Structural network control on the U-mineralization: Example of the Cigar North fault, Saskatchewan, Canada

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Summary

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Objectives

Uranium unconformity-related deposits of the Athabasca Basin are **often associated with polyphased basement-hosted fault system**, graphite or pyrite and hydrothermal alteration.

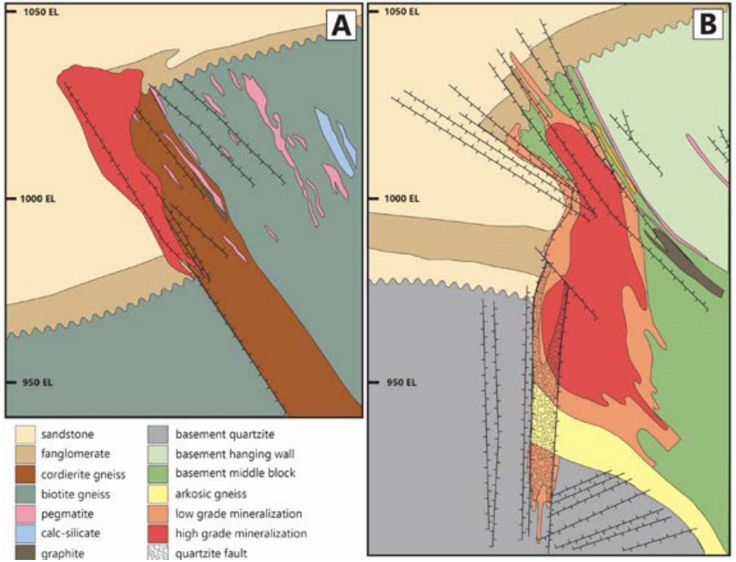
However the **footprint** between mineralized and barren fault **may be similar.**
How to explain **why uranium mineralization occurs at some specific shear zones segments?** What makes these segments different? Are these cases predictable?

Question

What are the key parameters that lead to the formation of uranium deposit?

Main objective

Provide elements to help in the exploration targeting process



Cross-sections of the McArthur River deposit (from Dee Guffey, 2017)

Methodology

Methodology:

Comparison of geological characteristics or process (structural, alteration…)
Start with non-mineralized zones and move to the mineralizations

Understand the structural organization and his evolution:

- Understand the structural network at the current state
- Retrace the structural evolution

Understand the fluid circulations in the structures and lithologies:

- Identifiy the draining structures at the different stages

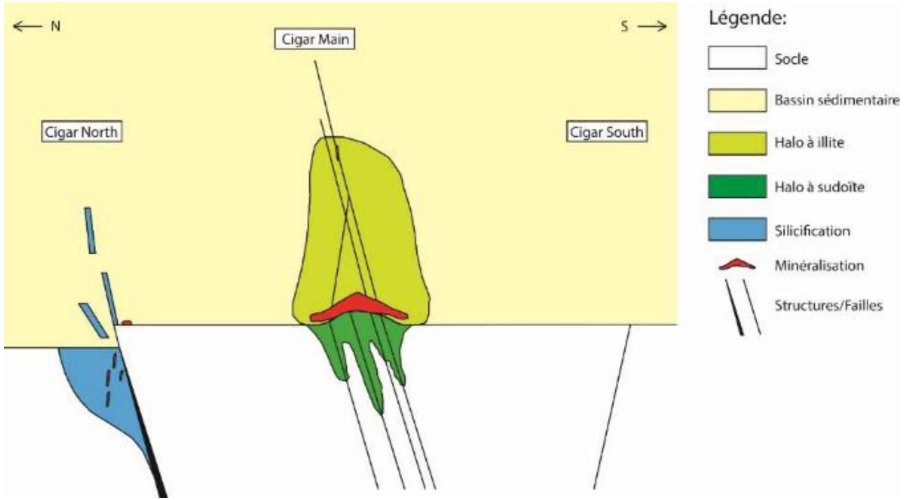
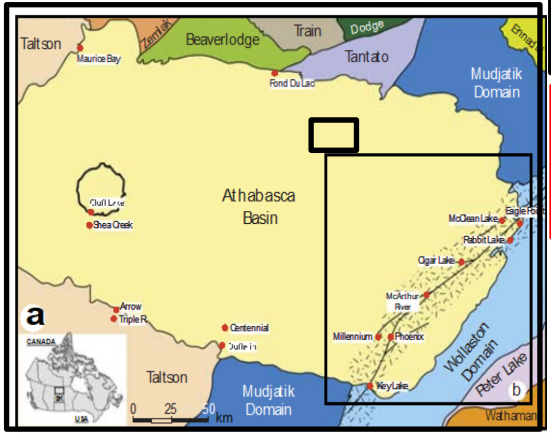
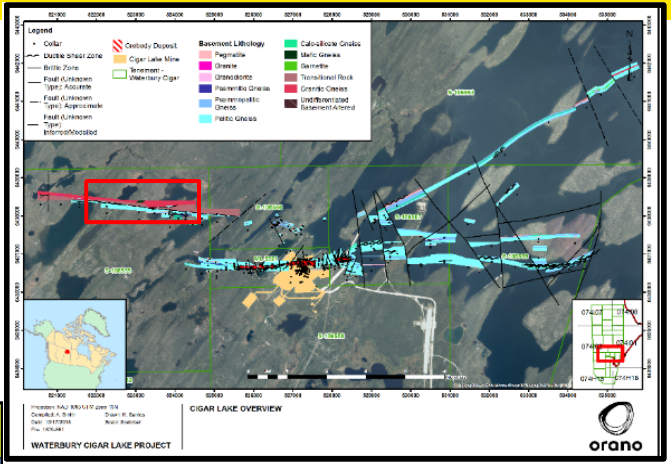


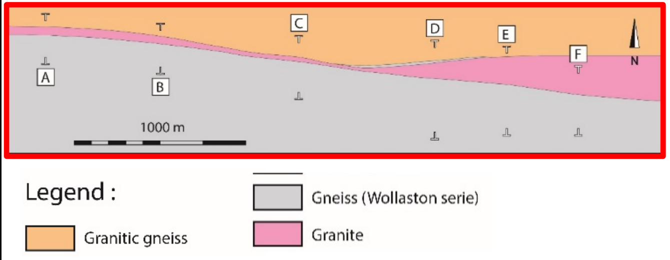
Diagram of the different morphologies of the Cigar Main, Cigar North and Cigar South conductors in a sectional view

Geological setting



Location of the lithostructural domains around the Athabasca Basin (from El Drusi et al., 2020)





Geological map of the basement geology projected at the unconformity surface (from Orano database) and simplified lithological map for the Cigar North zone

Cigar Lake deposit:

- 2nd bigger U unconformity type deposit
- 1,378 Ga (Martz, 2017)

Main graphitic shear zones:

- *Cigar South:* Barren, no reactivation
- *Cigar Main:* Giant deposit resting at the unconformity on top of a large shear zone, reactivation marked by semi-brittle faults, limited offset of the unconformity
- *Cigar North:* Local basement- and basin-hosted mineralization, strong reactivation and large offset of the unconformity

Host rocks and lithological contacts

Host rocks :

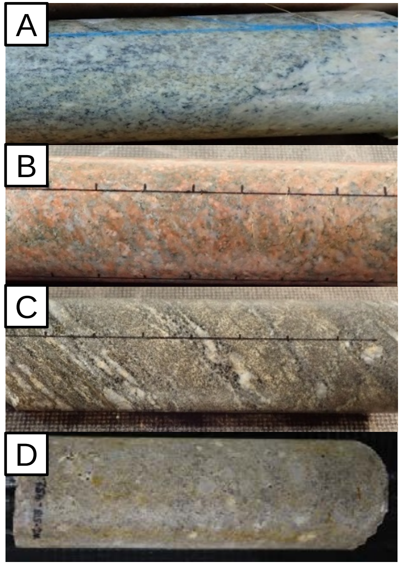
4 groups:

