

# Clay Distribution Patterns and Alteration in the Athabasca Basin Northern Saskatchewan

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Chief Geochemist



# Outline

- Introduction
  - Clay Mineralogy
  - Analytical Techniques
  - Common Sampling Techniques
  - Other Important Information
- Review Historical Information
- Clay Distributions
  - Regional Scale
  - District Scale
  - Deposit Scale
  - Drill Hole/Hand Sample
- Current Sandstone Clay Alteration Model
- Clay Distribution in Basement Rocks
- Exploration Highlights / Implications
- Kaolin Group “Minerals” in the Athabasca Basin

# Clay Mineralogy

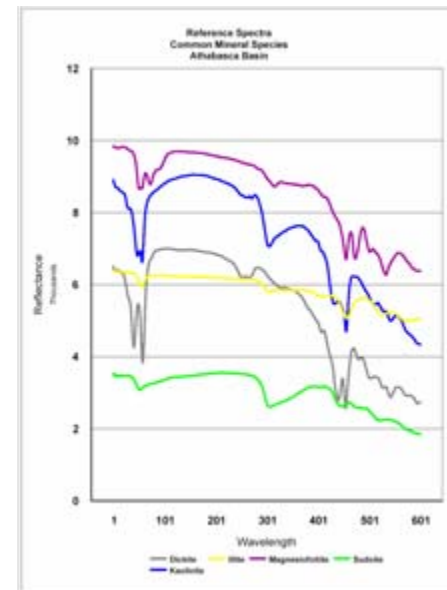
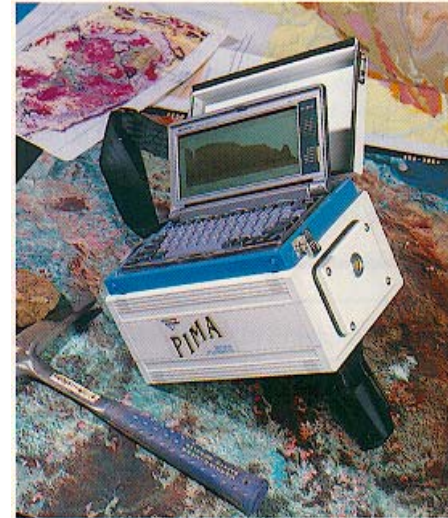
- Small hydrous layer silicates, generally of low temperature origin, that are part of the phyllosilicate family (Weaver, 1989)
  - without the size (<2  $\mu\text{m}$  or <4  $\mu\text{m}$ ) connotation (dickite booklets seen in thin section >50  $\mu\text{m}$  in size)
- Common in Athabasca Group:
  - Illite (potassium aluminum silicate)
    - $(\text{K},\text{H}_3\text{O})(\text{Al},\text{Mg},\text{Fe})_2(\text{Si},\text{Al})_4\text{O}_{10}[(\text{OH})_2]$
  - Kaolin Group (Dickite, Kaolinite, S-Kaolinite) aluminum silicates
    - $\text{Al}_4\text{Si}_4\text{O}_{10}(\text{OH})_8$
  - Chlorite (Sudoite, Mg and Fe chlorites)
    - $(\text{Al}_6\text{Mg}_4)(\text{Si}_6\text{Al}_2)\text{O}_{20}(\text{OH})_{16}$
  - Dravite (Magnesiofoitite, Zhang, 2000)
    - $[(\text{Mg}_2\text{Al})\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH})_4]$

# Analytical Techniques

- **Normative** – calculated illite, chlorite, kaolinite ± dravite proportions based on the assumption that all the  $\text{Al}_2\text{O}_3$ ,  $\text{MgO}$ ,  $\text{K}_2\text{O}$  and B contents are associated with the clay minerals
- **X-ray Diffraction** – either whole rock or clay separates
- **Shortwave Infrared Reflectance Spectroscopy** – PIMA or ASD

# Short-wave Infrared Reflectance Spectroscopy

- first introduced to Athabasca Basin in 1994 by Steve Earle of Grasswood Geoscience
- portable, rapid and relatively inexpensive
- utilizes 1300 - 2500 nm wavelength region of electromagnetic spectrum
- capable of providing structural and chemical information
- capable of distinguishing the common clay minerals in the Athabasca Basin
- most importantly distinguishes kaolin polytypes dickite and kaolinite
- limited by the quality of the available spectral library and is not able to provide a total clay content



# Common Sampling Techniques

- **Composite Samples**
  - boulder or drill core
  - regular intervals
  - primarily sandstone
- **Systematic Samples**
  - regular intervals
  - sandstone or basement lithologies
- **Selective Samples**
  - sandstone or basement lithologies



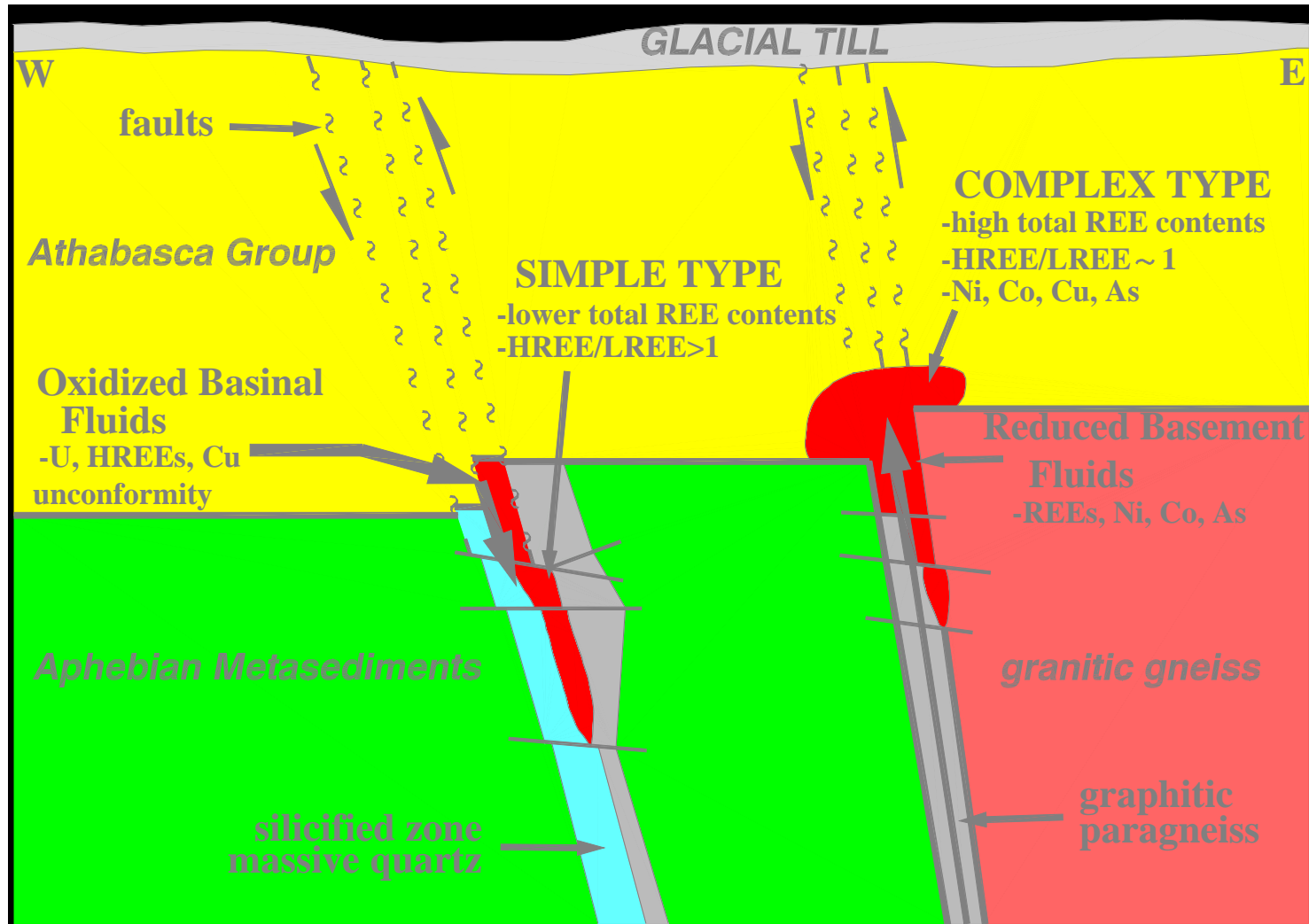
# Other Important Information

- Mapping / Drill Logging
- Petrography
- Isotopes (stable and radiogenic)
- Geochemistry (multi element with majors and pathfinders)

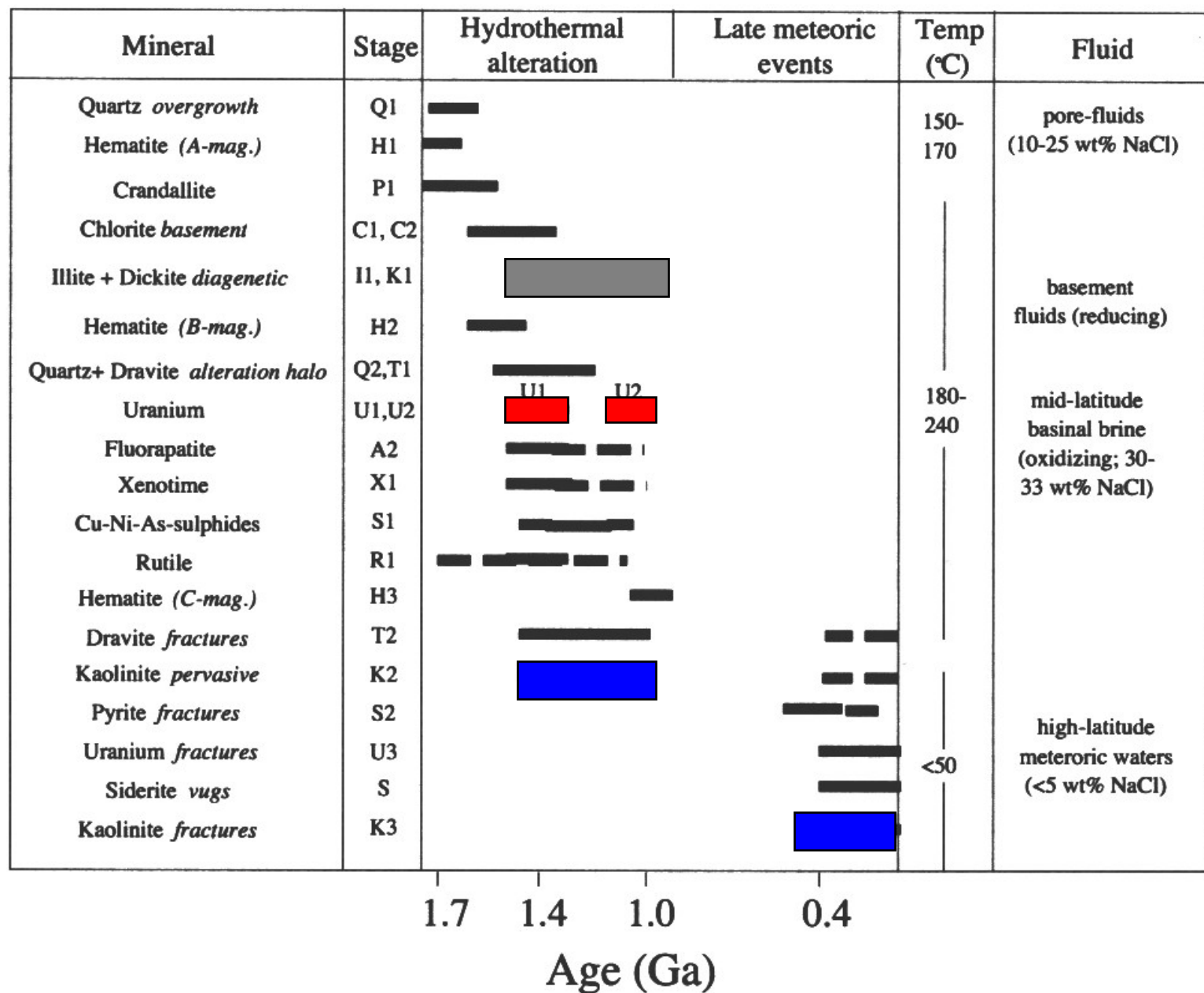
All of which will assist in placing any observed distribution patterns into the proper geological context

# Ore Formation Models

(Hoeve and Quirt, 1984; Fayek, 1996)



# Athabasca Basin Mineral Paragenesis

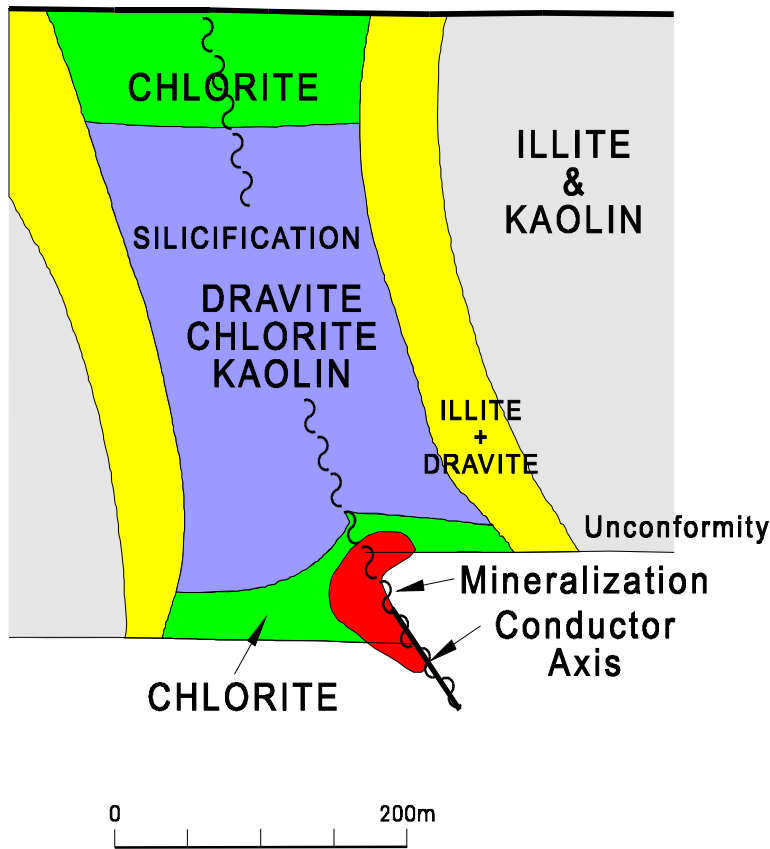


# Historical Information

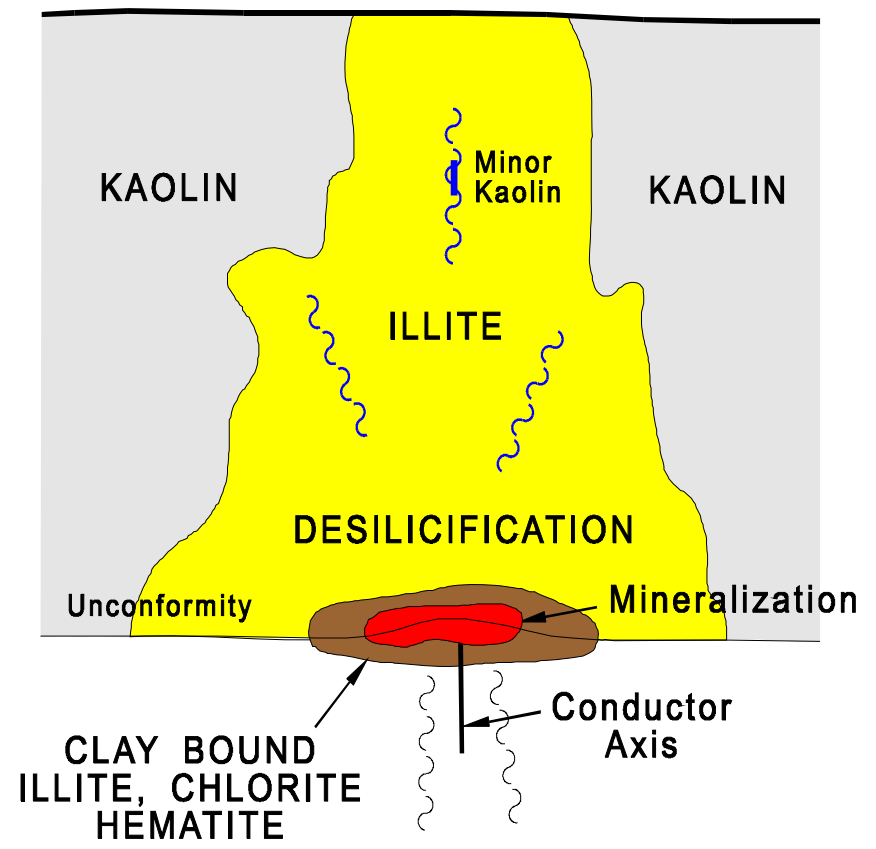
# Clay Alteration Models

(Earle and Sopuck, 1989)

