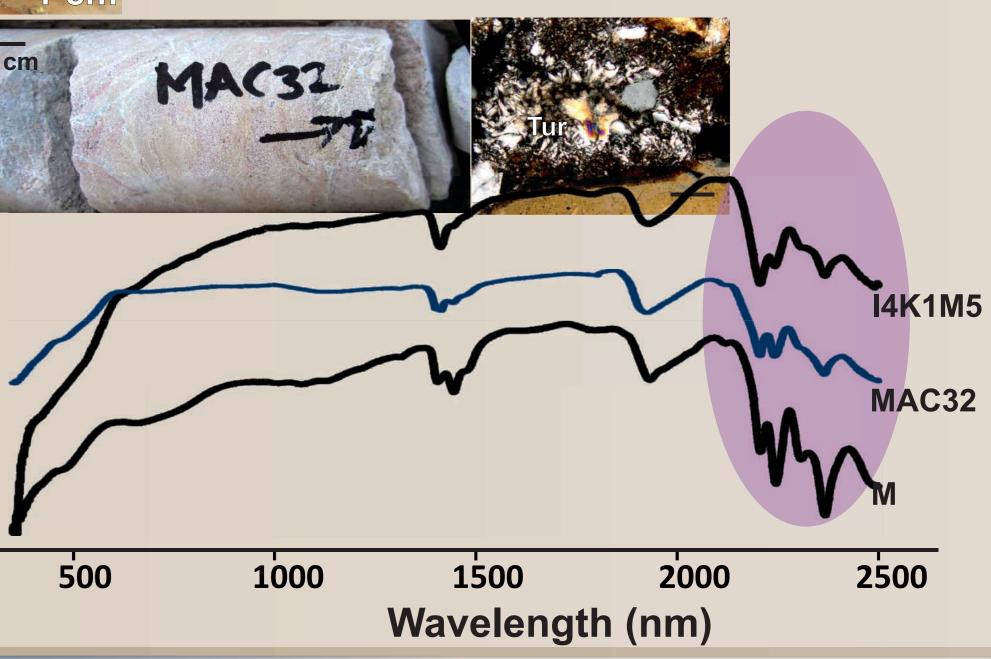
# Hydrothermal alteration

Intense hydrothermal alteration occurs below the Zone 2 ore body at the McArthur River Mine, between the P2 and VQ faults. It destroyed the original textures and produced aggregates of white, yellow, green, red and blue clays. Blue clay is abundant along the VQ (H201) and P2 zone proximal to i) sub-economic mineralization (MC-370), and ii) in the Zone 2 ore-body (H493). The blue clay yields SWIR spectrum of tourmaline. Other clays show spectra similar to



P2 fault zone below Zone 2 mineralization; **B)** red and green alteration within the P2 zone from MC-349; and C) green and yellow clay within the VQ fault zone within Zone 2.

Figure 8: A drill-core photo and the spectrum of blue clay alteration phase (MAC32; sandstone from the P2 zone at the unconformity) compared to those of Athabasca standard clays: magnesiofoitite (M), and 40% illite 10% kaolinite & 50% magnesiofoilite (I4K1M5). A XPL photomicrograph shows radial tourmaline from a metapelite breccia (MC370).



# deposit). B) An XPL thin Summary & on-going work

The Green Zone formed during retrogression of regional metamorphism and was likely enhanced during weathering. It is comprised of Fe-rich chlorite and fine-grained illite. The Red Zone formed during the weathering and overprints the Green Zone, resulting in the formation of hematite and kaolinite. The Red Zone was overprinted during the deposition of the Athabasca sandstones by the Bleached Zone, which formed dickite and coarse-

Boron was introduced during hydrothermal activity, forming tourmaline in the vicinity of uranium mineralization at the McArthur River mine, P2 and VQ faults. Two types of hematitic alteration are identified: one associated with the weathering Red Zone and a later one with hydrothermal activity.

llite, kaolinite, chlorite and dickite are ubiquitous in the McArthur River mine and along the P2 fault. Although SWIR is an efficient method in identifying mono-minerallic samples, it may yield ambiguous spectra from mixed clays. Additional methods are necessary for the identification of mixed clays.

### On-going work:

Mineral chemistry and crystal structures of individual alteration phases XRD of mixed clay samples

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### **Acknowledgements:**

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