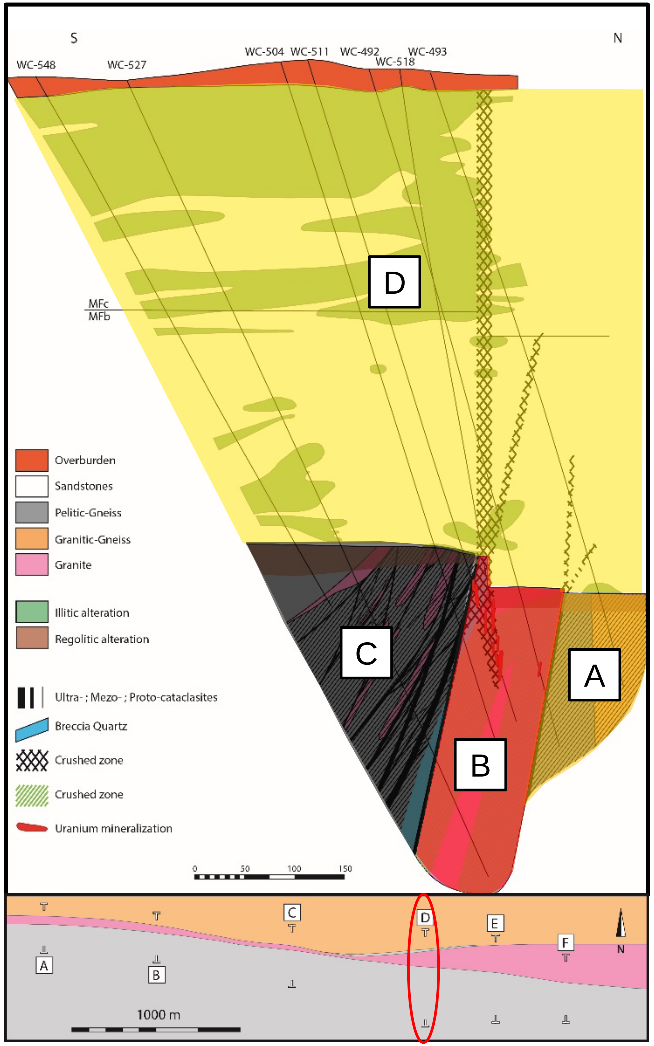
- Archean dome : ortho-gneiss and amphibolite
- Metasediments serie of Wollaston : gneiss : pelitic, psammo-pelitic, psamitic, augen) and cals-silicate
- Granite intrusion
- Sedimentary rocks : sandstone and conglomerate

Major lithological contacts :

2 types:

- Intrusive (2 contacts, to the North and to the South)
- Unconformity





Several offset surfaces shift the unconformity surface

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Structures classification

Structural classification:

First order structures (Fault cores):

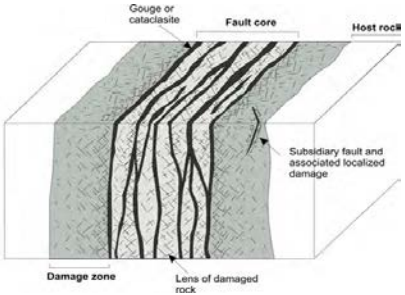
- Based on the matrix and clasts proportion
- Cohesive or incohesive
- Foliated or not

Second order structures (Damage zones):

- Two types: veins or dissolution plans

Mineralogical classification:

- Minerals infills: Graphite, Clay minerals, Quartz, Carbonate, hematite…
- Mineral assemblages determined on field and in laboratory on thin sections (Optical microscopy, MEB)

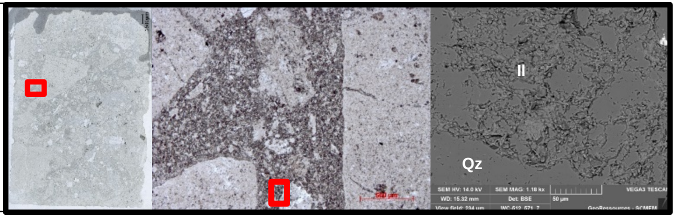


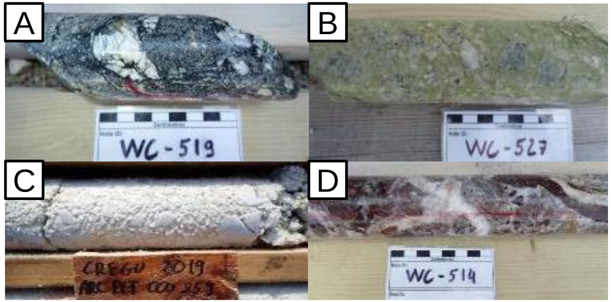
Conceptual models for large strike slip fault zones compared, from Faulkner, 2003

a			random fabric	foliated	
incohesive			fault breccia (>30% visible fragments) [C] fault gouge (<30% visible fragments)	?	
cohesive	NATURE OF MATRIX	glass or devitrified glass	pseudotachylyte	?	PROPORTION OF MATRIX
		tectonic reduction in grain size dominates grain growth by recrystallisation	crush breccia (fragments >5 mm) [B-D] fine crush breccia (fragments 1-5 mm) crush microbreccia (fragments <1 mm)		0-10%
			protocataclasite [A]	protomylonite	10-50%
			cataclasite	mylonite	50-90%
			ultracataclasite	ultramylonite	90-100%
		grain growth pronounced	?	blastomylonite	

Classification of faults rocks from Sibson, 1977 revival from Killick, 2003 (modified from Woodcock and Mort, 2008)

Illite-Quartz fault breccia



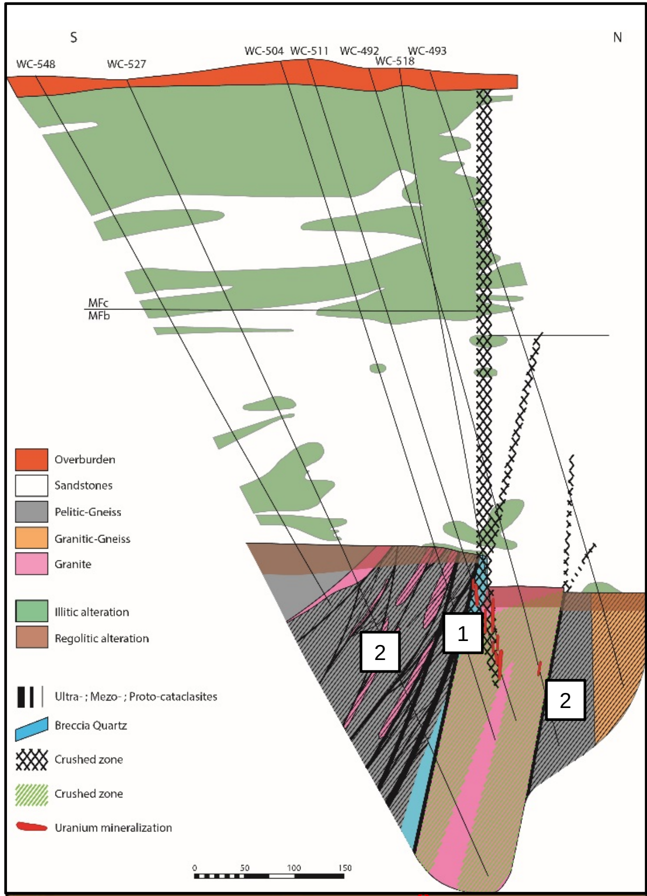


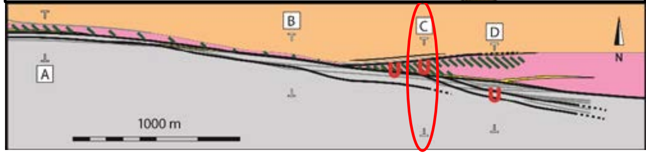
(A) Cataclasite; (B-D) Crush breccias; (C) Fault breccia

Fault cores location

Fault cores location:

- Cataclasites = gneissic lithologies (basement), main structures along the lithological contacts
- Cohesive breccias = granitic intrusion or near the intrusive contacts (basement)
- Incohesive breccias = all lithologies (basement and basin), mark the unconformity shifts





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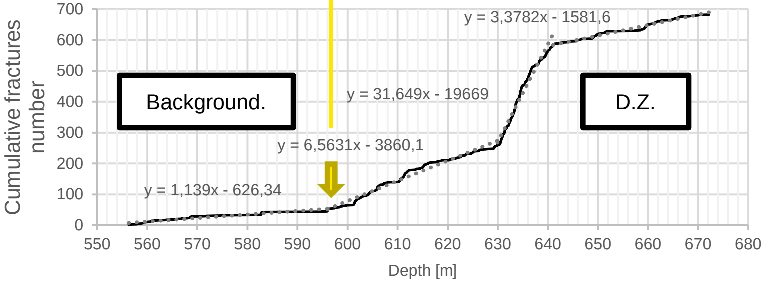
Damage zones location