## South Athabasca

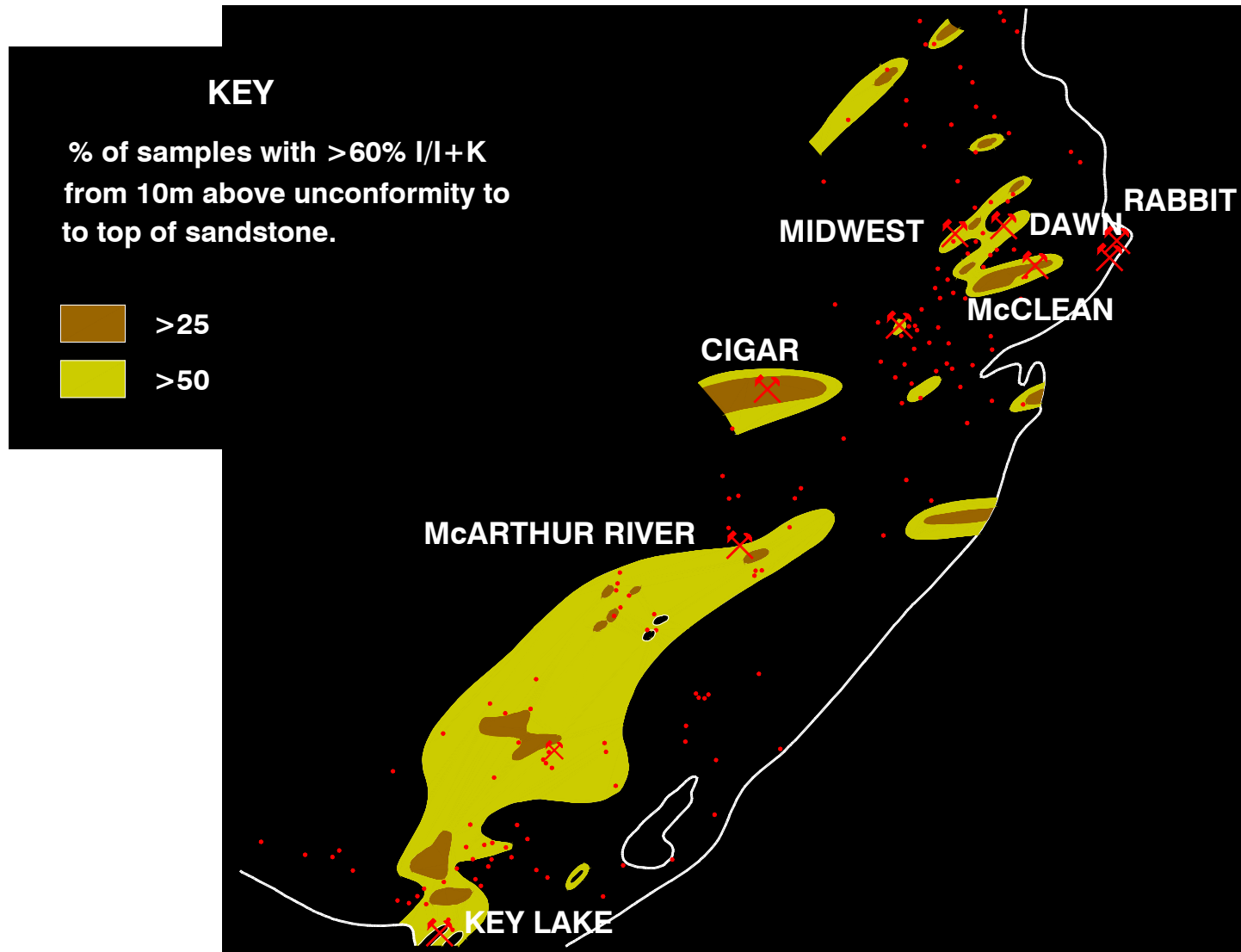


## North Athabasca



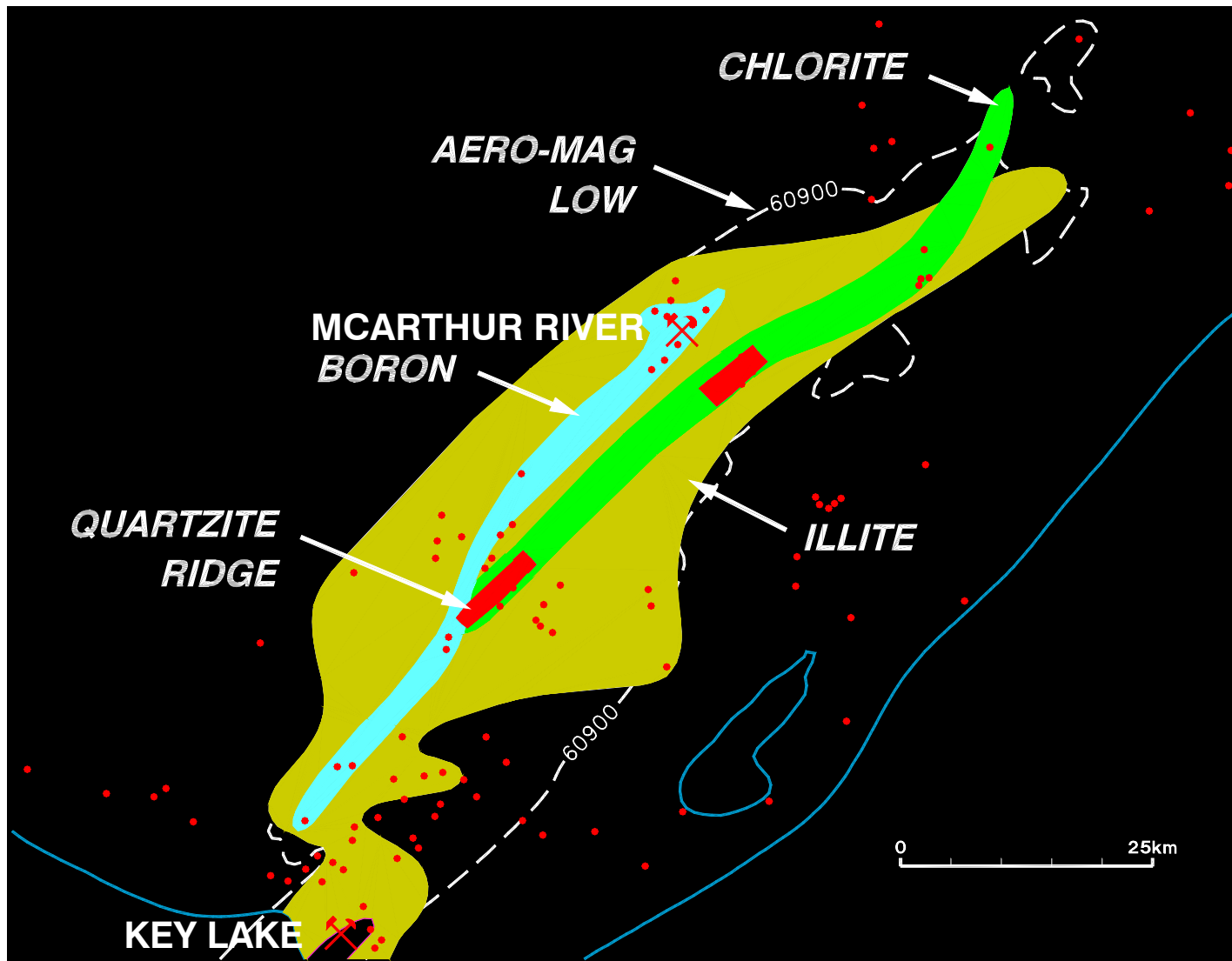
# Regional Illite Distributions

*(from Earle & Sopuck, 1989)*

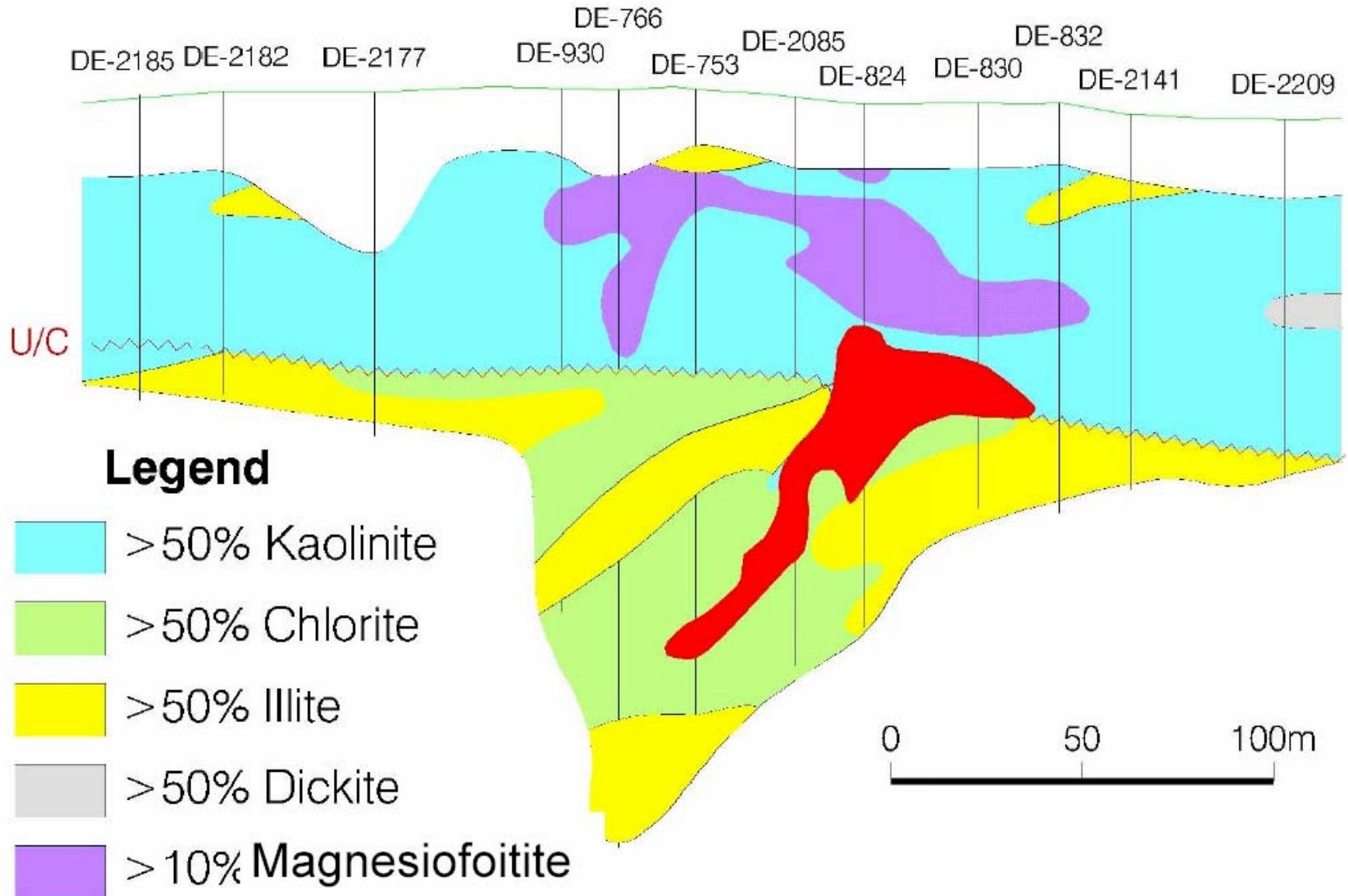


# Regional Clay Distributions

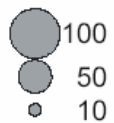
(from Earle & Sopuck, 1989)



# KEY LAKE DEILMANN DEPOSIT



Dickite Proportion (SWIR)  
Athabasca Group



MFb



Key Lake Mine

Deilmann

P Patch

Gaertner



Kilometers

Kaolinite Proportion (SWIR)

Athabasca Group



MFb



Key Lake Mine

Deilmann

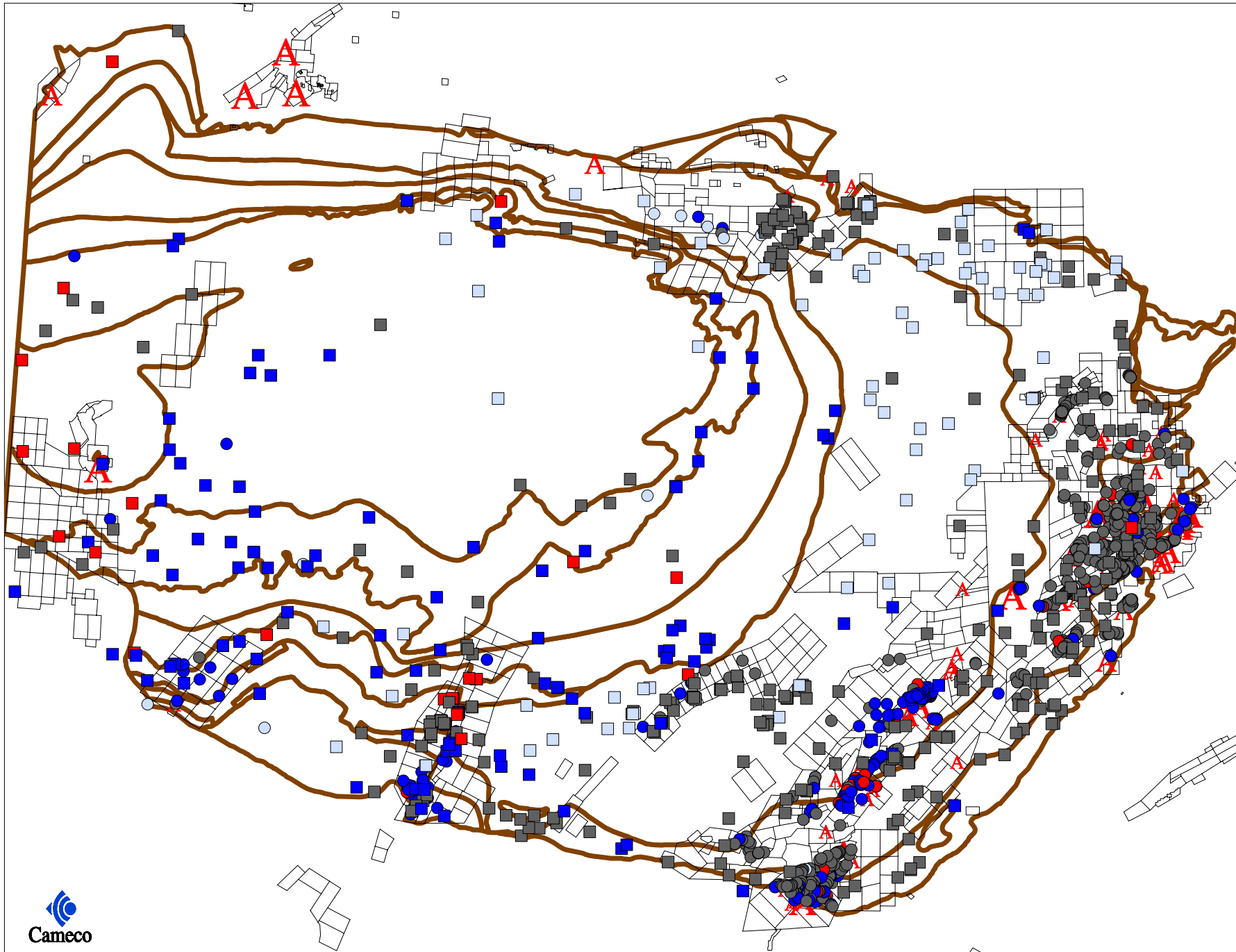
P Patch

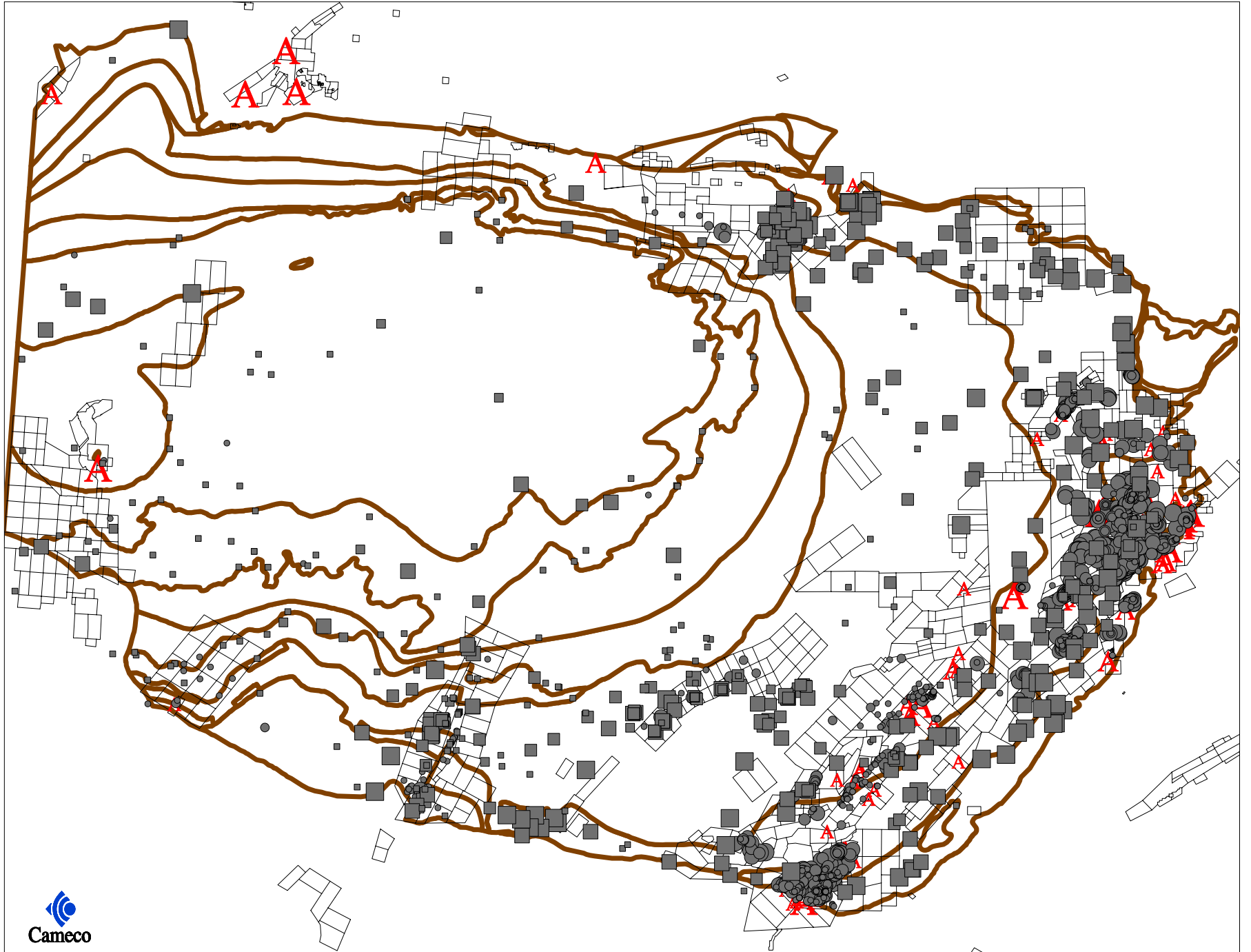
Gaertner

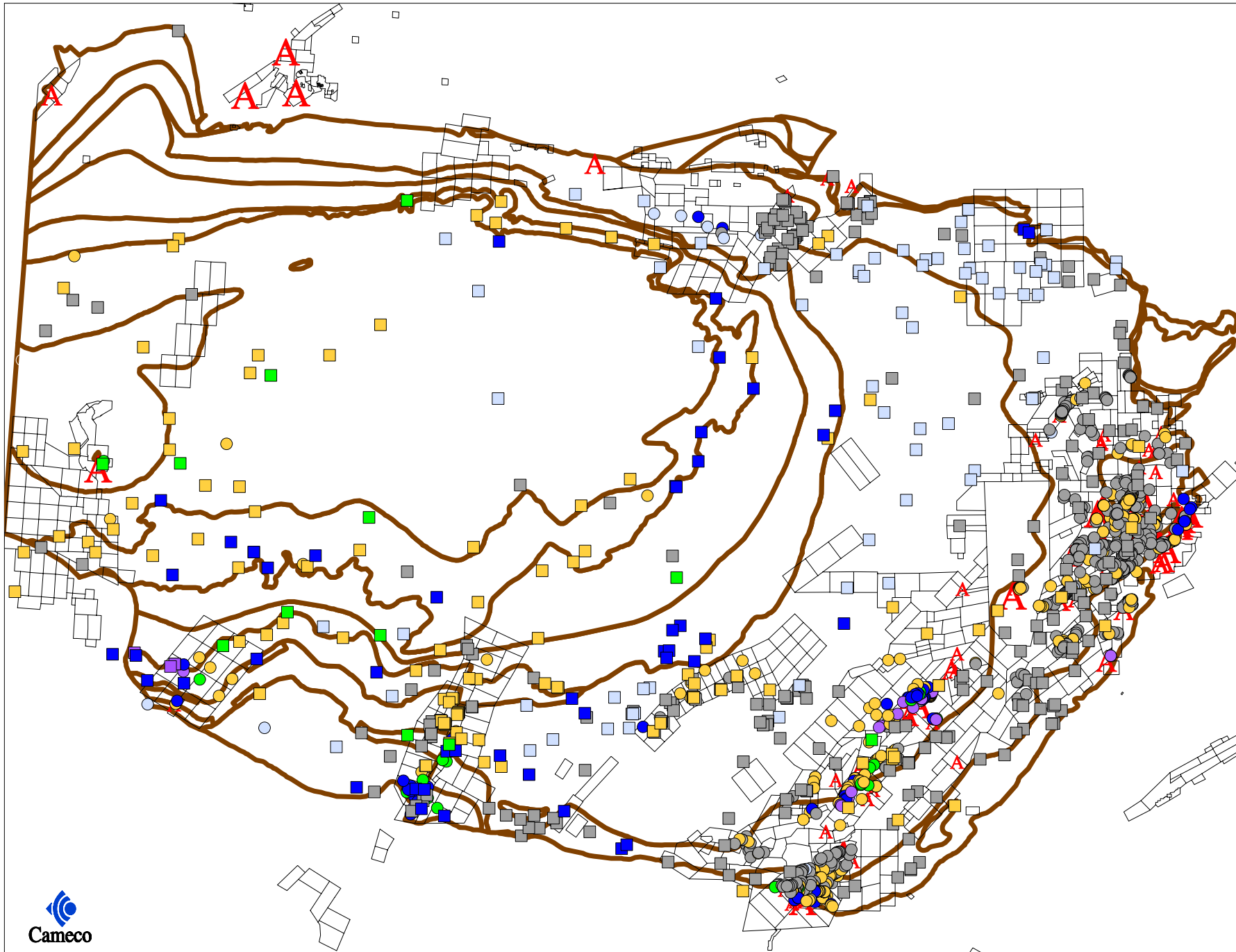
0 1 2 3

Kilometers

# Regional Clay Distribution Patterns







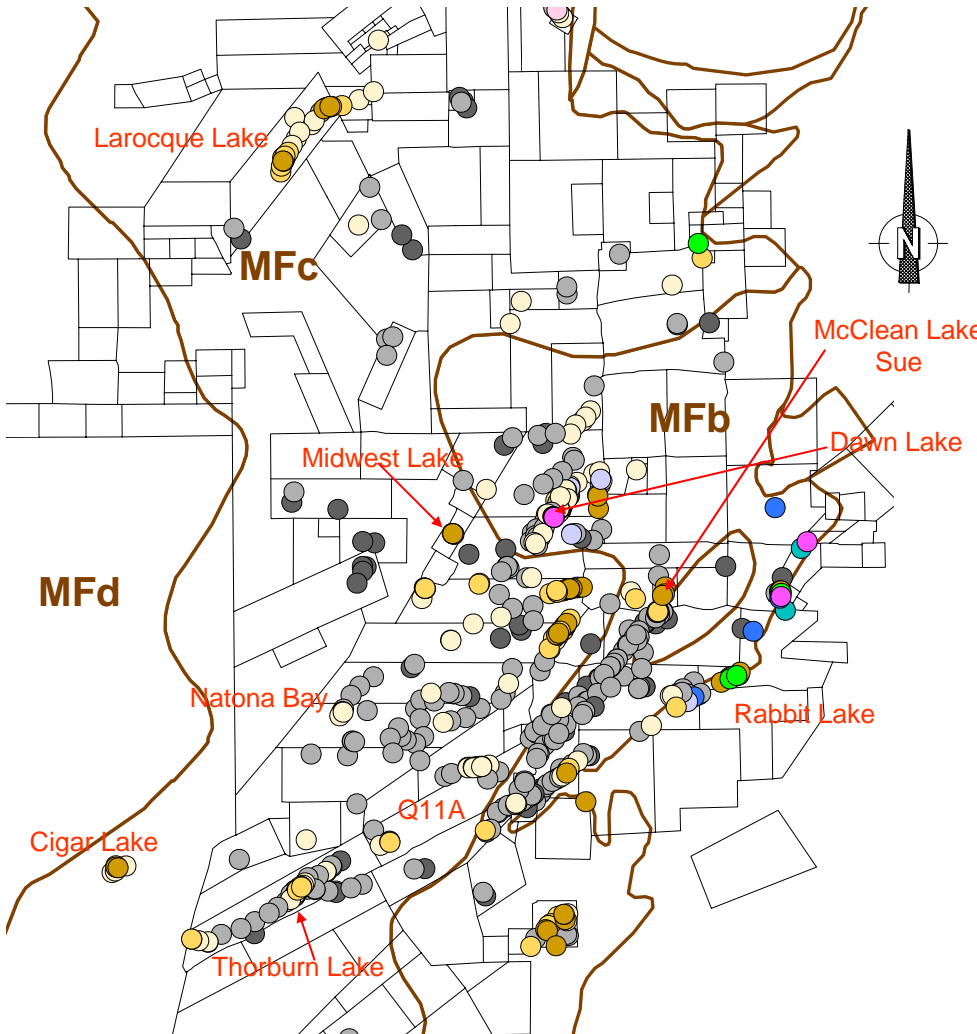
# Northeastern Athabasca Basin

## Dominant Clay Mineralogy

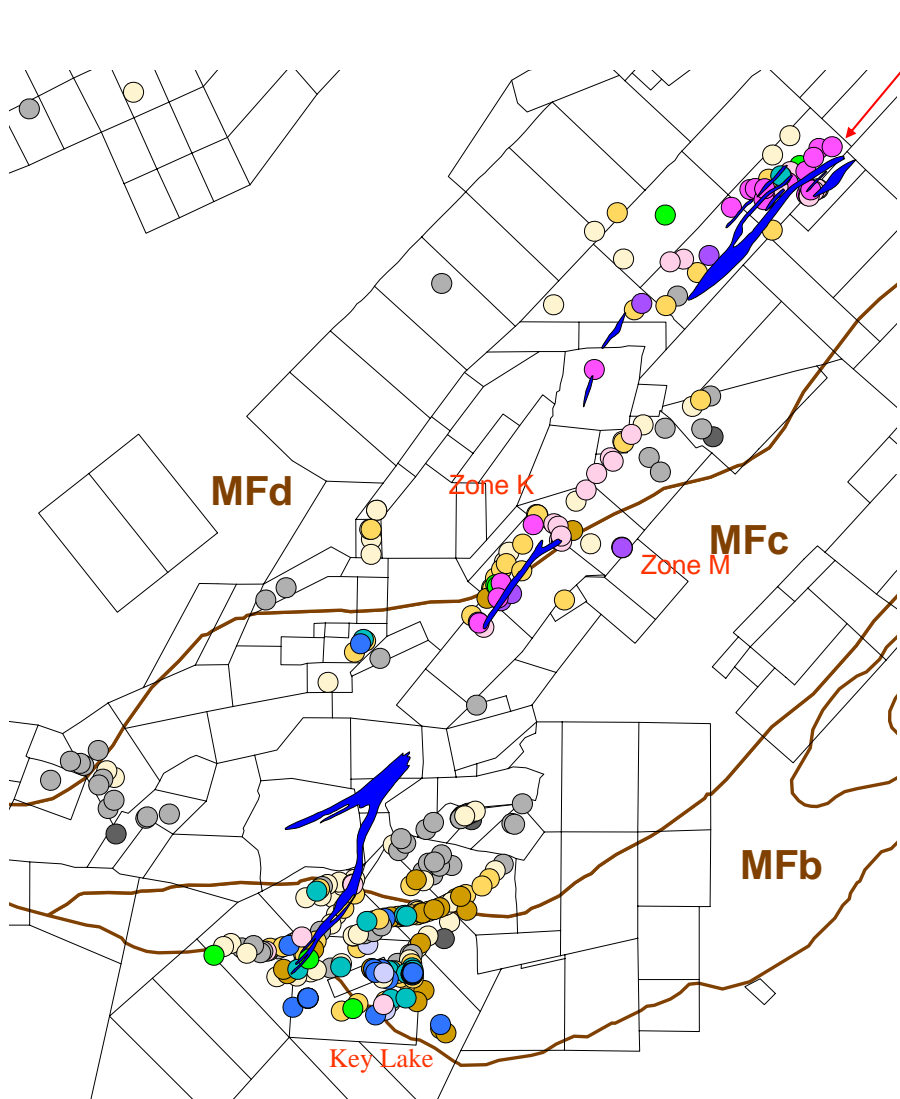
- Dickite >80%
- Dickite >60,<80%
- Mixture Illite & Dickite
- Illite >60%,<80%
- Illite >80%
- Mixture Illite & Kaolinite
- Kaolinite >60%
- Mixture Kaolinite & Dickite
- Chlorite >40%
- Dravite >40%
- Mixture all Clay Species (Dickite)
- Mixture all Clay Species (Kaolinite)

0 5 10 15 20 25

Kilometres



# Southeastern Athabasca Basin



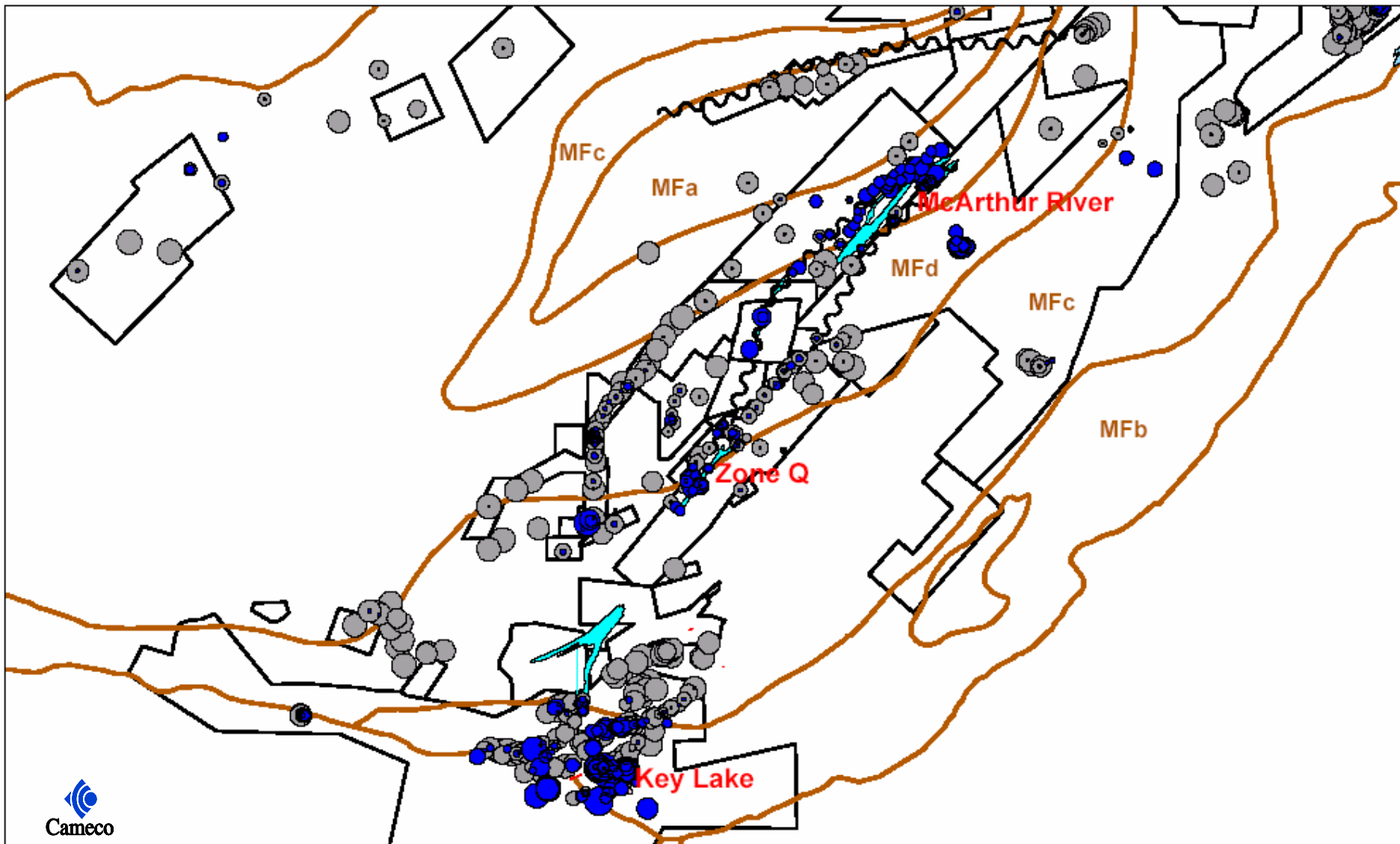
McArthur River

## Dominant Clay Mineralogy

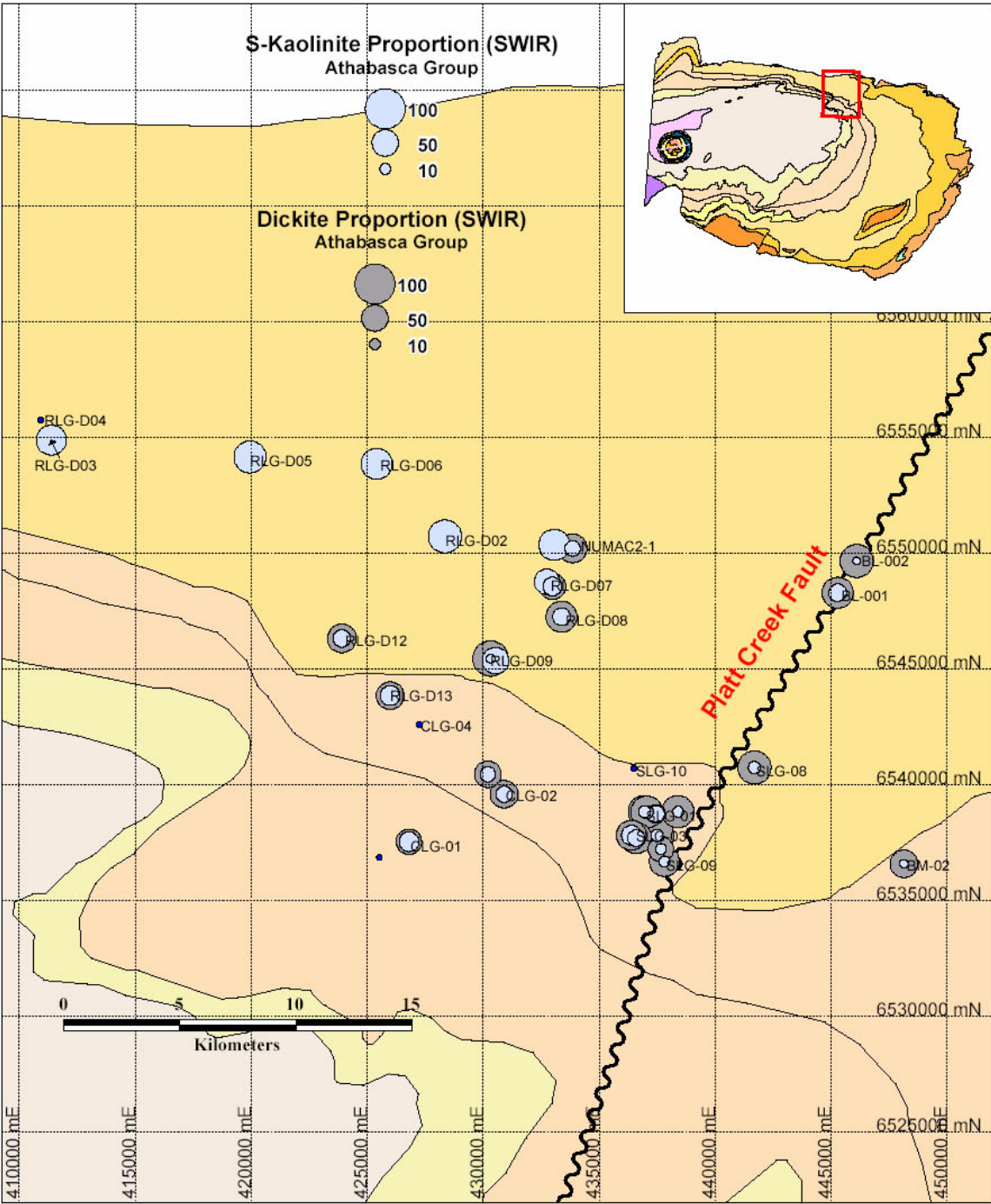
- Dickite >80%
- Dickite >60,<80%
- Mixture Illite & Dickite
- Illite >60%,<80%
- Illite >80%
- Mixture Illite & Kaolinite
- Kaolinite >60%
- Mixture Kaolinite & Dickite
- Chlorite >40%
- Dravite >40%
- Mixture all Clay Species (Dickite)
- Mixture all Clay Species (Kaolinite)

0 5 10 15 20 25  
Kilometres

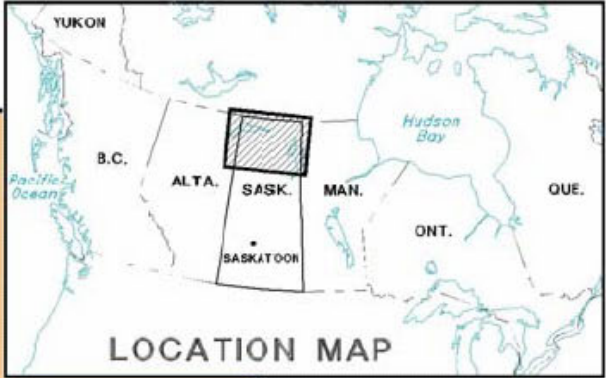
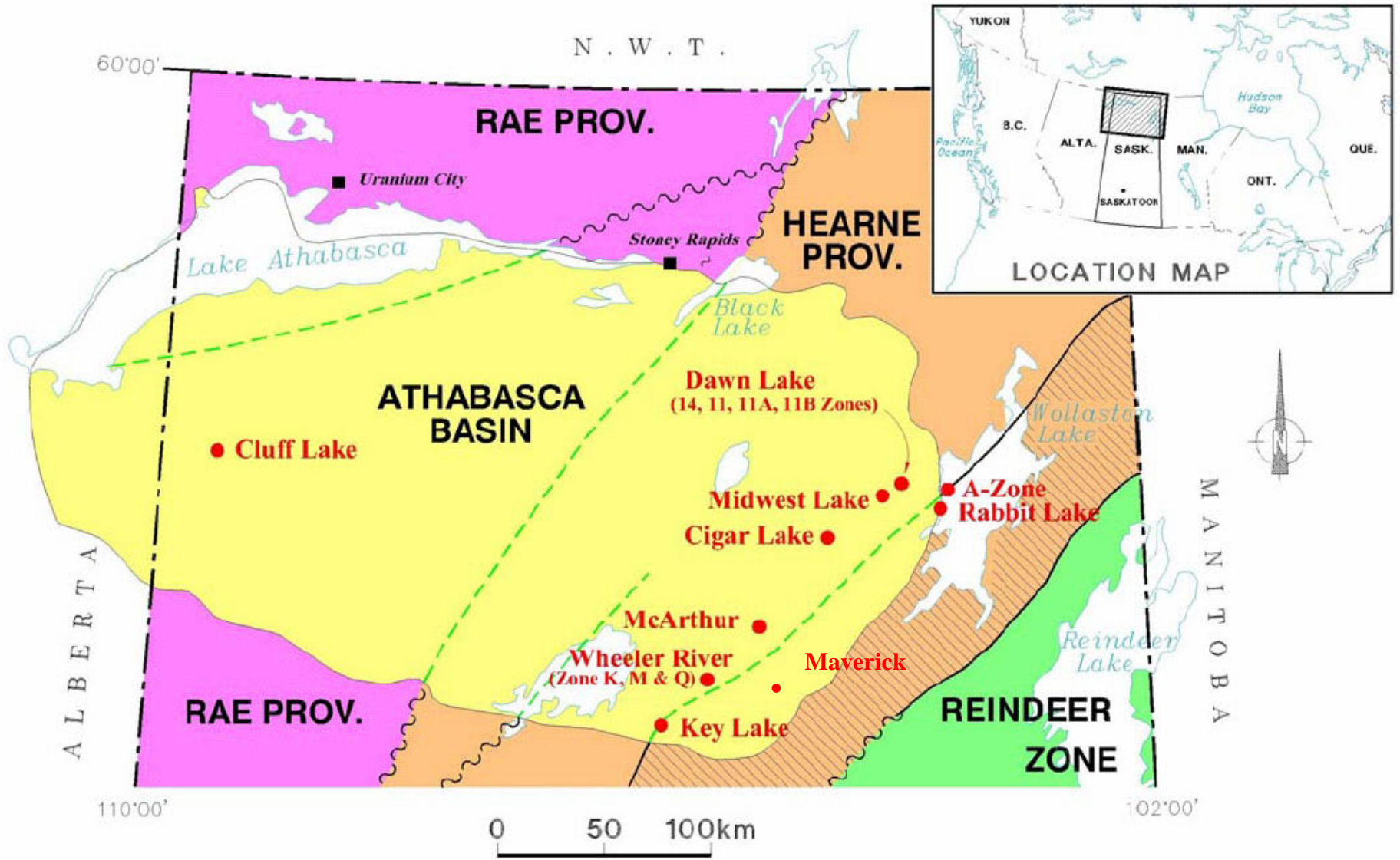
# Southeastern Athabasca Basin – Kaolinite and Dickite Distributions



# Northern Athabasca Basin



# Deposit Scale Clay Distribution Patterns



A L B E R T A

M A N I T O B A

N . W . T .