Field observations:

- Damage zone structures (veins and dissolution plans) observation
- Realization of structural logs

Thickness determination of the damage zones:

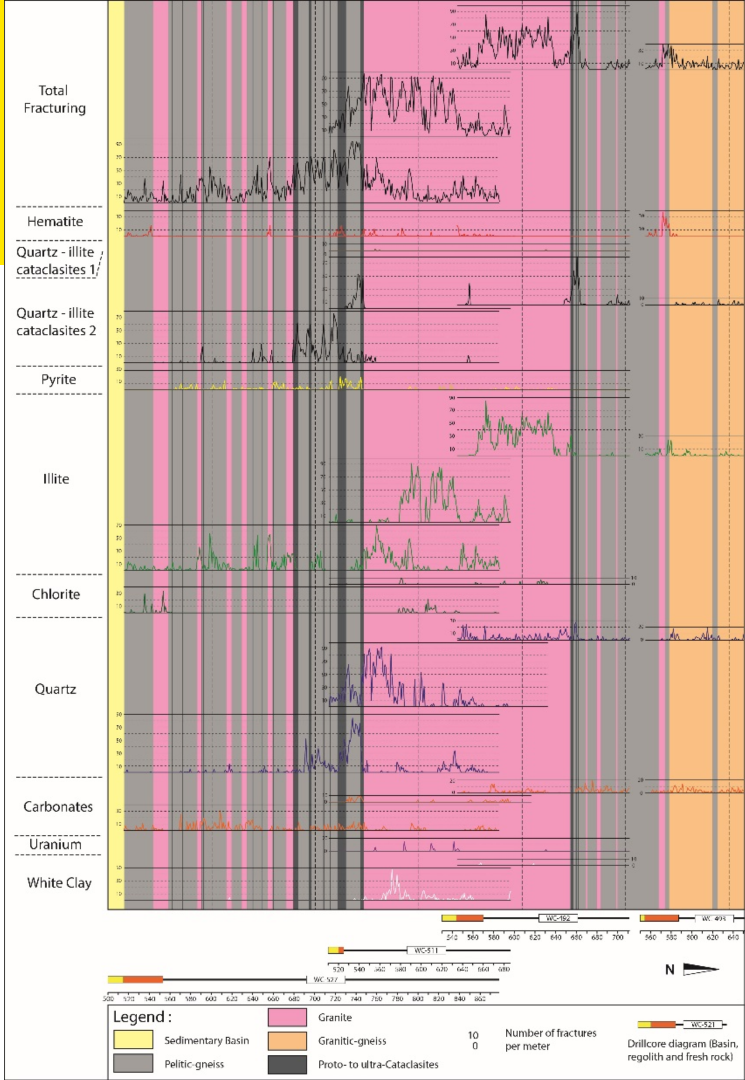
- Fractures count along a scanline
- 4 cross-sections
- Background <2 frac/m ; Damage zone >2 frac/m
- Cumulative frequency curves



Fracture location:

- Illite and quartz veins = mainly in the granitic intrusion
- Dissolution plans associated to the cataclasites = gneiss

Lithological control

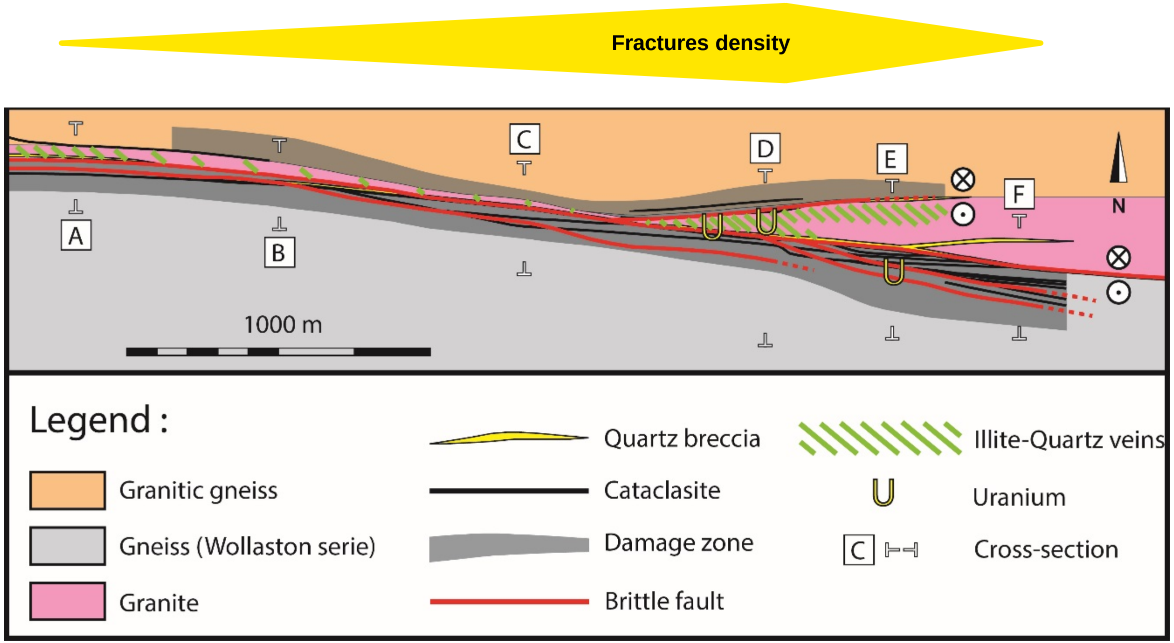


Structural network

- Cataclasites on both side of the granitic intrusion

- Junction zone between C and D cross-sections

- Increase of the fracture densities near the junction zone



Paragenesis

Relative chronology of the polyphased Cigar North Fault

Replaced in the geological context

- Cataclasites = pre-Athabasca
- Illite veins associated to uranium veins

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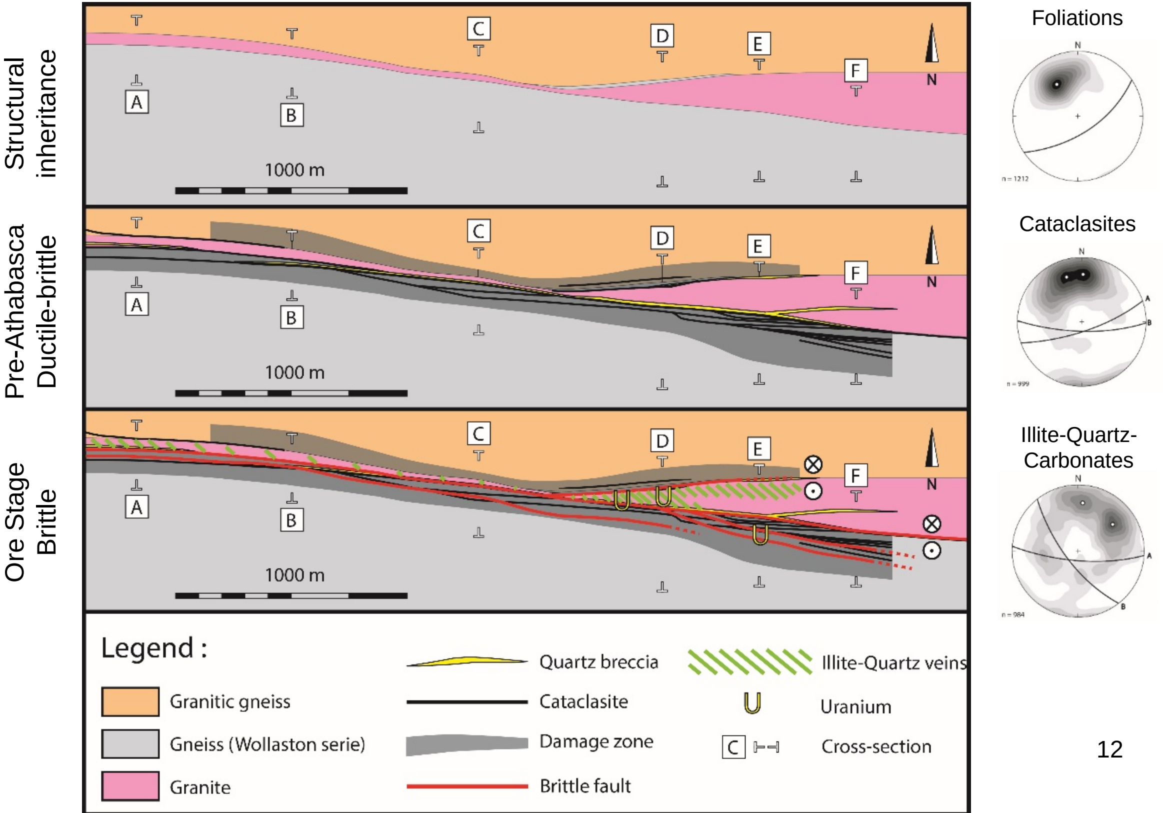
Cigar North fault zone evolution: alteration and control of U-mineralization

A polyphased structural zone:
- Inherited lithological discontinuities
- Ductile structures → Brittle structures

Structures are surimposed:
- Structural reactivations along inherited structures

3 tectonic blocs:
- Compression zones – South and North blocs
- Extension zone – Granitic intrusion

Uranium at the structural interaction zone at the junction of post-Athabasca brittle structures:
- Structural interaction zone marked by high vein densities and alteration (basement)
- **Uranium at the junction of brittle structures**



Petro-physical properties

Uranium mineralizations are spatially associated to illite-chlorite veins and their alteration.