0 50 100km

60°00'

110°00'

102°00'

**RAE PROV.**

**HEARNE PROV.**

**ATHABASCA BASIN**

**REINDEER ZONE**

**RAE PROV.**

● **Cluff Lake**

**Dawn Lake**  
(14, 11, 11A, 11B Zones)

**Midwest Lake**

**Cigar Lake**

**McArthur**

**Wheeler River**  
(Zone K, M & Q)

**Key Lake**

**Maverick**

**A-Zone Rabbit Lake**

Lake Athabasca

Black Lake

Wollaston Lake

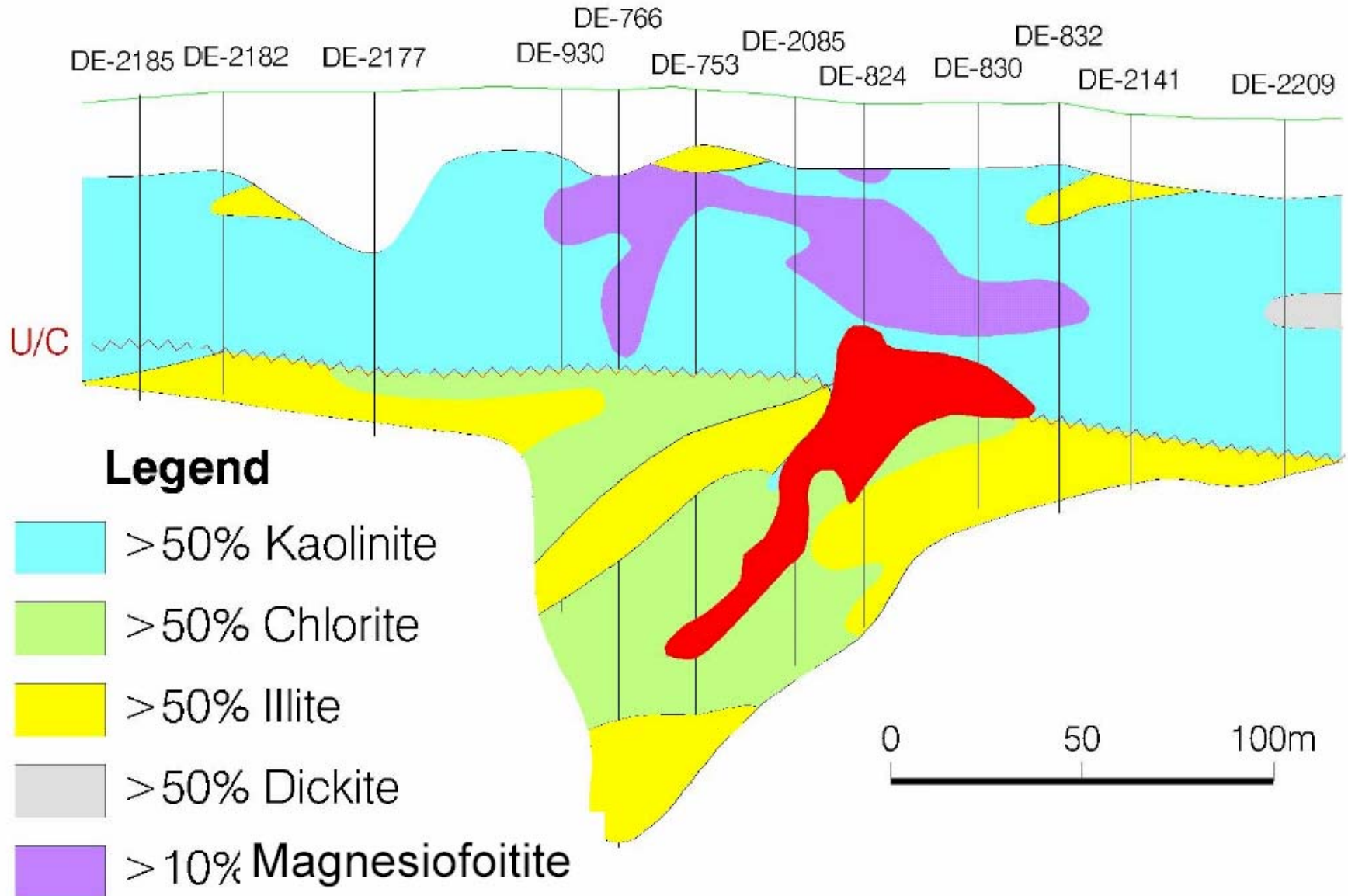
Reindeer Lake

■ Uranium City

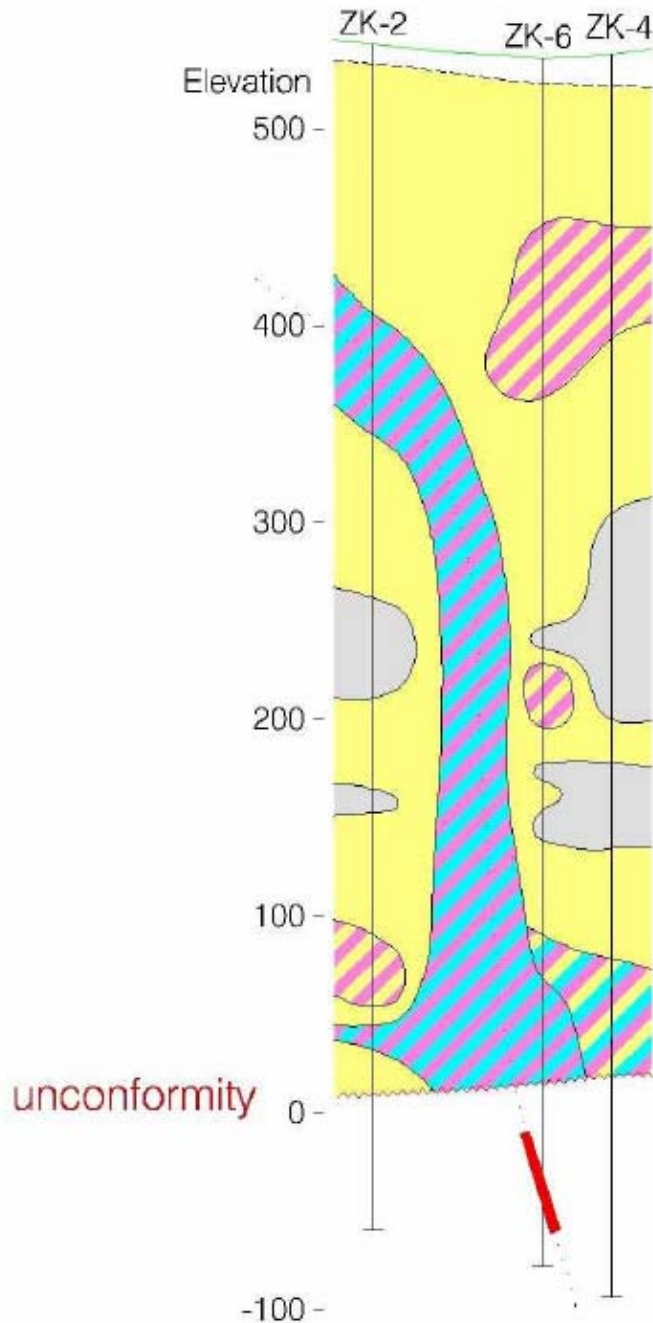
■ Stoney Rapids

YUKON  
B.C.  
ALTA.  
SASK.  
MAN.  
ONT.  
QUE.  
SASKATOON  
Hudson Bay  
Pacific Ocean

# KEY LAKE DEILMANN DEPOSIT



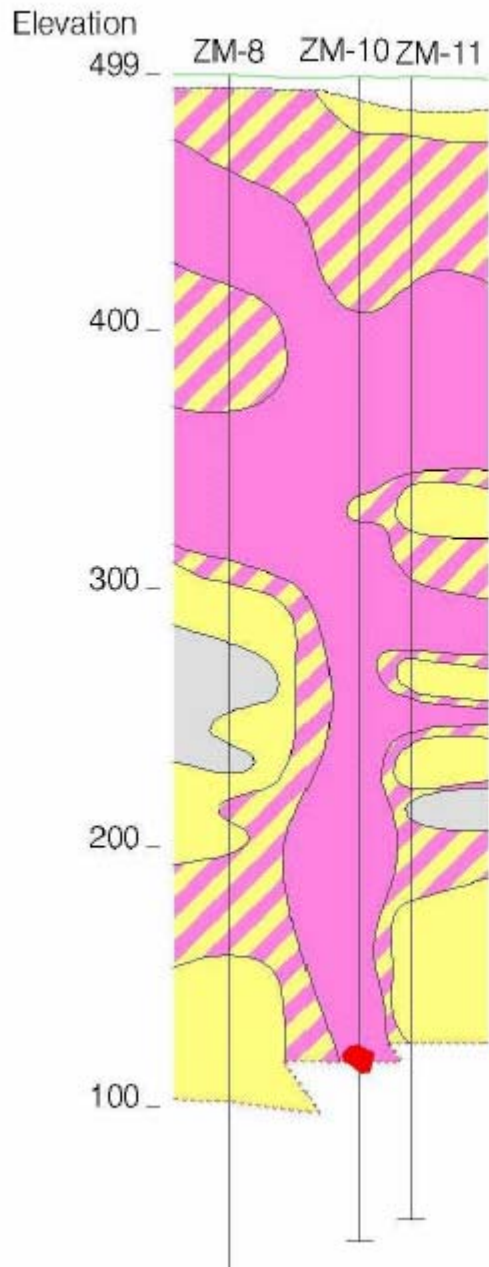
# WHEELER RIVER - ZONE K



## Legend

- Dickite
- Illite
- Magnesiofoitite / Illite
- Magnesiofoitite / Kaolinite
- Magnesiofoitite / Illite / Kaolinite

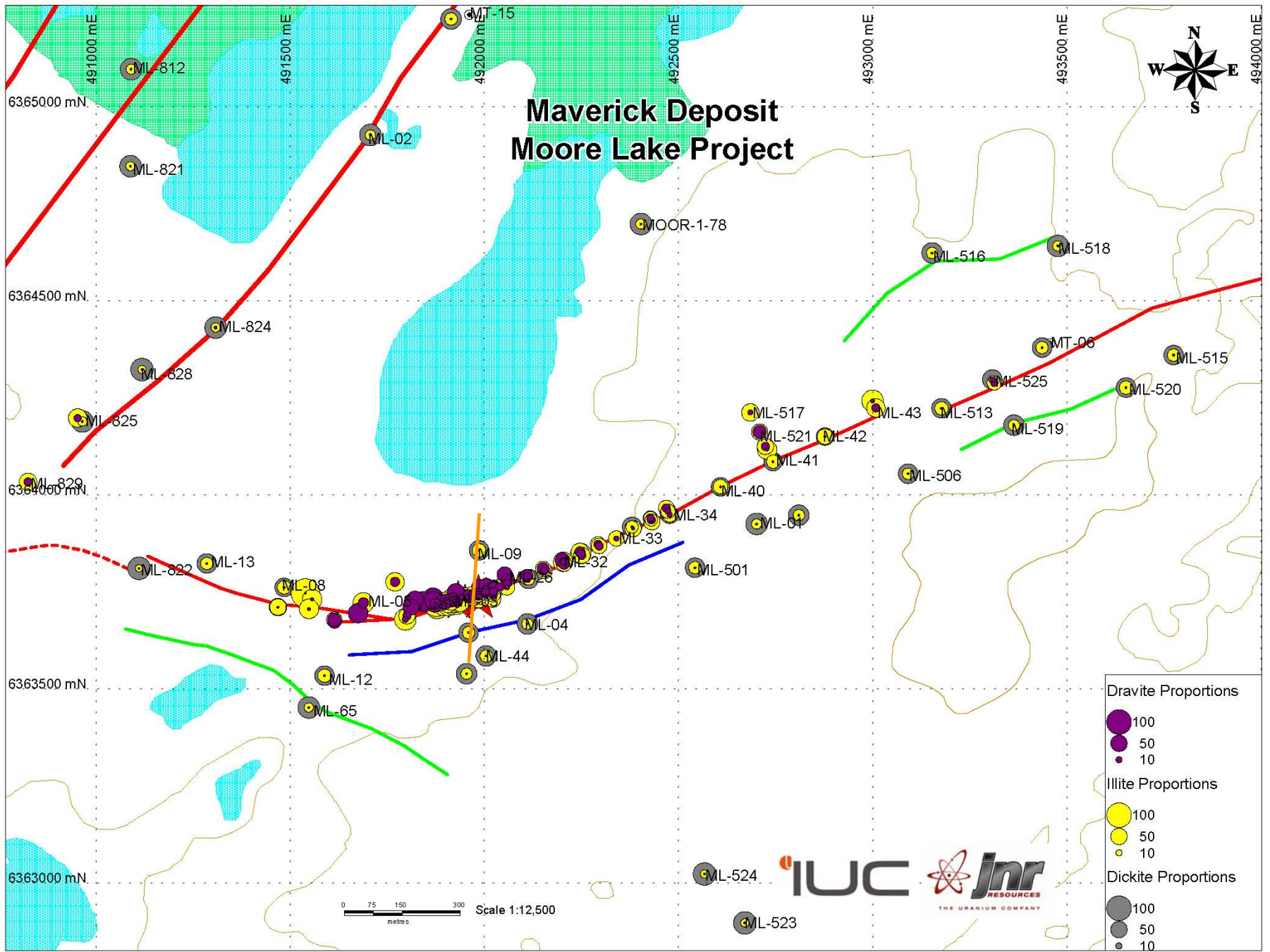
0 100 200m



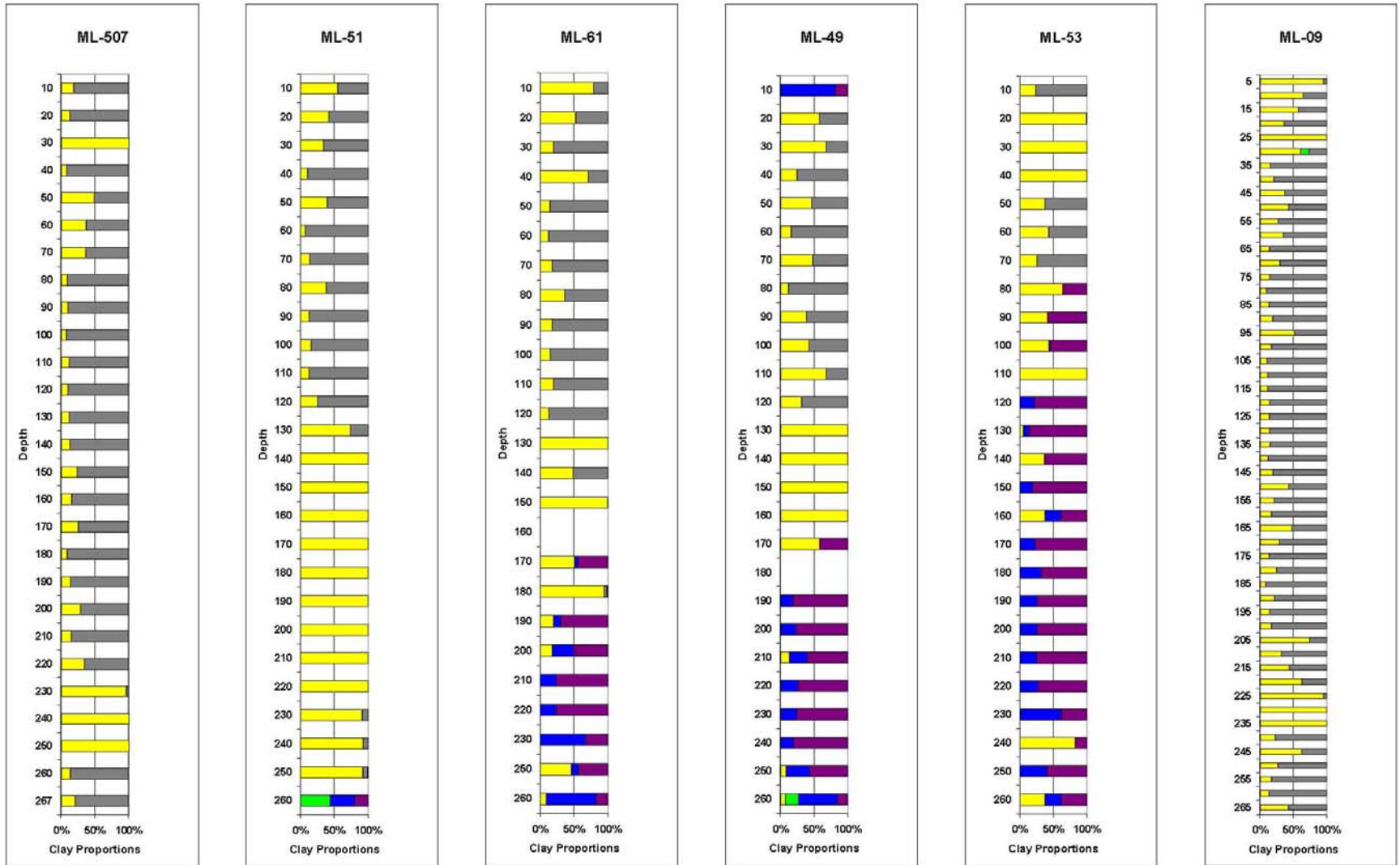
# WHEELER RIVER - ZONE M

## Legend

-  Dickite
-  Illite
-  Magnesiofoitite

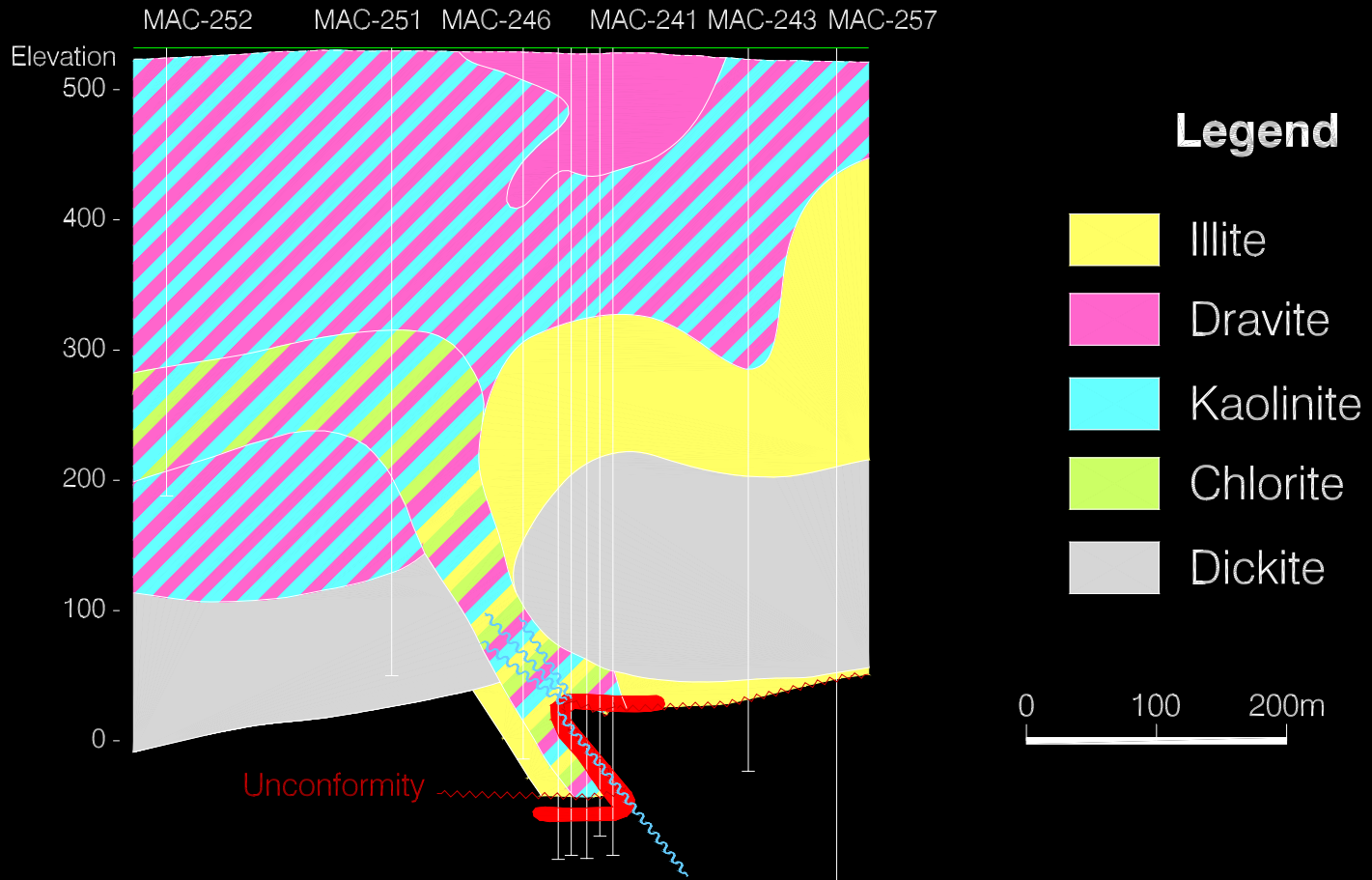


# Maverick Deposit – Section ML-61 Looking West

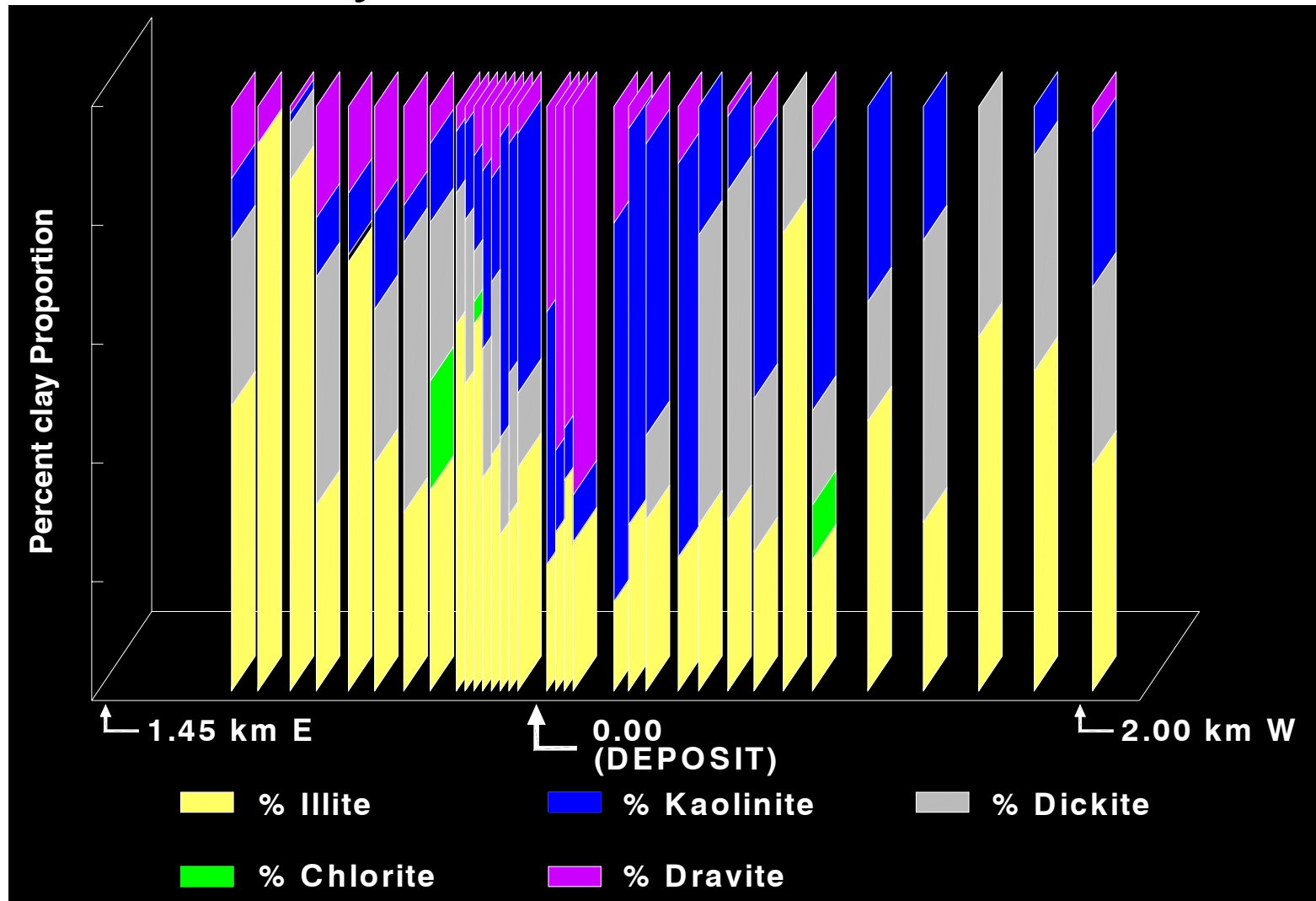


Illite Chlorite Dickite Kaolinite Dravite

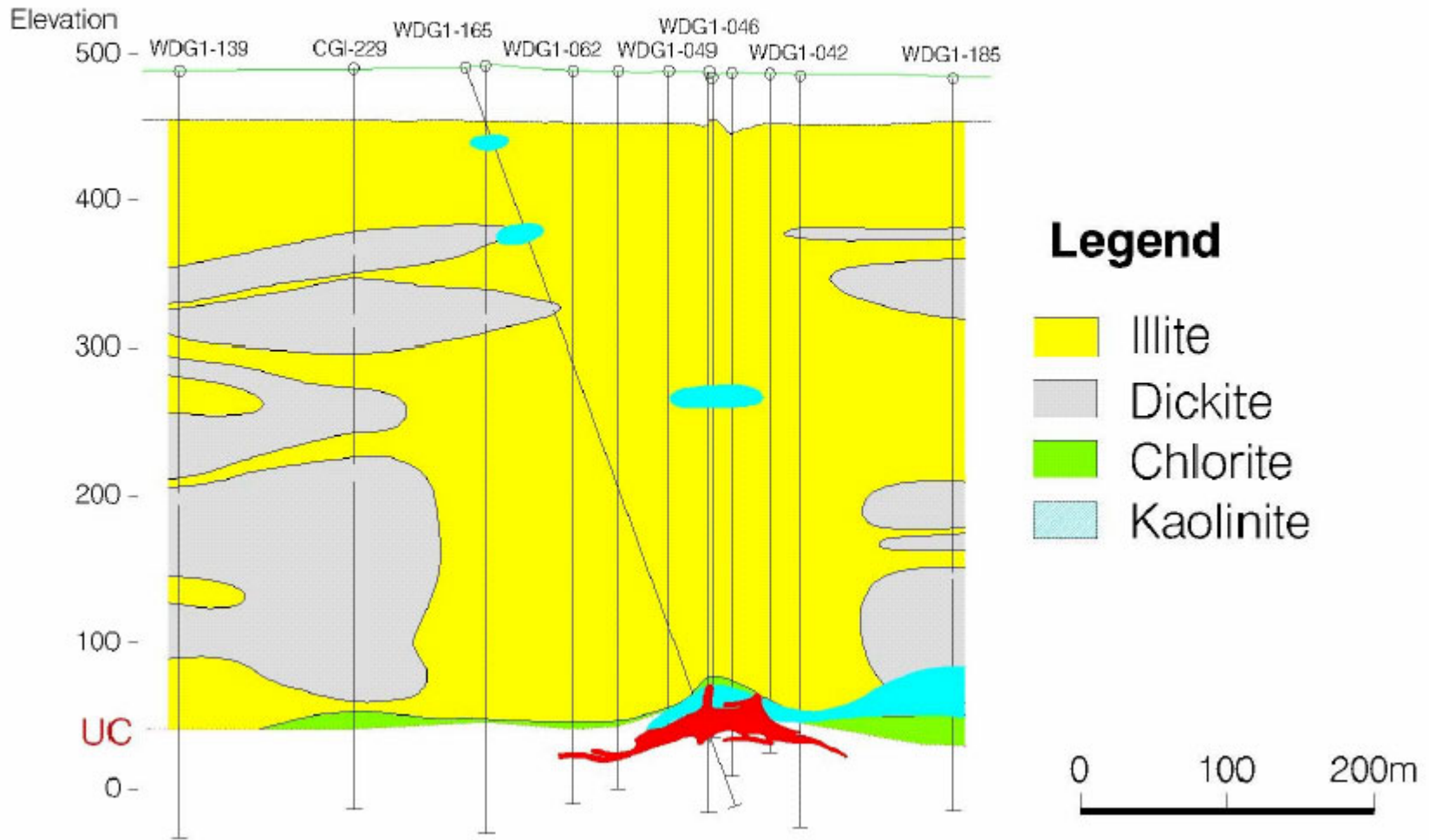
# McARTHUR RIVER - P2 NORTH



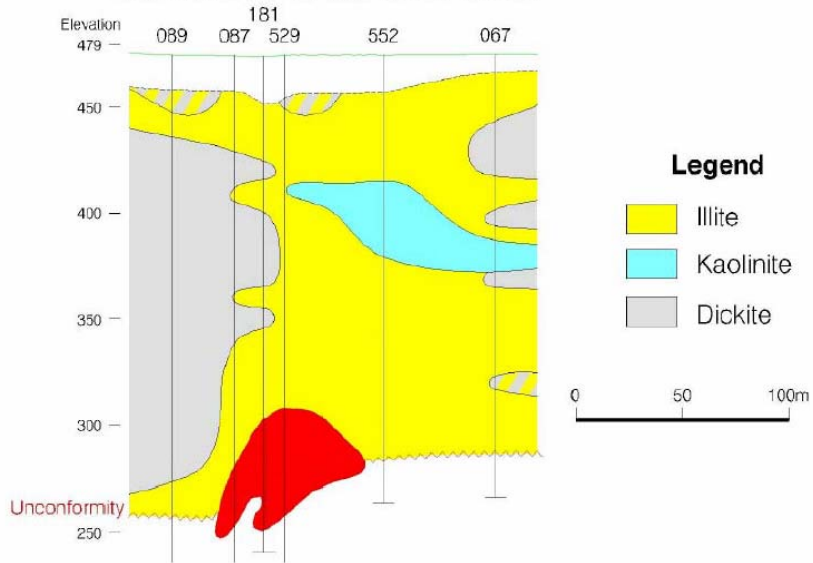
# McArthur River Project Clay Estimates in Boulders



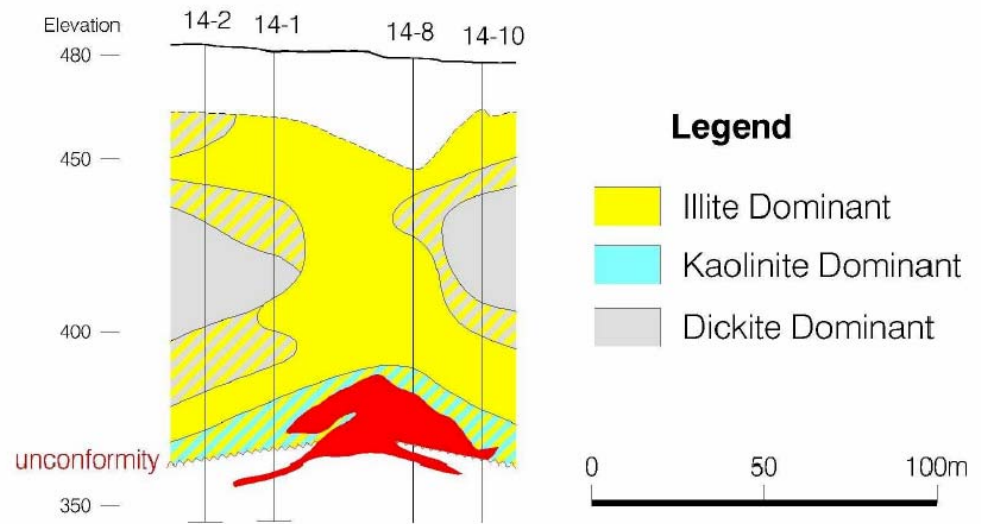
# CIGAR LAKE DEPOSIT



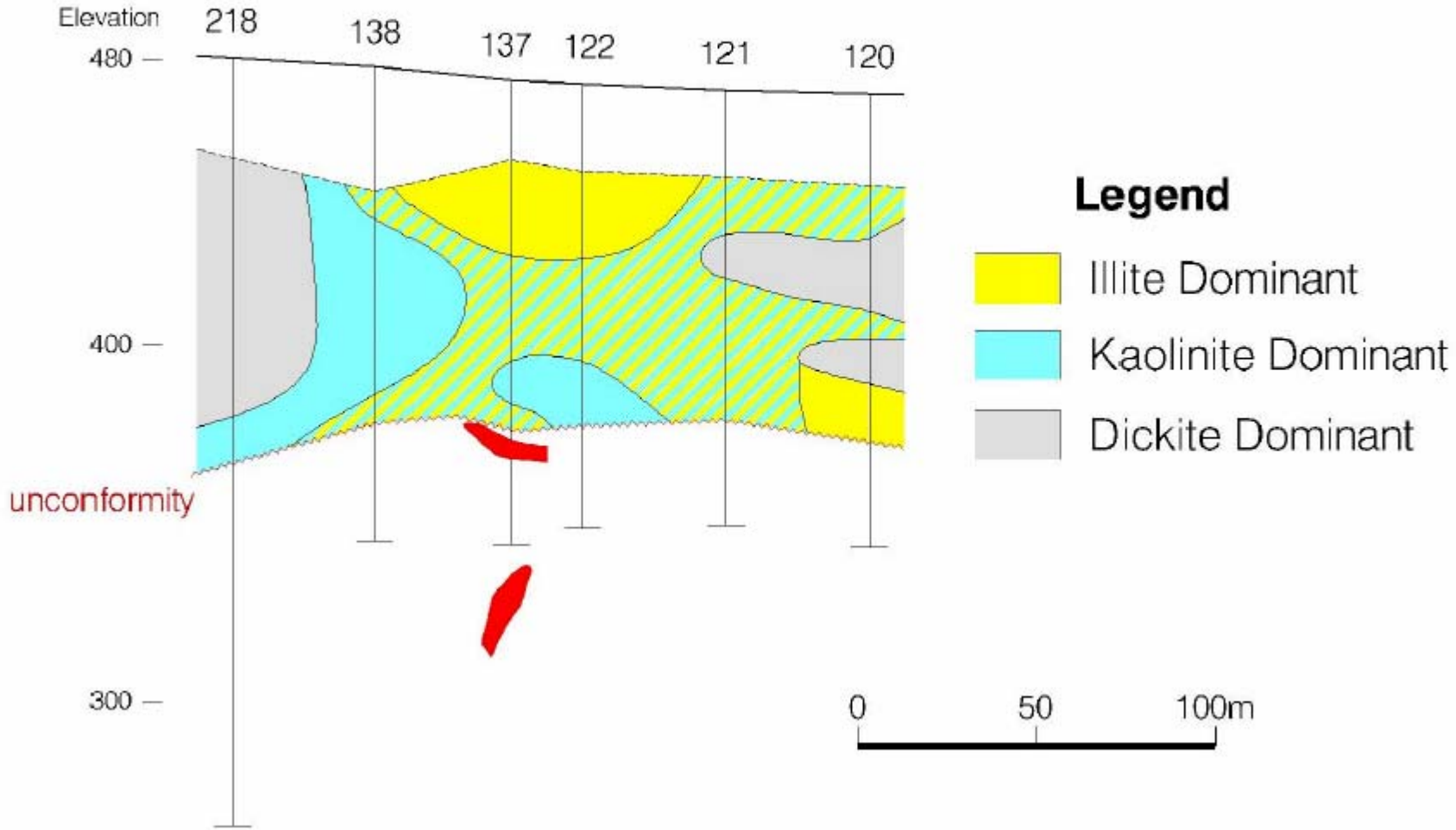
## MIDWEST LAKE DEPOSIT



## DAWN LAKE - 14 ZONE

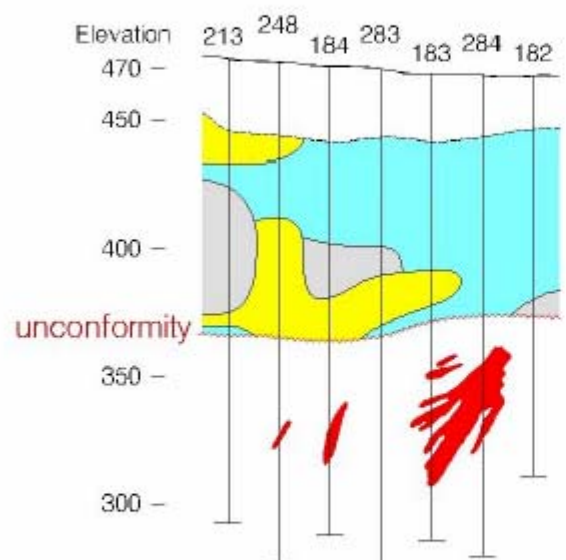


# DAWN LAKE 11A ZONE

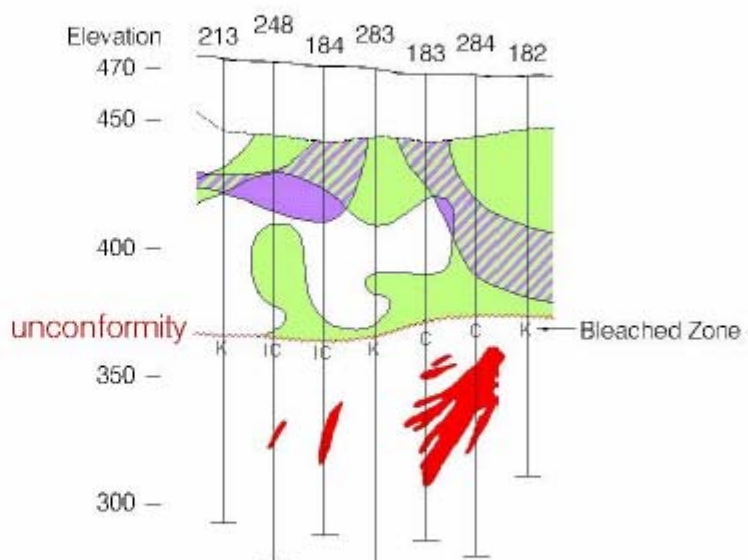


# DAWN LAKE 11B ZONE

**Sandstone  
Kandite & Illite**

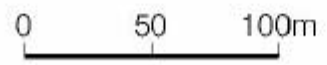


**Sandstone  
Chlorite & Dravite**



**Legend**

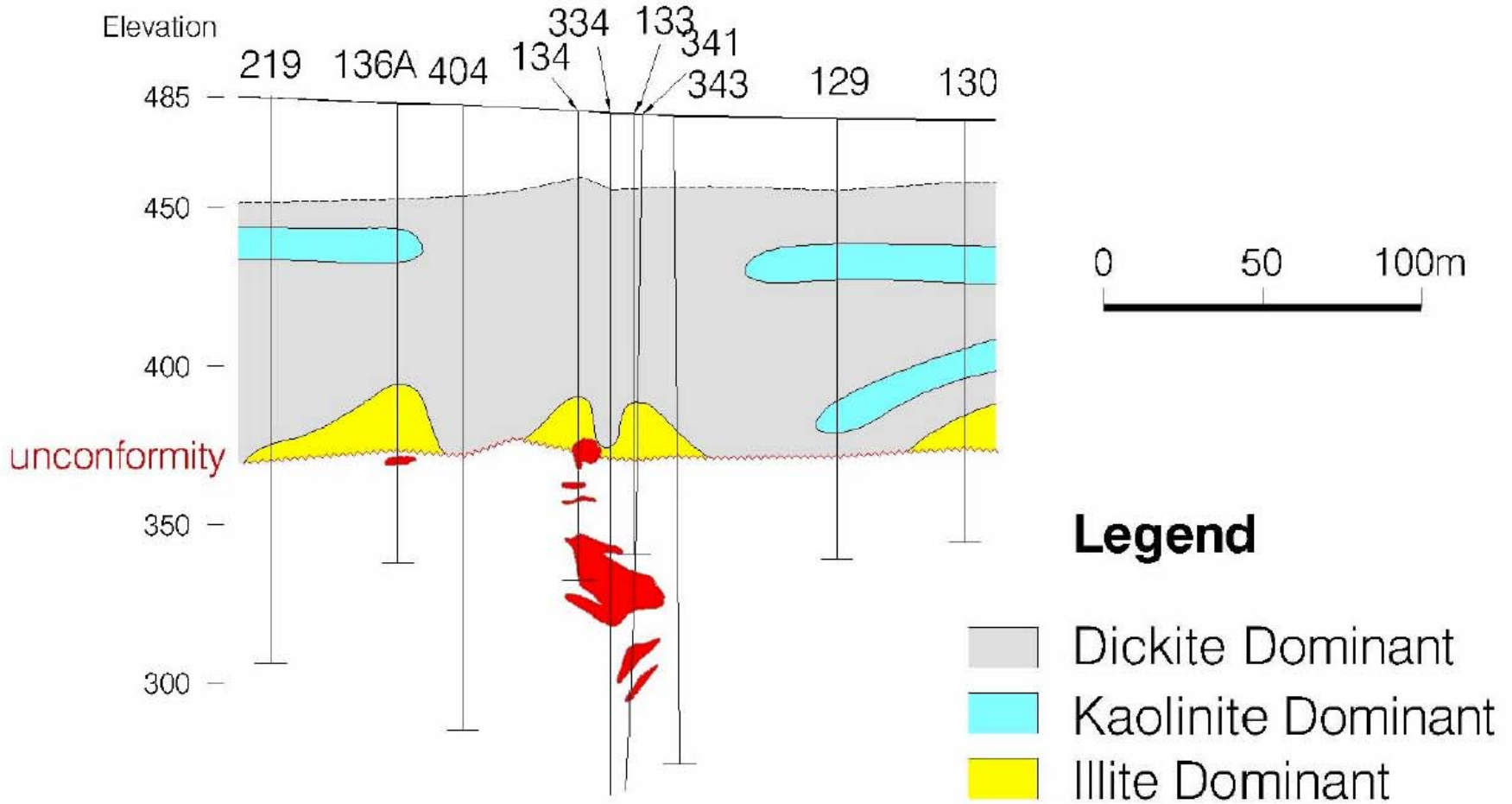
- Illite Dominant
- Kaolinite Dominant
- Dickite Dominant