This veins are the last structural event before the U-mineralizations.

Question:

Does this structural event has created the drains to channel the mineralizing fluids?

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Petro-physical measures

Vp/Vs
Mineralogy, porosity
Vp/Vs saturated
Pores connectivity
Porosity by water saturation
Porosity
Mercury porosimetry
Threshold radius
Permeability
Thermic conductivity
Mineralogy, porosity

	Cigar North		
	This PHD	Orano	Tot
Vp	129	46	175
Vs	129	46	175
Vp sat	75		75
Vs sat	75		75
d	99	83	182
ϕH20	100	83	183
ϕHg	36		36
k	78		78
TC	123		123

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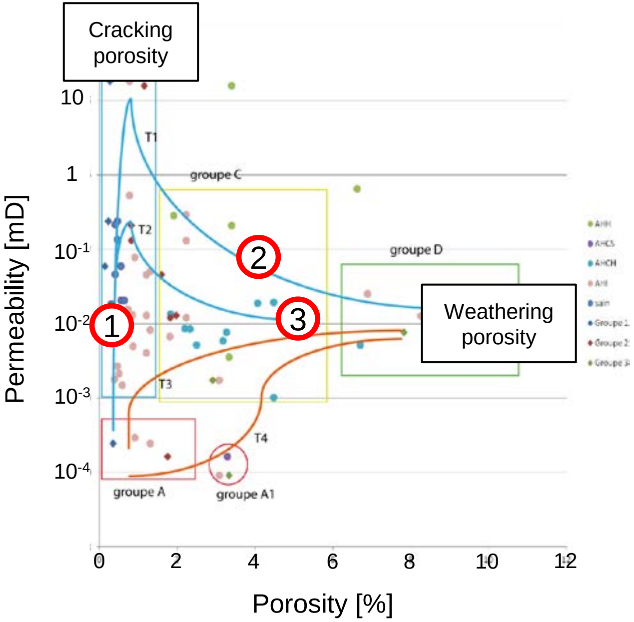
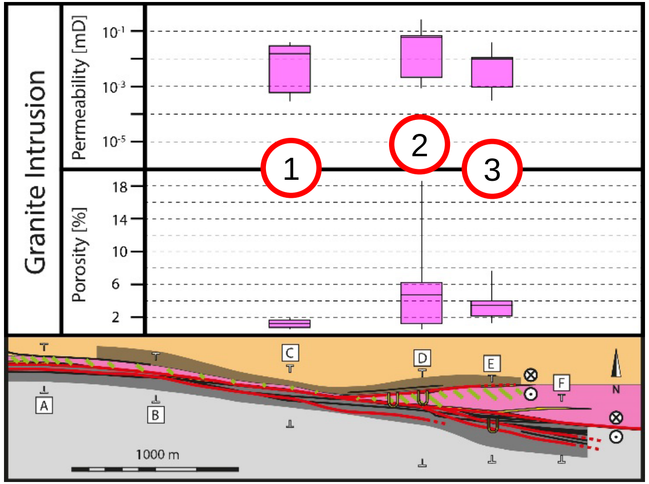
Permeability and porosity relationship: input of porosity origin



Granitic intrusion :

- Eastern part : development of weathering porosities (mark fluid circulations)
- Western part : Cross-section C does not show weathering porosity due to the development of weathering.



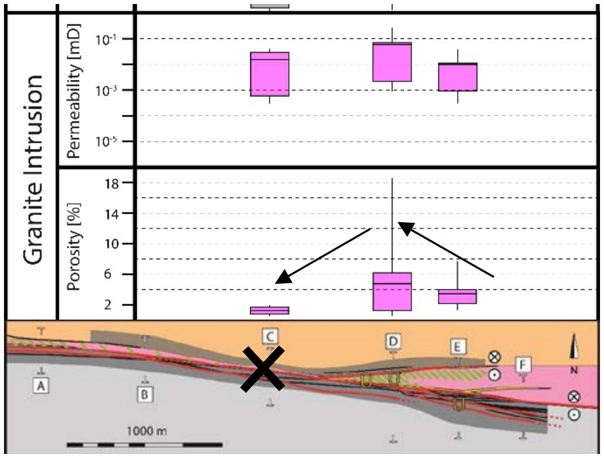
Porosity-permeability relationship, from Géraud et al., 2010

East-West porosities variations in granite

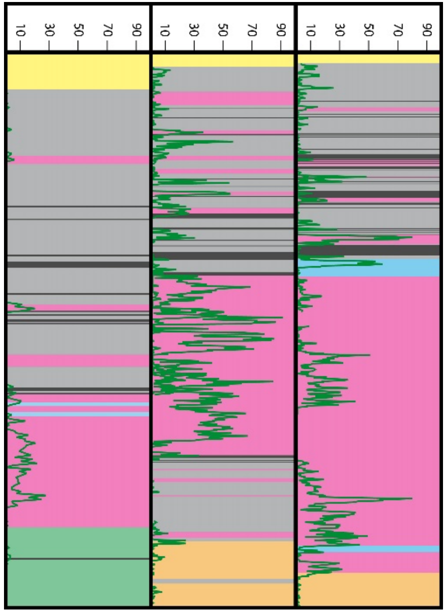
- Cross-section D shows the highest porosity average for the granite with extreme values greater than 18%. These high porosity values are correlated with the highest illite-chlorite fractures densities.
- Cross-section C has the lowest porosities for the granite and the lowest illite-chlorite fracture densities indicates few fluid circulation.

This is a East-West correlation between variations of porosities and illite-chlorite fractures densities.

Porosity increase with the high veins densities in the granite.