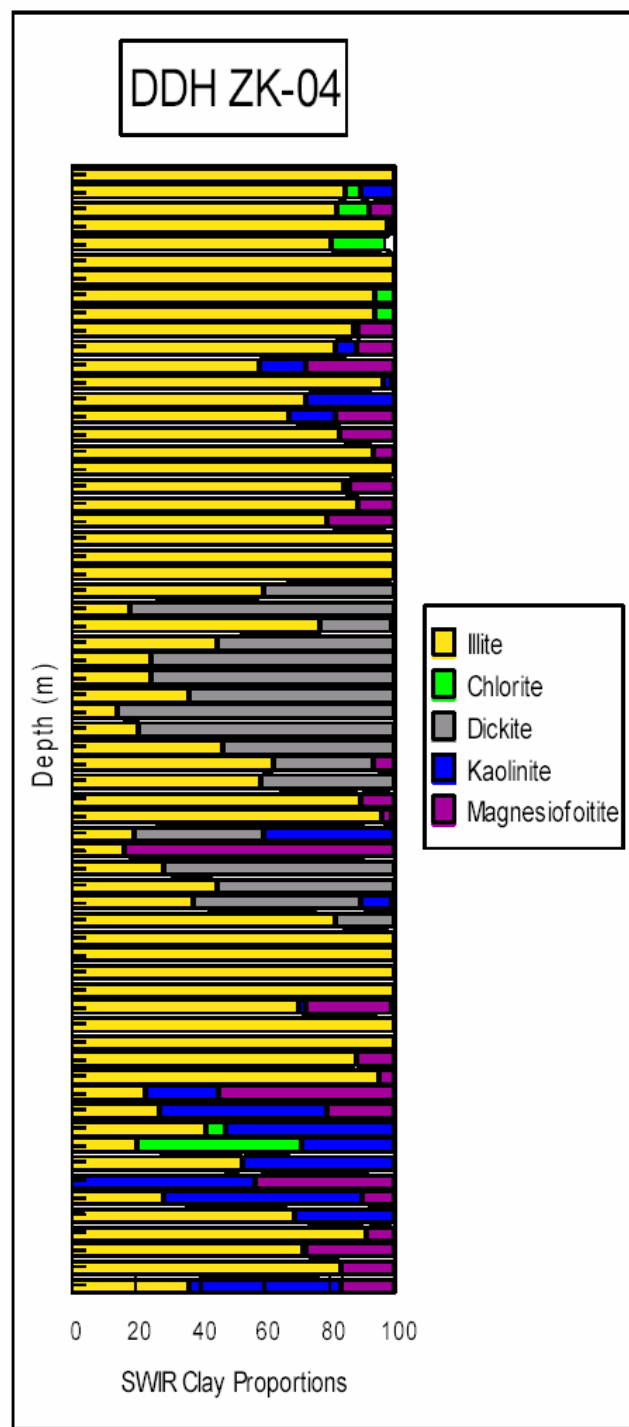
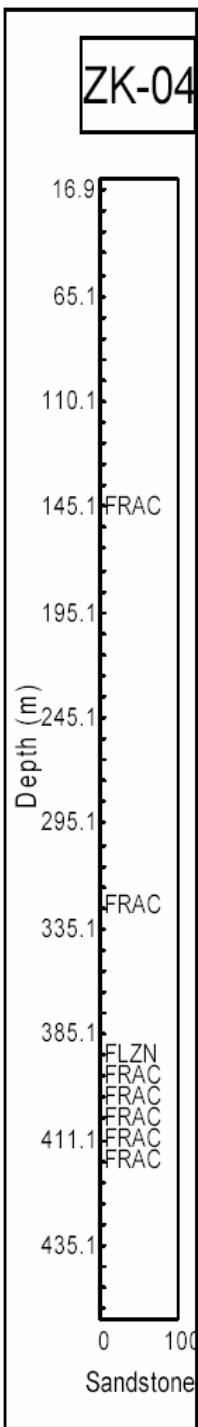
**Legend**

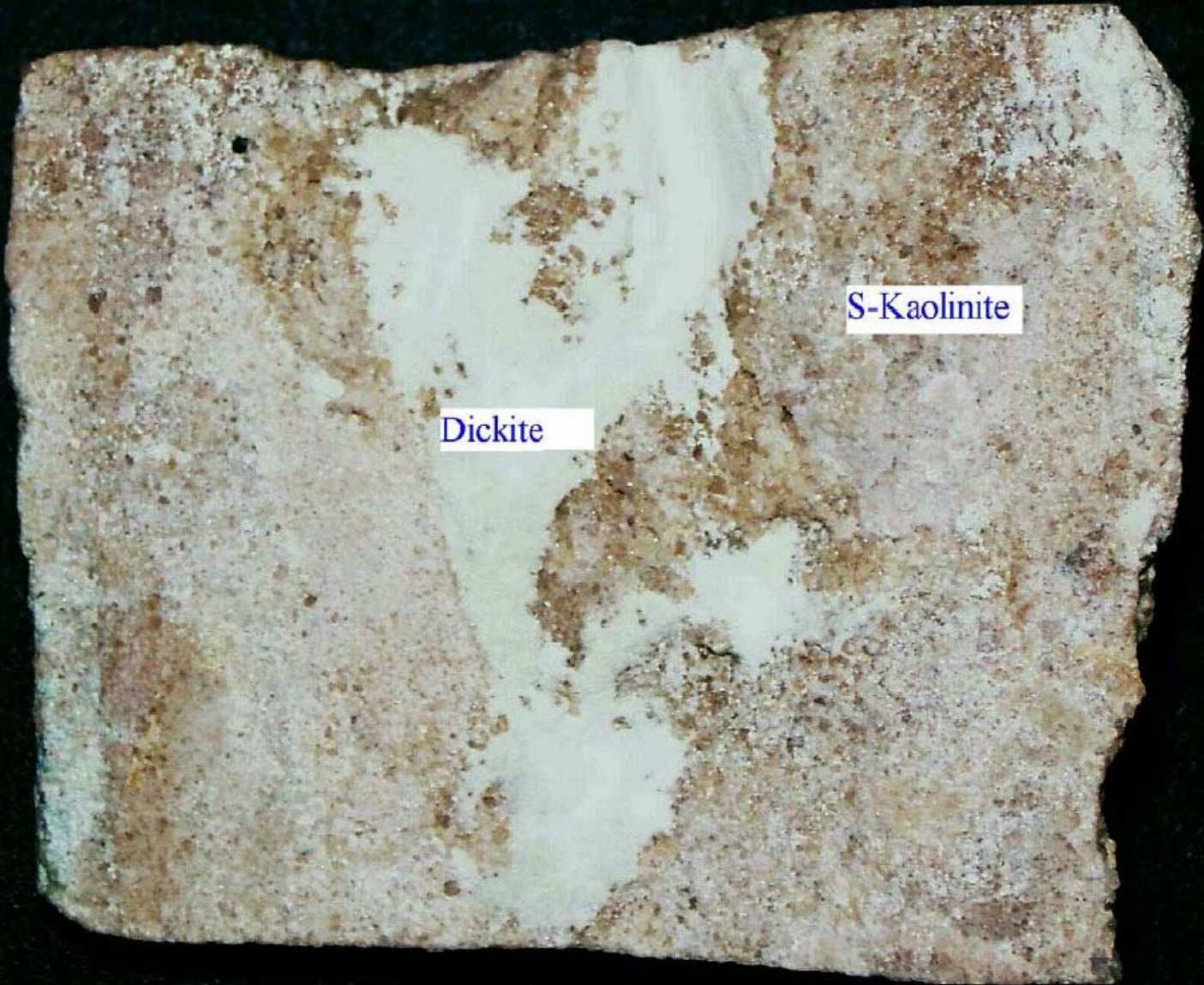
- Sudoite
- Magnesiofoitite

# DAWN LAKE 334 POD



# Drill Hole and Hand Sample Clay Distribution Patterns

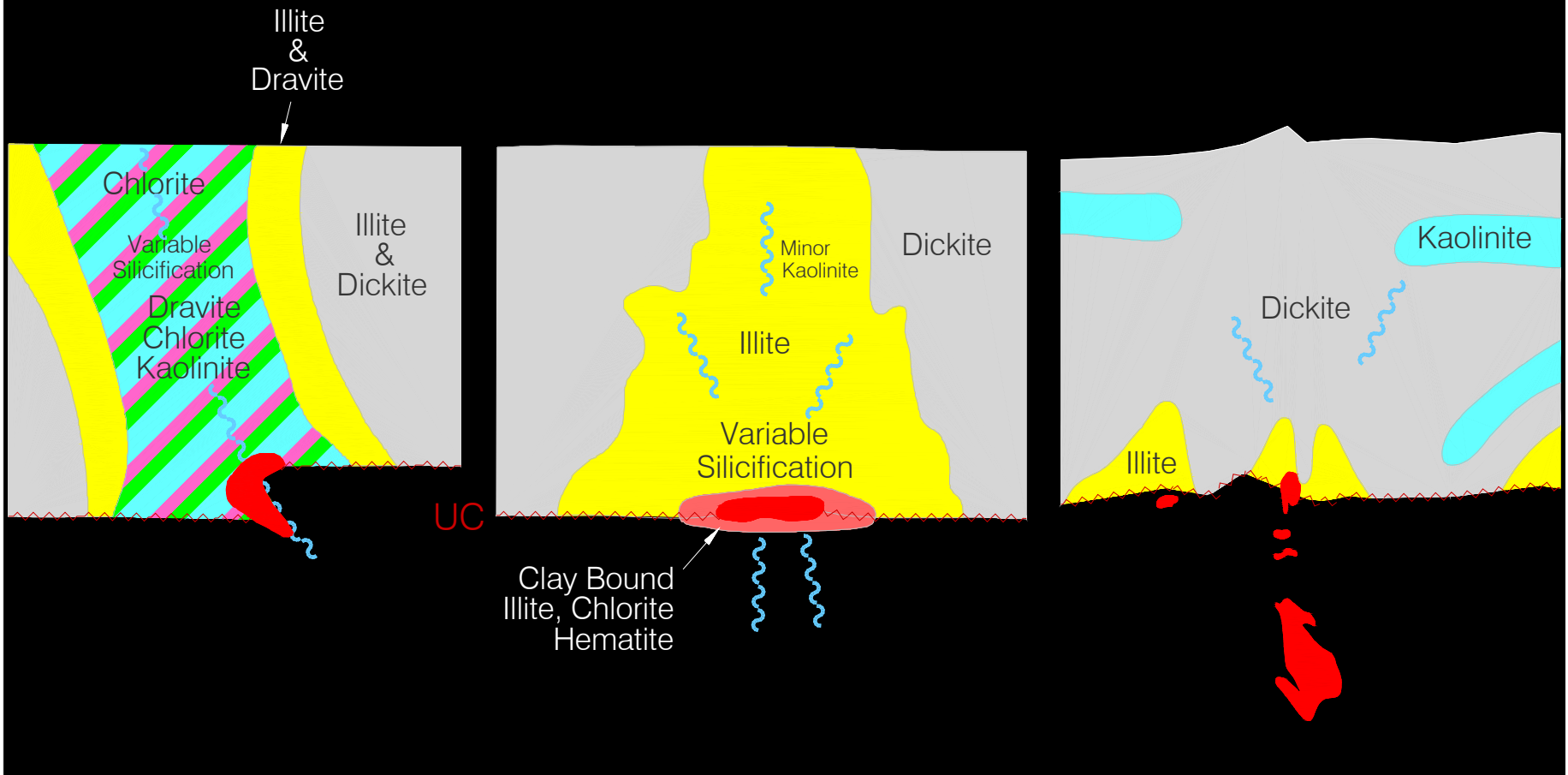




Dickite

S-Kaolinite

# SANDSTONE ALTERATION MODELS (1999)



# Clay Distributions in Basement Rocks



# Exploration Highlights (Basement)

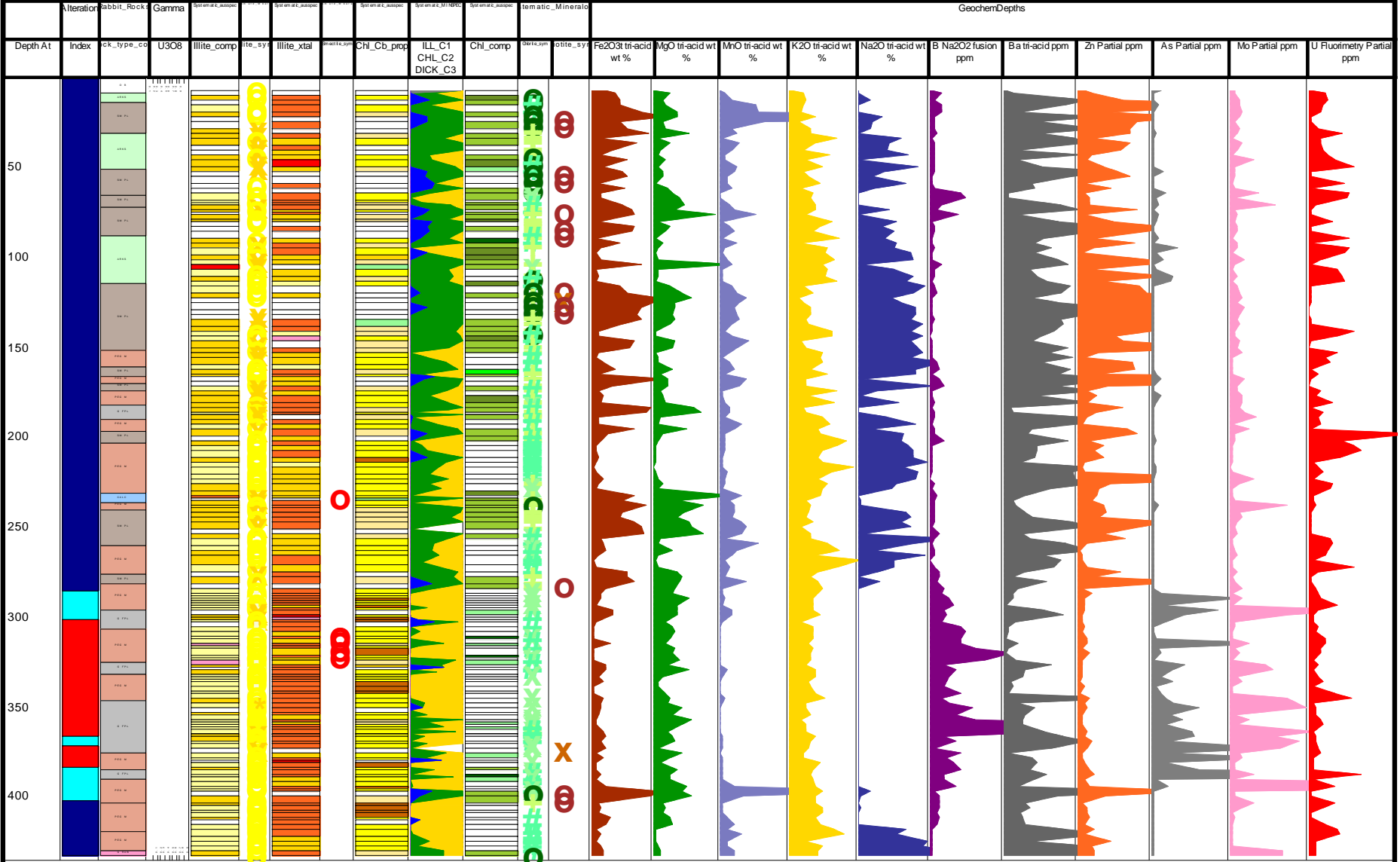
- illite/chlorite proportional increases with alteration intensity (somewhat controlled by lithology and not manifested in chemistry)
- biotite and Fe chlorites preserved in fresh pelitic gneisses
- Fe depletion (bleaching) manifested in higher Mg chlorites
- Na-Ba-Zn is depleted from all lithologies and intensifies with alteration
- U-B plus typical pathfinders (Ni,Pb,As,Mo etc.) enriched in all lithologies



EPT\_Study.dhx

Segment Start Depth :0.00

Segment End Depth :434.50



# Exploration Highlights (Sandstone)

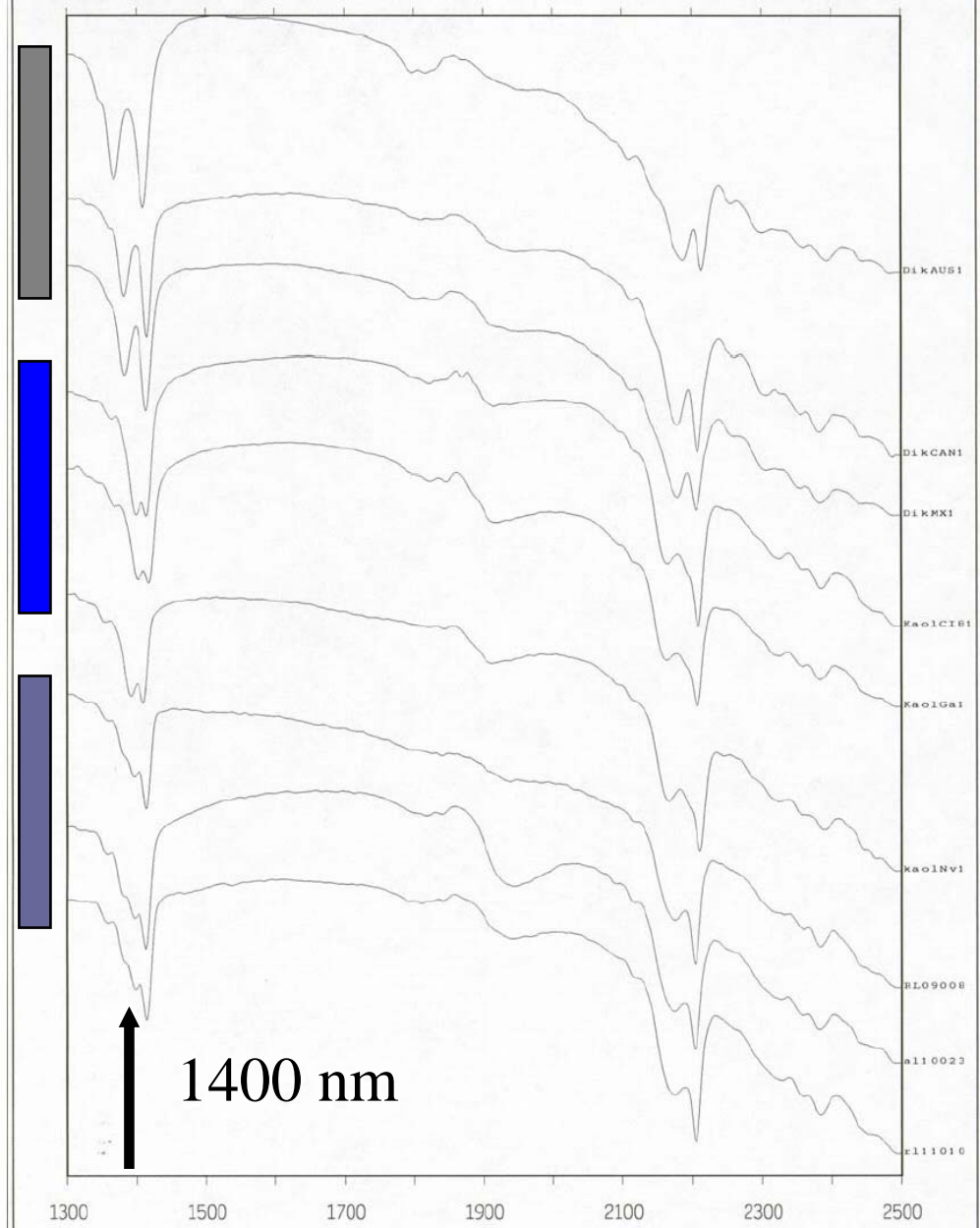
- dickite is commonly developed in regional holes away from mineralization
- illite, kaolinite, dravite and chlorite are commonly developed near mineralization
- similar clay distributions occur around mineralization in both north and in south (ie. Dawn Lake)
  - dickite--->illite--->kaolinite+-dravite/chlorite
- these clay distributions can occur on all scales (from individual faults within drill holes, to deposit, district and regional)
- regional clay alteration patterns are reflected in both the drill core and boulder geochemistry
- alteration crosscuts stratigraphy in the Manitou Falls Formation
- variations of clay patterns at all scales indicates that the clay minerals are sensitive indicators of hydrothermal and diagenetic events
  - however the variations at the regional, local and deposit scale also show the need for consistent sampling and the establishment of background clay patterns
- use clay distributions as a vector towards hydrothermal centres and mineralization

# Kaolinite Group “Minerals” in the Athabasca Basin

Dickite  
(standards)

Kaolinite  
(standards)

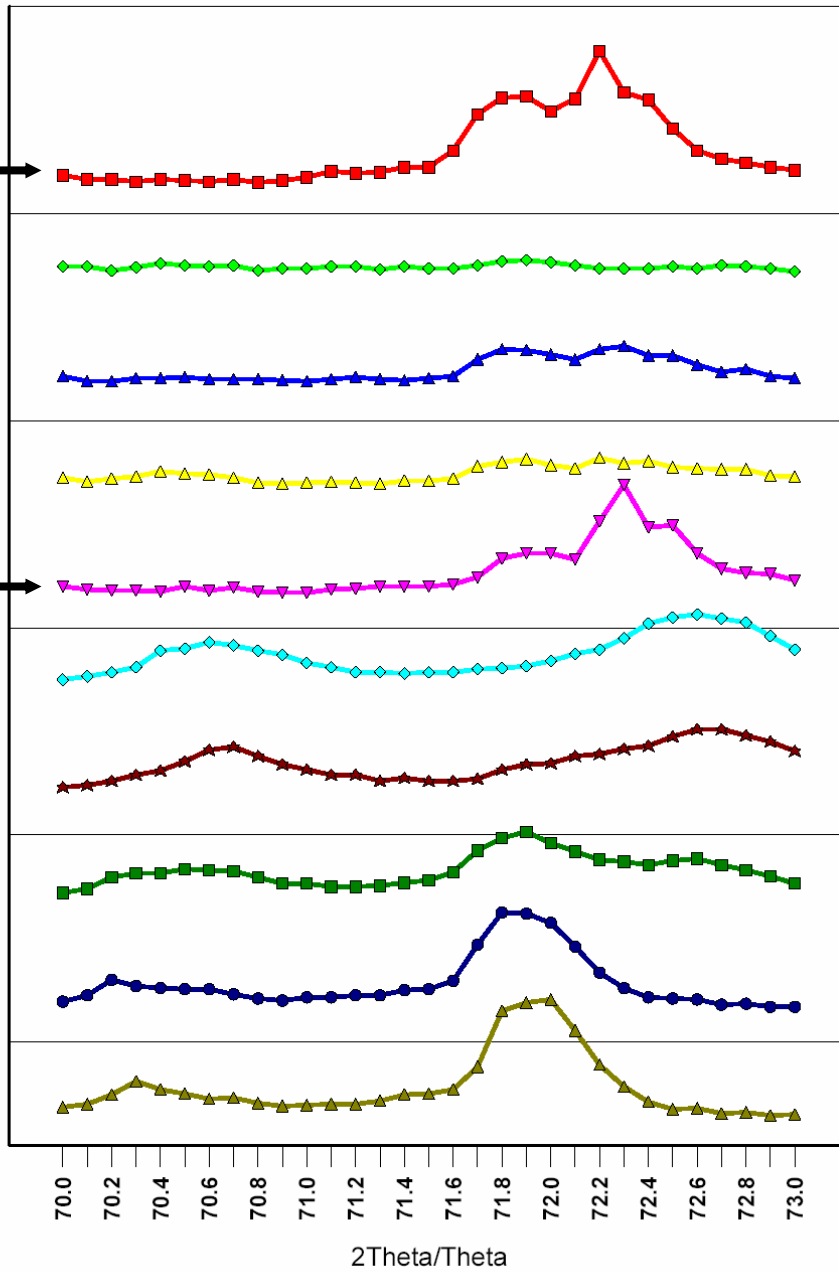
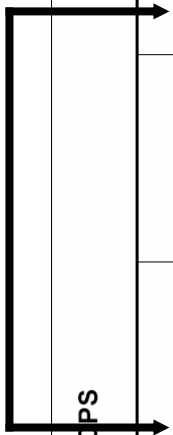
S-Kaolinite  
(Mixed Layered)  
Athabasca  
Basin



1400 nm

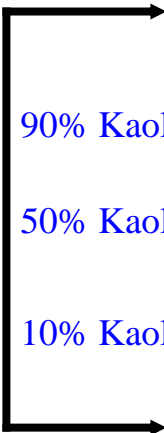
### Samples From Athabasca Basin

Athabasca Samples  
with Unique SWIR Characteristics



- 42095-96
- 42124-26
- 42025-27
- 42075-76
- 42171-73
- 99K-1D
- 90K-10D
- 50K:50D
- 10K:90D
- 1K:99D
- 100% Dickite

100% Kaolinite



90% Kaolinite/10% Dickite

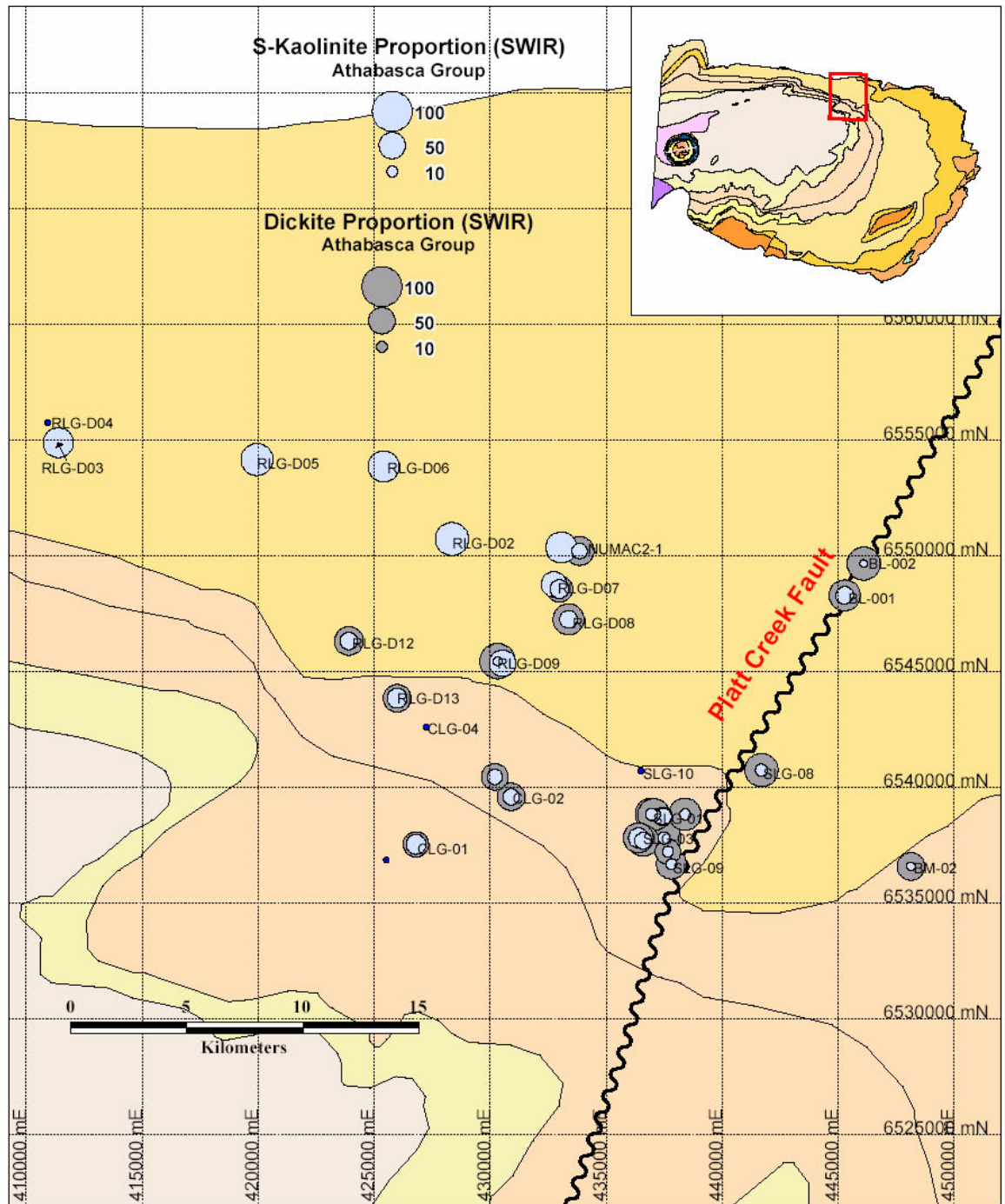
50% Kaolinite/50% Dickite

10% Kaolinite/90% Dickite

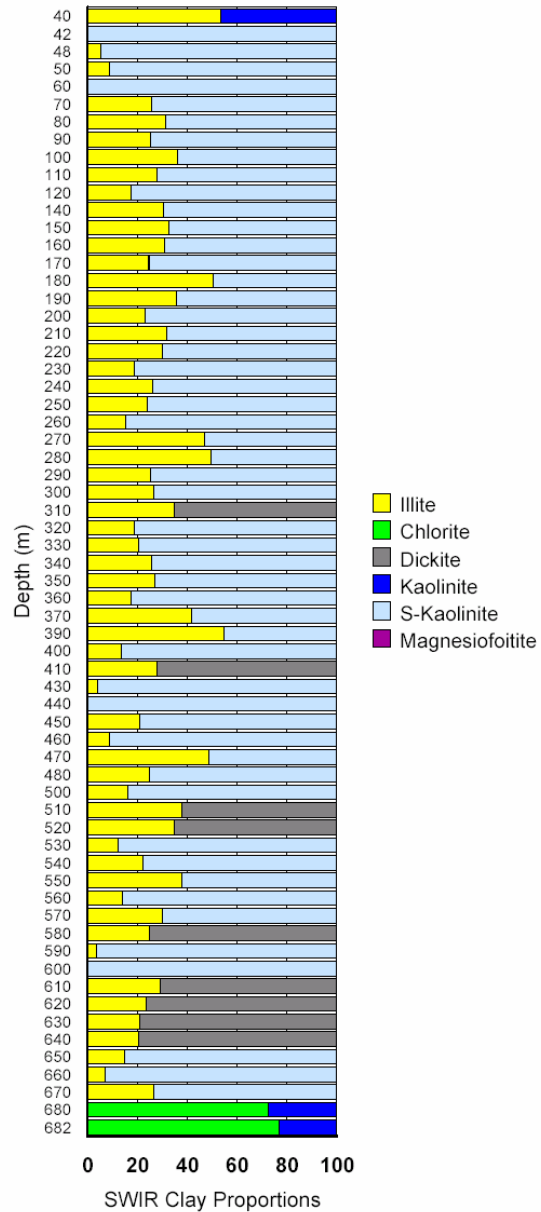
100% Dickite

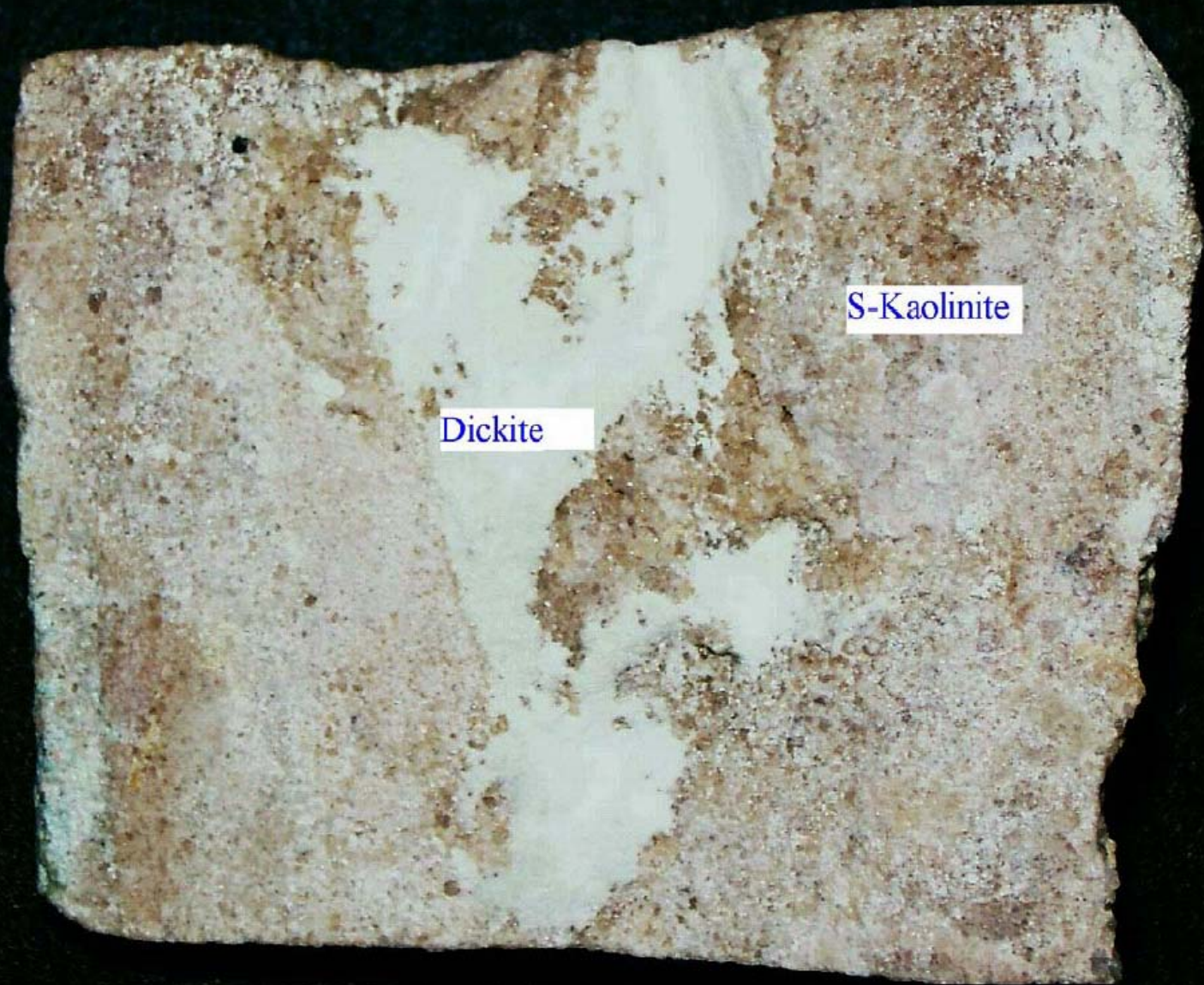
Experimental Samples  
Mechanical Mixtures

2Theta/Theta



# SWIR Clay Proportions DDH RLG-D06

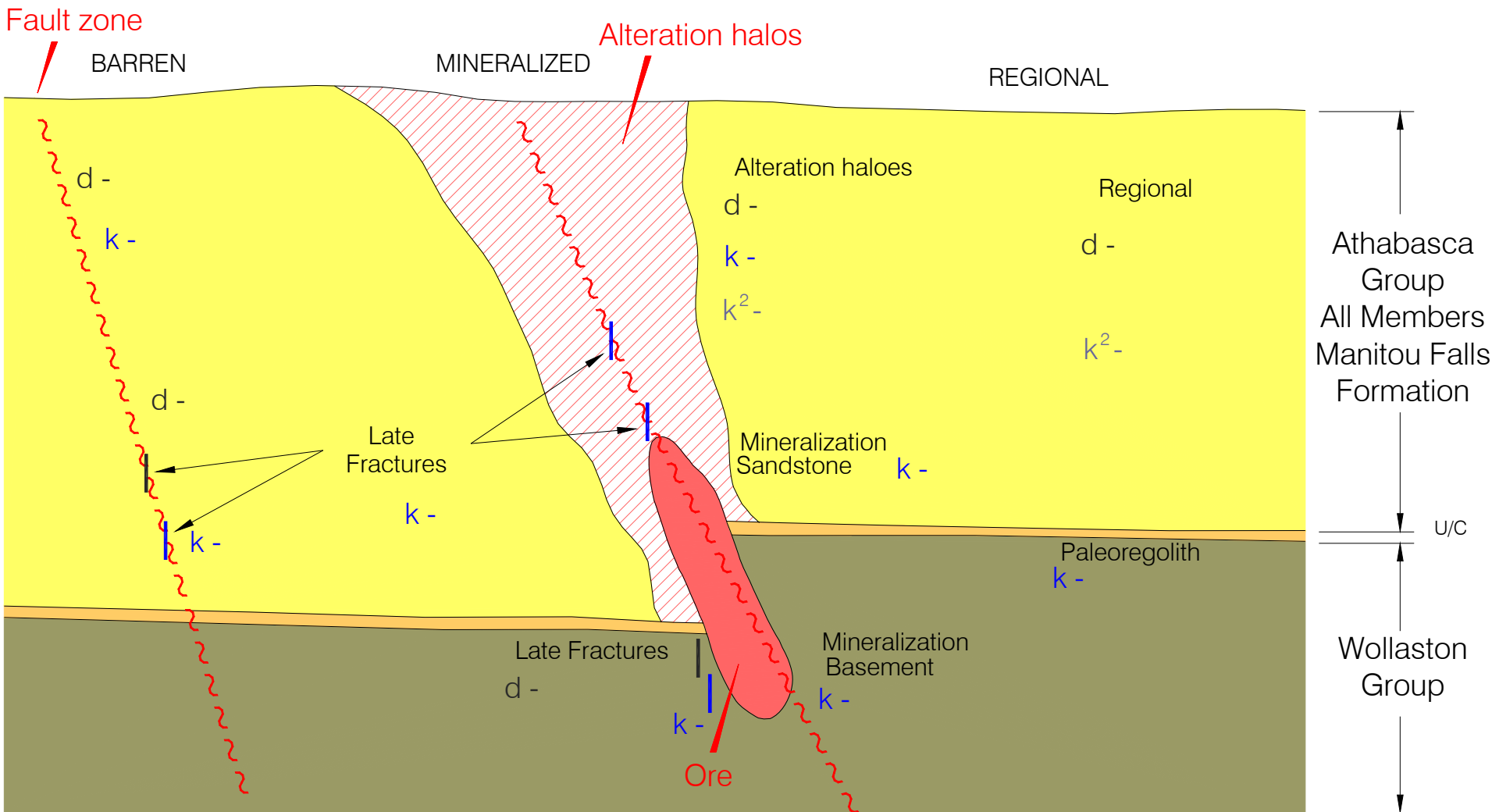




Dickite

S-Kaolinite

# KAOLINITE MINERAL SETTINGS IN ATHABASCA BASIN



## Legend

k = kaolinite

d = dickite

k<sup>2</sup> = S-kaolinite (mixed layer)