Illite fracture densities per meters



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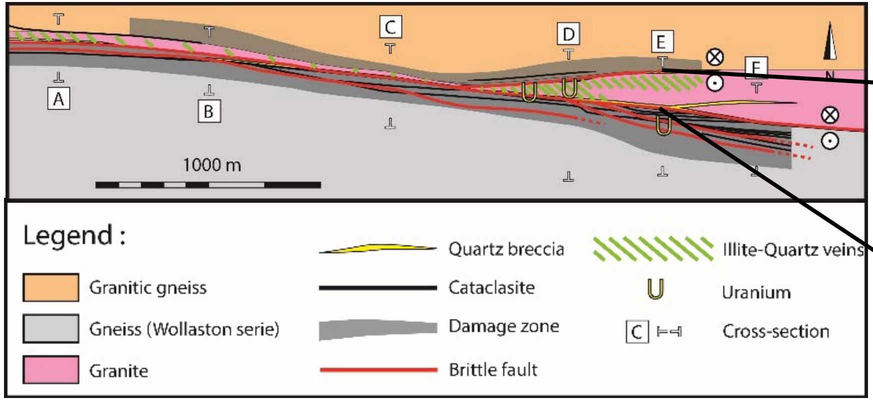
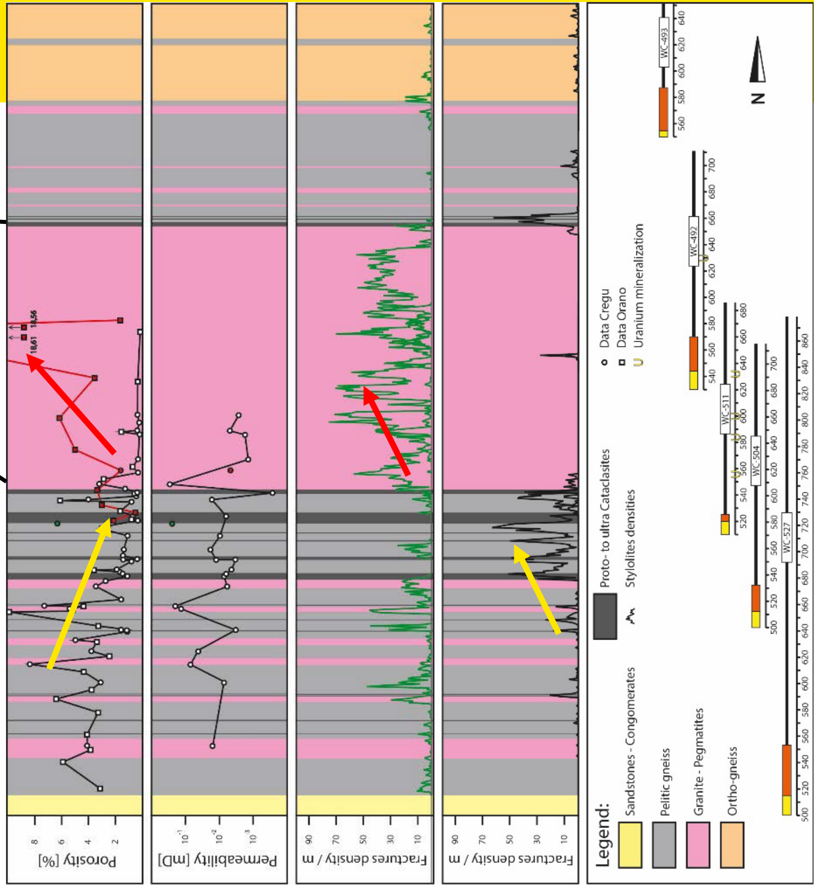
North-South porosities / permeabilities variations

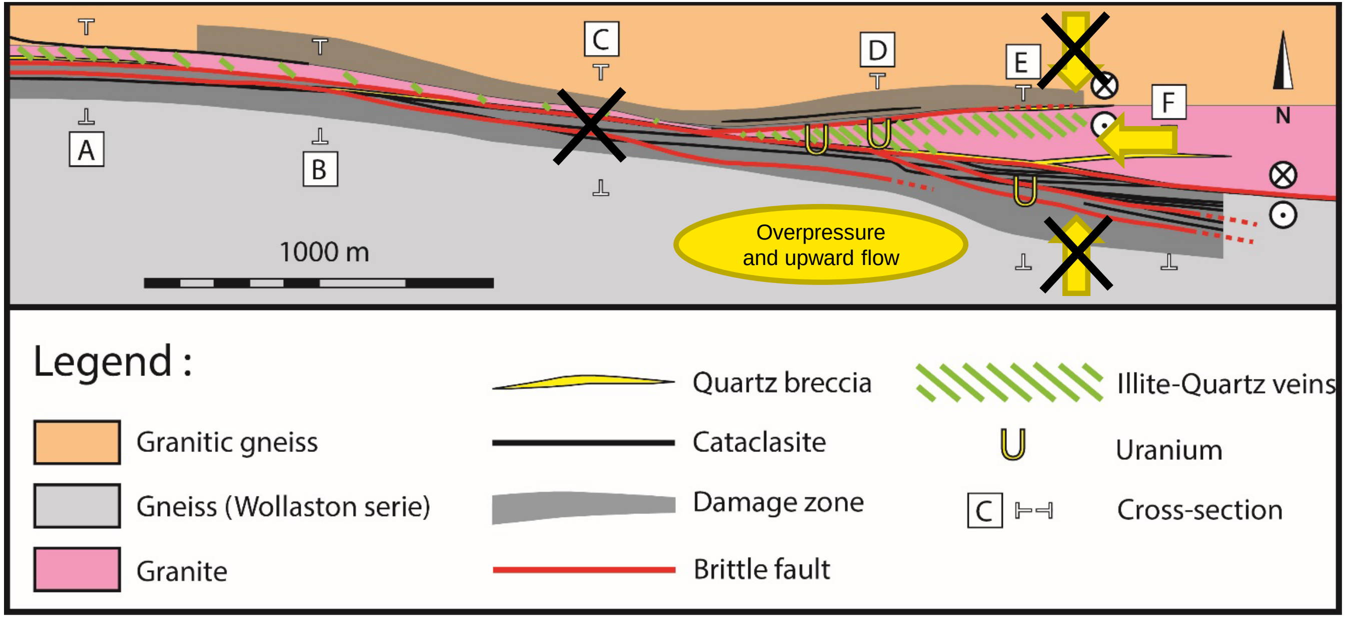




- When cataclasites and associated dissolution plans increase, the porosity decreases.
- Cataclasite intervals in the gneiss are marked by the lowest porosity values.
- As the East-West correlation, when illite-chlorite vein densities increase, the porosities increase.
- The porous zone in the granitic intrusion is bordered to the South by low porous/permeable cataclasites.

Fluid circulation model for the Cigar Nord fault zone (Pre- to syn-U stage)

- No possible fluid flow from the West, North and South
- Fluid flow from the East (from the recharge area to the U-mineralized zone)
- Channelled fluid circulation by the impermeable cataclasites and their low porosities damage zones
- Fluid flow overpressure in the structural node
- Upward flow towards the basin



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Giving nuclear energy its full value

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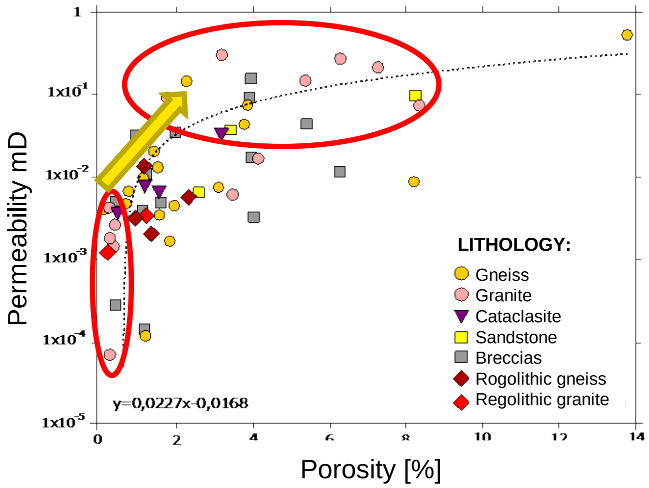
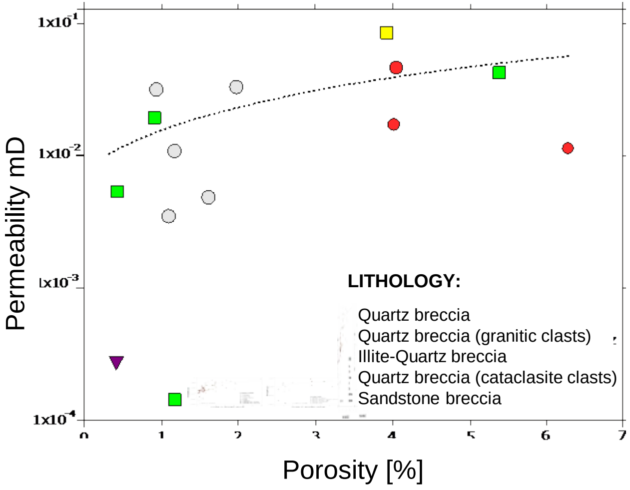
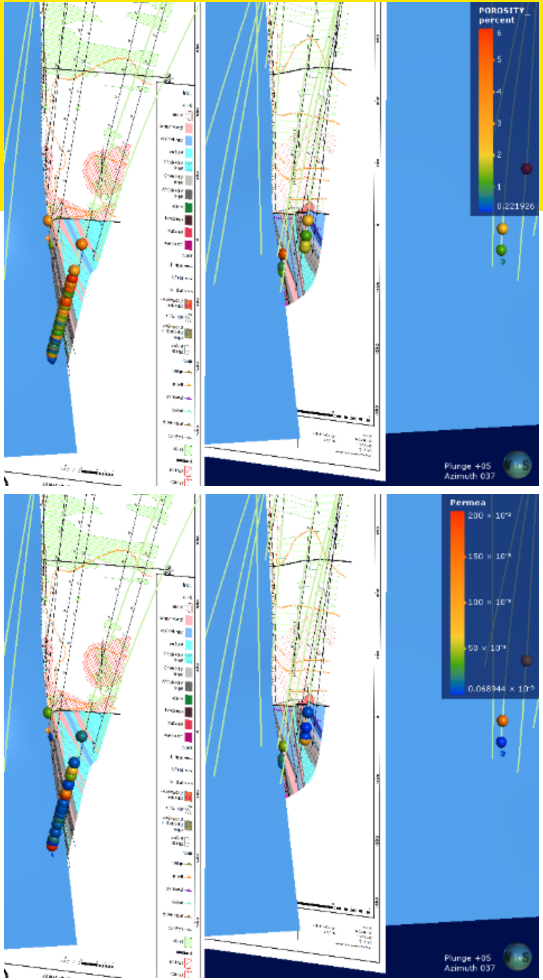
Permeability



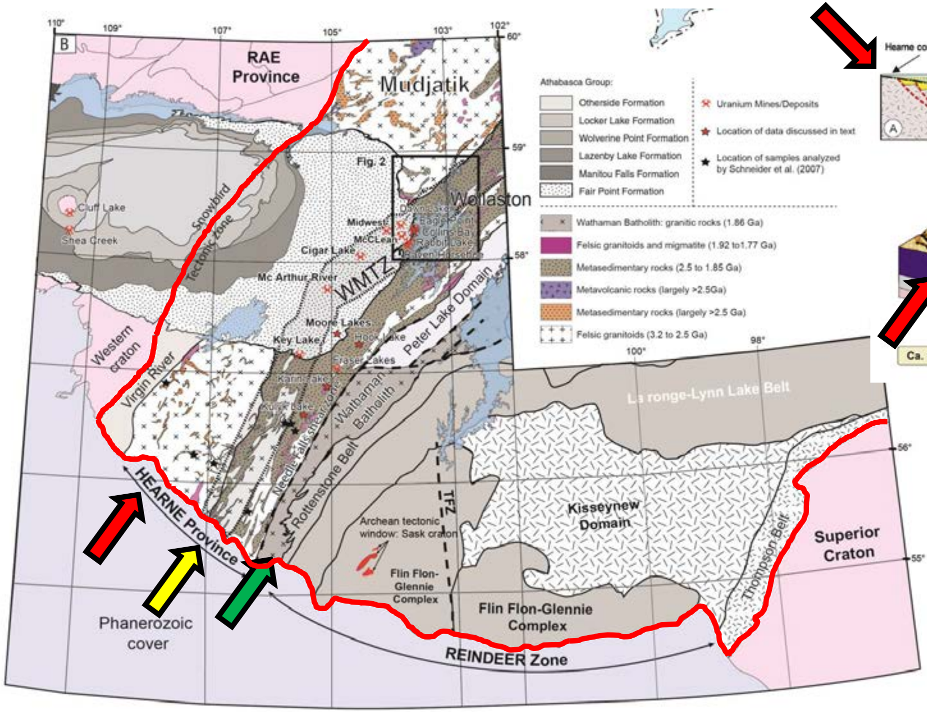




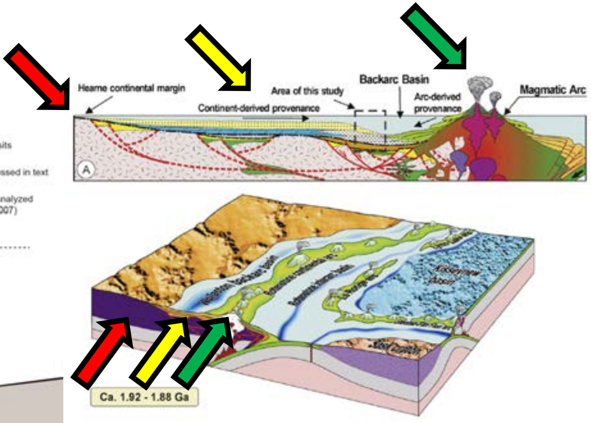
- Permeability evolution of granite and gneiss
- Low permeability of the regolith

- Low permeability of cataclasites

L’orogène Trans-Hudson (1,86 – 1,775 Ga)



Carte géologique simplifiée de l’orogène Trans-Hudson (trait rouge) montrant les principales subdivisions litho-tectoniques et les éléments structuraux majeurs de la Hearn Province et de la Reindeer Zone (modifiée d’après Jeanneret, 2016)



Coupe (A) et modèle (B) montrant la zone de subduction issue de la fermeture de l’océan Manikewan ainsi que la configuration des différentes provinces géologiques (d’après Tran et al., 2008)

Domaine Mudjatik

Domaine Wollaston

Domaine Rottenstone

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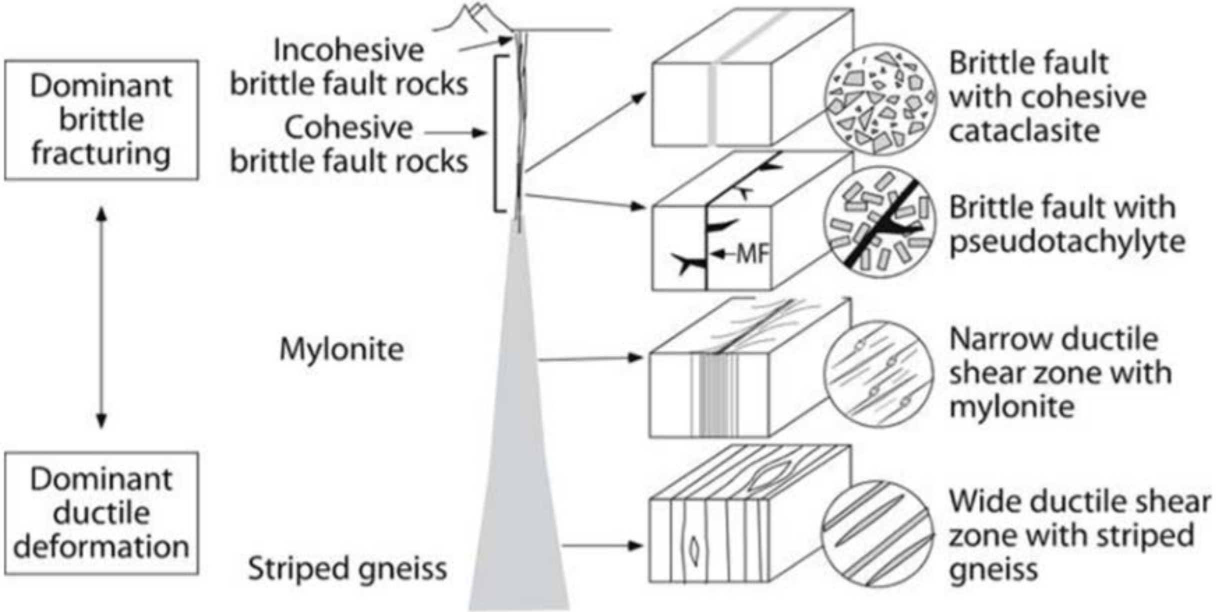
Relation between fault rocks classification and the crustal depth



Distribution of the main fault rocks as a fonction of crustal depth (from Passchier et Trouw, 2005)