# SETTING OF KAOLINITE GROUP MINERALS WITH LOW $\delta D$ VALUES

< -90 ‰

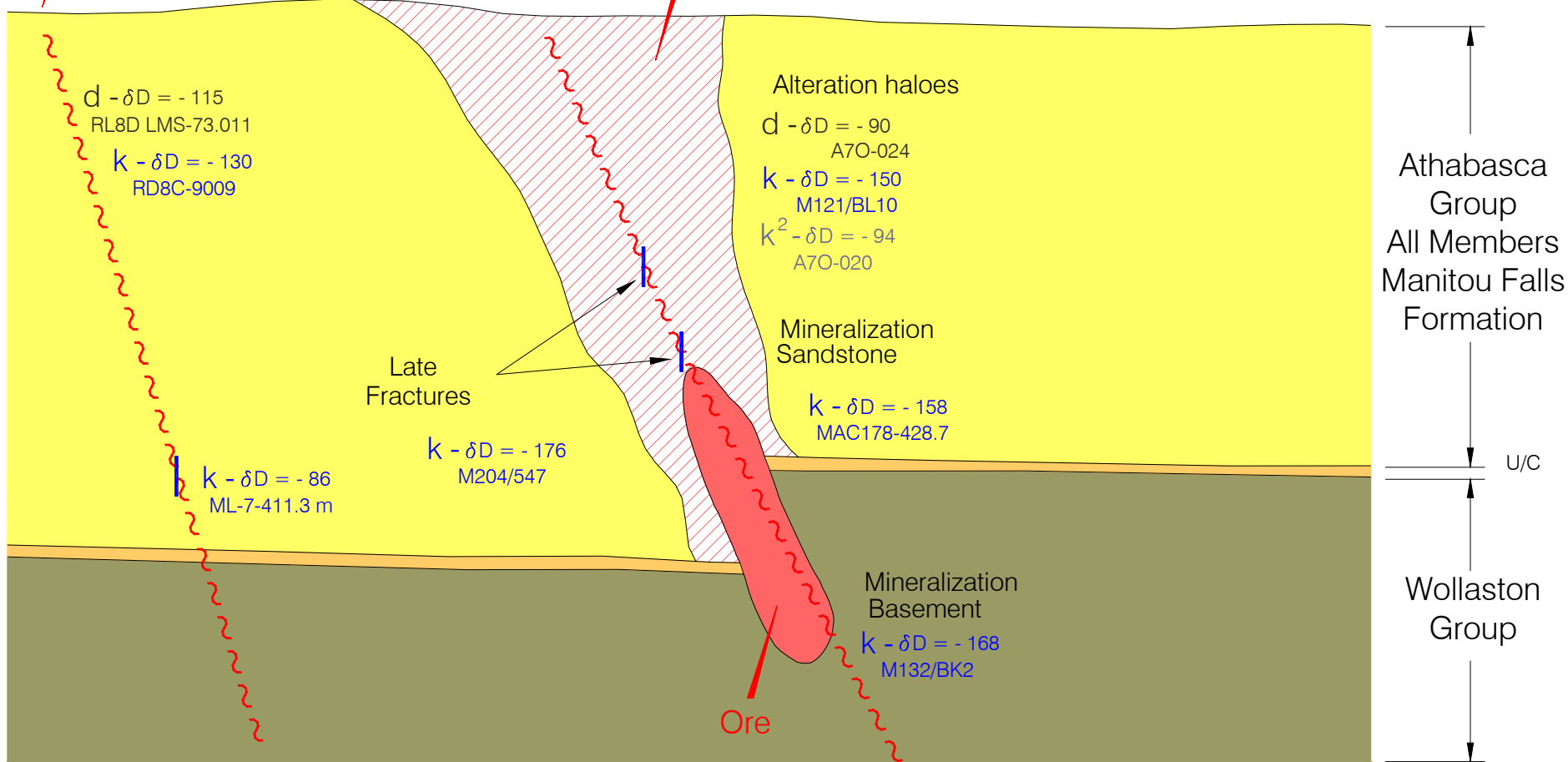
Fault zone

Alteration halos

BARREN

MINERALIZED

REGIONAL



## Legend

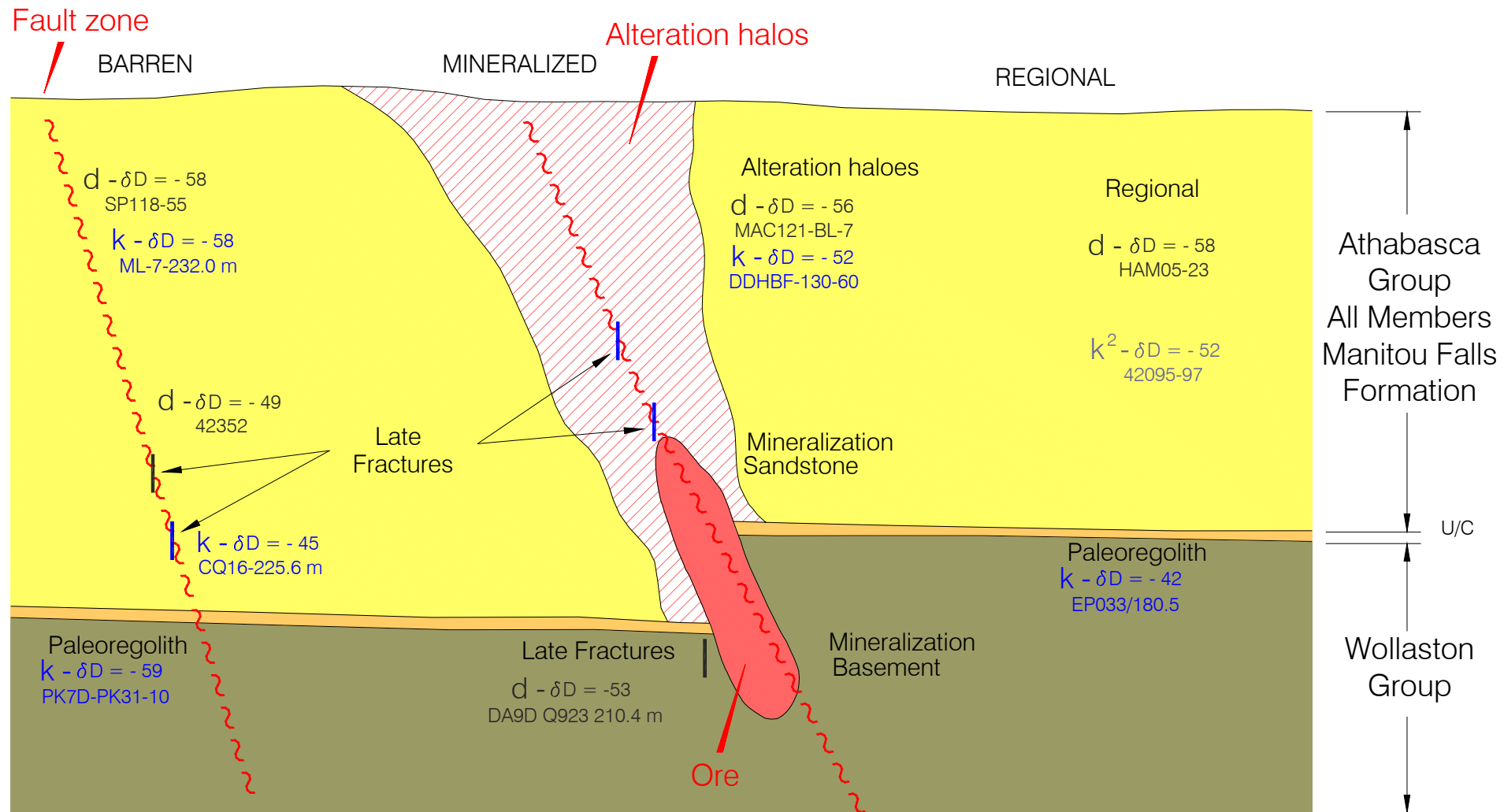
$k$  = kaolinite

$d$  = dickite

$k^2$  = S-kaolinite (mixed layer)

# SETTING OF KAOLINITE GROUP MINERALS WITH HIGH $\delta D$ VALUES

~ -40 to -60 ‰



## Legend

k = kaolinite

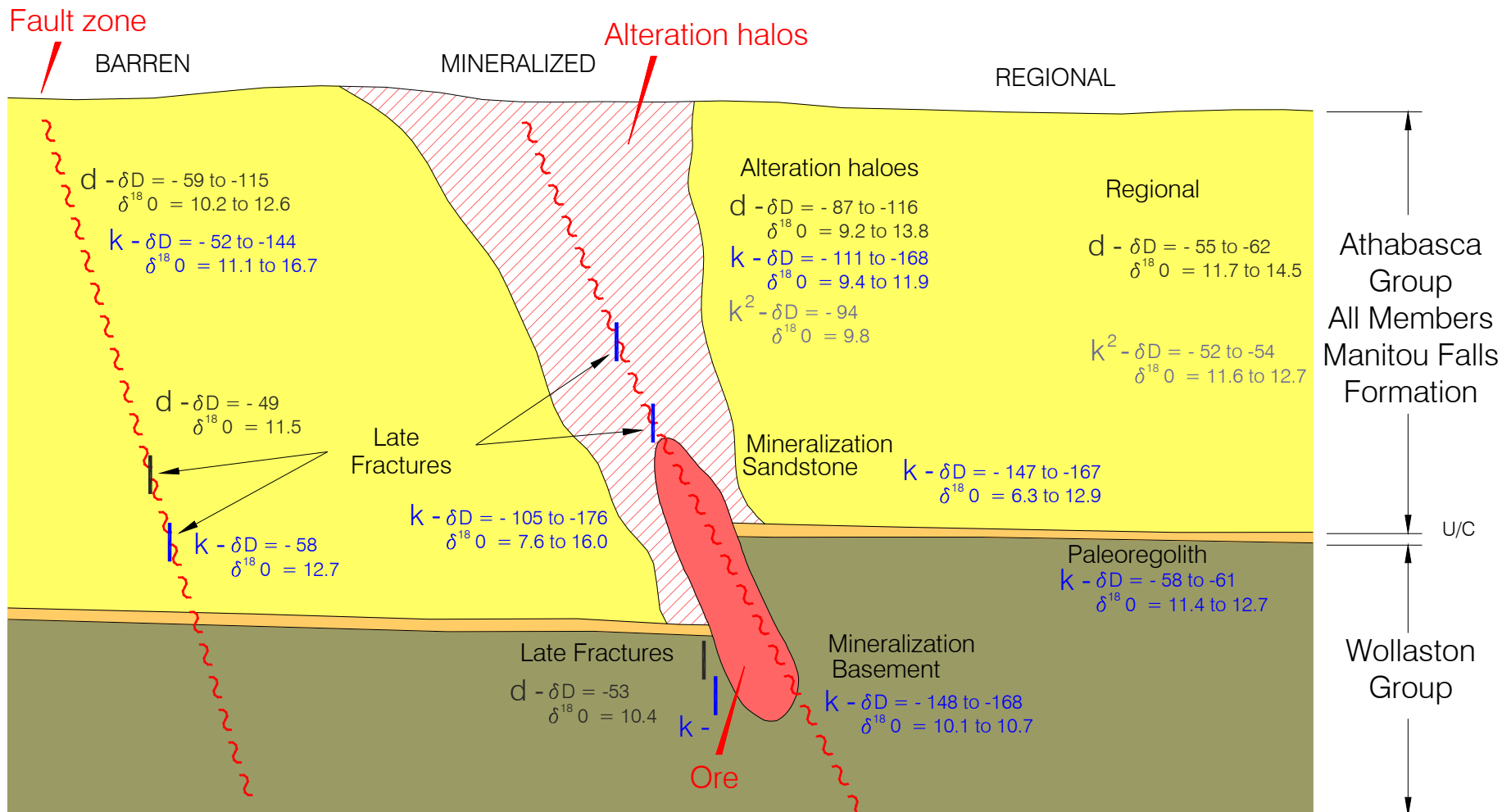
d = dickite

k<sup>2</sup> = S-kaolinite (mixed layer)

<b>Polytype (# of samples)</b>	<b><math>\delta\text{D}</math> (‰) (mean)</b>	<b><math>\delta^{18}\text{O}</math> (‰) (mean)</b>
Undifferentiated (13)	-35 to -167 (-90)	8.8 to 12.7 (12.5)
Dickite (19)	-49 to -116 (-72)	9.2 to 14.1 (11.8)
<i>S</i> -Kaolinite (3)	-52 to -94 (-67)	9.8 to 12.7 (11.4)
Kaolinite (44)	-45 to -176 (-121)	6.3 to 17.1 (11.7)

# KAOLINITE MINERAL SETTINGS IN ATHABASCA BASIN

## ISOTOPIC COMPOSITION RANGES OF KAOLINITE GROUP MINERALS



### Legend

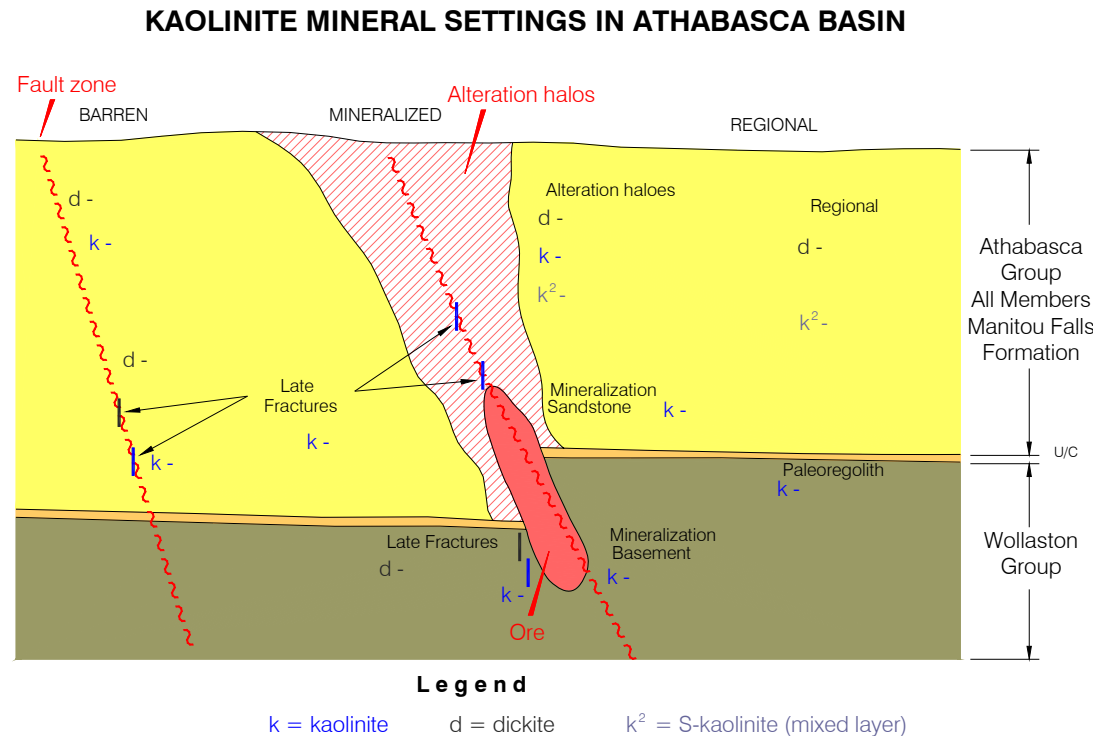
k = kaolinite

d = dickite

k<sup>2</sup> = S-kaolinite (mixed layer)

# Summary

- Kaolinite
  - alteration haloes (mineralized or “barren”)
  - “bleached” zone of paleoregolith
  - faults and fractures (basement and sandstone)
- Dickite
  - regional sandstone
  - alteration haloes (not common)
  - faults and fractures (basement and sandstone)
- S-Kaolinite
  - regional sandstone
  - alteration haloes (rare)



# Deilman Pit Samples

(Ramaekers, 1989)

<b>Sample</b>	<b>Paragenesis</b>	<b>Kaolin Polytype (SWIR)</b>
<b>D-450-01A</b>	<b>early &amp; late</b>	<b>kaolinite</b>
<b>D-450-03</b>	<b>late</b>	<b>kaolinite</b>
<b>D-458-05A</b>	<b>early &amp; late</b>	<b>kaolinite</b>
<b>D-458-05B</b>	<b>early</b>	<b>kaolinite</b>
<b>D-458-11</b>	<b>early</b>	<b>kaolinite</b>
<b>D-458-15</b>	<b>late</b>	<b>kaolinite</b>
<b>D-458-18</b>	<b>late</b>	<b>kaolinite</b>
<b>D-466-39</b>	<b>early</b>	<b>kaolinite</b>
<b>D-474-22</b>	<b>early and late</b>	<b>kaolinite</b>
<b>D-474-26</b>	<b>early and late</b>	<b>kaolinite</b>

# Spectral Analysis of Paragenetically “Late” Kaolinite (Hubregtse, 1987)

<u>Drill Hole</u>	<u>Depth</u>	<u>Kaolinite Polytype (SWIR)</u>
RL-44A	400.00	dickite
RL-16	185.00	kaolinite
RL-36	451.5	dickite

# Implications of Kaolinite Polytype Distributions

- Temperature, depth of burial, fluid to rock ratios and time (duration) together not individually control kaolinite polytypism in the Athabasca Basin
- Dickite and kaolinite are present in alteration haloes as well as fractures and faults where high fluid fluxes would be anticipated
- Mixed layer kaolinite in regional sandstone suggests the polytype transformation process has not been achieved
- All kaolinite polytypes can have low  $\delta D$  ( $< -90$  ‰) values providing evidence that preferential and retrograde hydrogen exchange with post-Cenozoic meteoric waters occurs without dissolution or reprecipitation along selected post Athabasca structures.
- The present distribution of kaolinite polytypes are controlled by earlier processes such as diagenesis and ore formation
  - Kaolinite polytype distribution is not a product of late meteoric waters
- Clay mineralogy can be related to the primary fluids involved in the ore forming process and as such can be used to model paleofluids in the Athabasca basin, particularly those associated with uranium mineralization (can be used as a vector towards hydrothermal centres)