The fracture counts

Input data

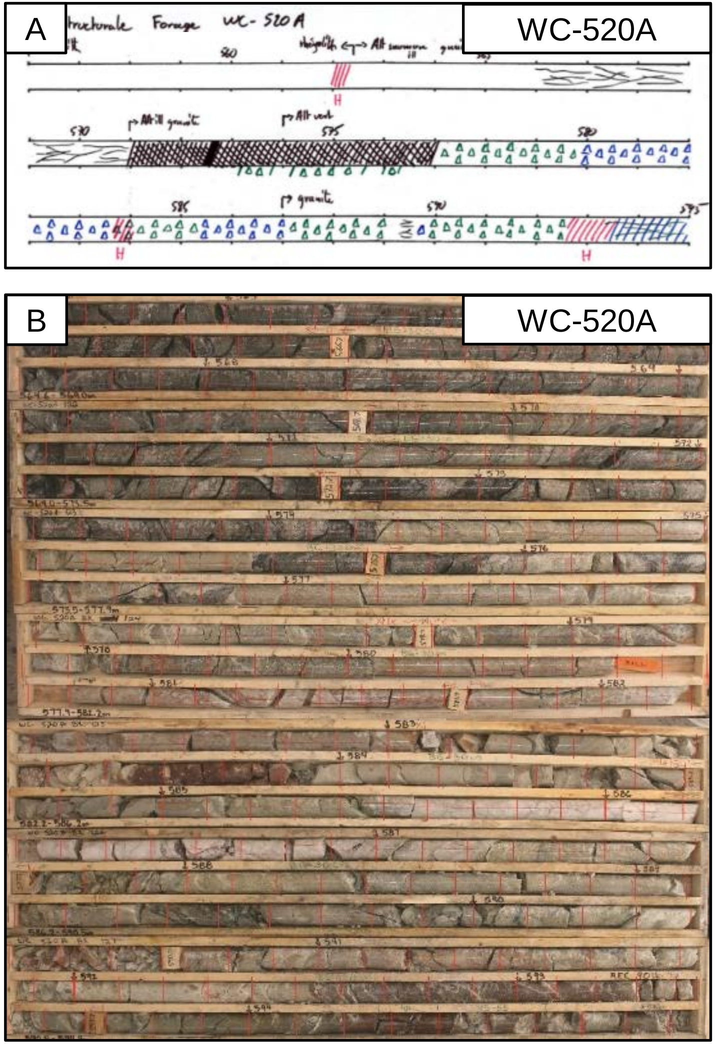
- 1. **Drill core** pictures : allows to plot every fractures intersected by the drill hole
- **2. Field observations** (summer 2019) : systematic **structural break down** (intervals + description) + field based **fracture classification** + numerous descriptions
- 3. **Orano's logs** as complementary source of information

Information collected on fractures

- Depth
- Infills color : inferred mineralogy
- Angle between fracture plane and core axis
- **These are not oriented data**

"Control points"

- **Field work :** fracture intervals + numerous fracture descriptions
- **Sampling** + high resolution sample pictures (higher precision
- **Thin sections** observations in selected samples



WC-520A drillhole (A) Field structural log (B) Cores boxes photographies.

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How to define the damage zone?

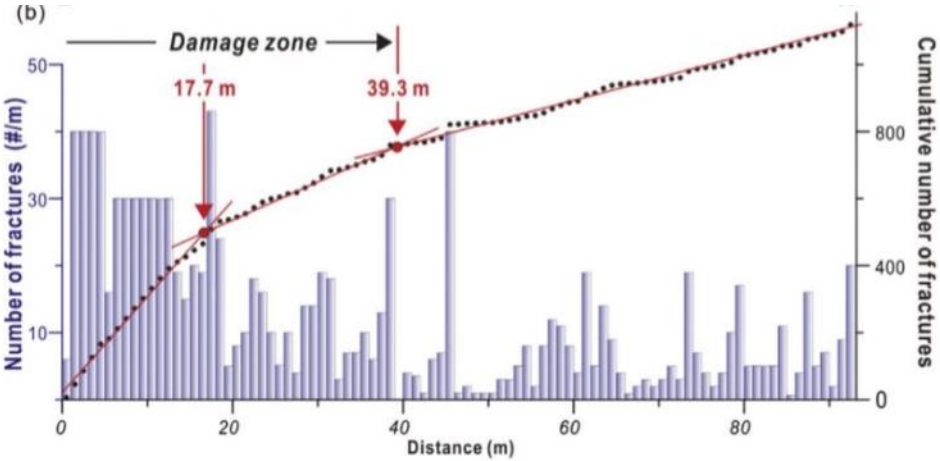
The fractures counting

Spotting all the fractures observed along a scanline (middle of the drill core)

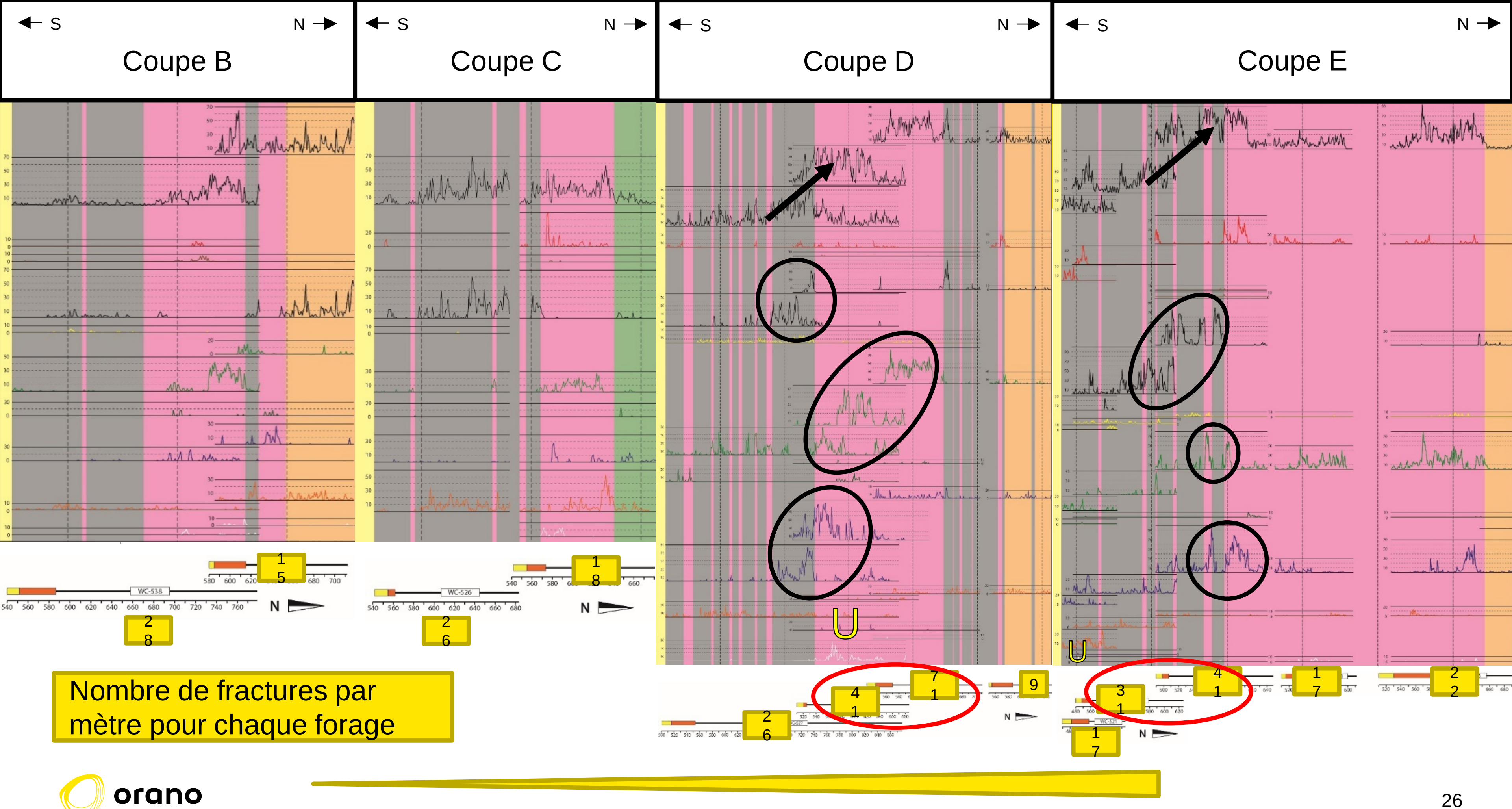
Describe the distribution of the fractures

Cumulative number of fractures diagram

Enable to defined intersection points between slopes of a damage zone and the slopes of the background



Distribution of fracture frequency based on both interval and cumulative methods, The results indicate the damage zone extent based on the intersection point of different slope gradients (from Choi and al., 2016)



Densité de fractures

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Imput data

Orano oriented data

Data reprocessing: code the mineral filled the structure in a new column

Ex: upr cntct to m-scale cohesive silicif breccia below (Orano description) → **Qz**

Field oriented data

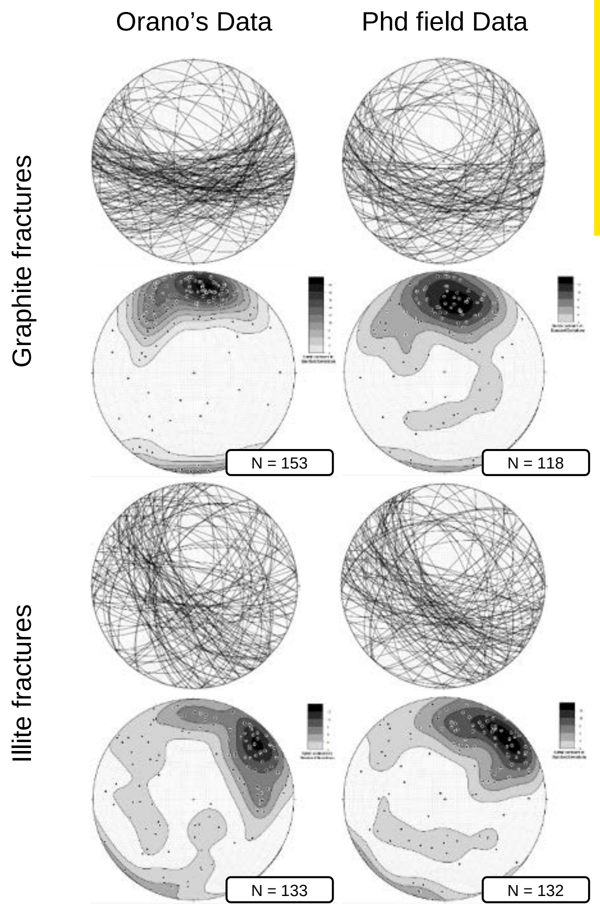
Same measurement method than Orano

Same information + column infill

Orano and field oriented data fusion

Control:

- Same orientations for each infill minerals families
- Presence of duplicates in each drill holes



Control of the main orientations for graphite and illite infill in the Orano and Phd field data base (drillholes WC492/511/520A/526/527)

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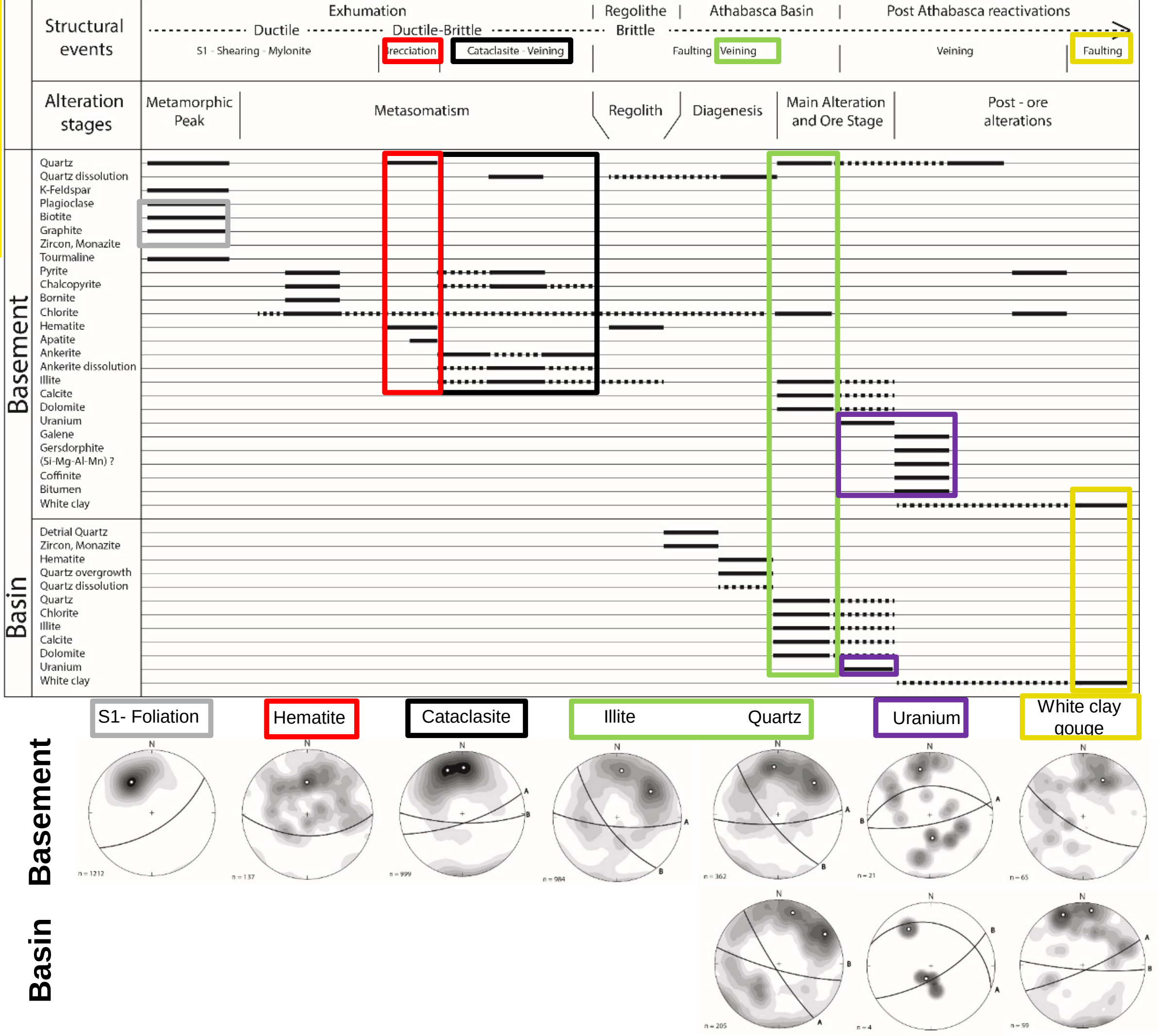
Oriented data

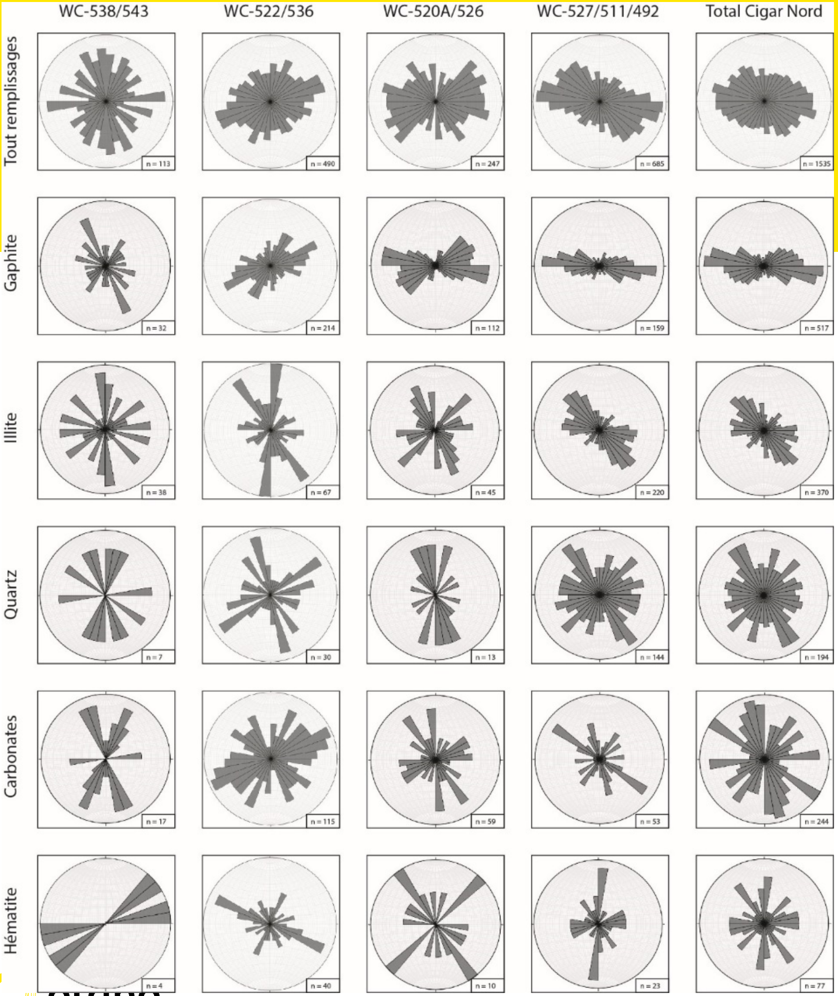
- Coupling structural sequence and oriented data

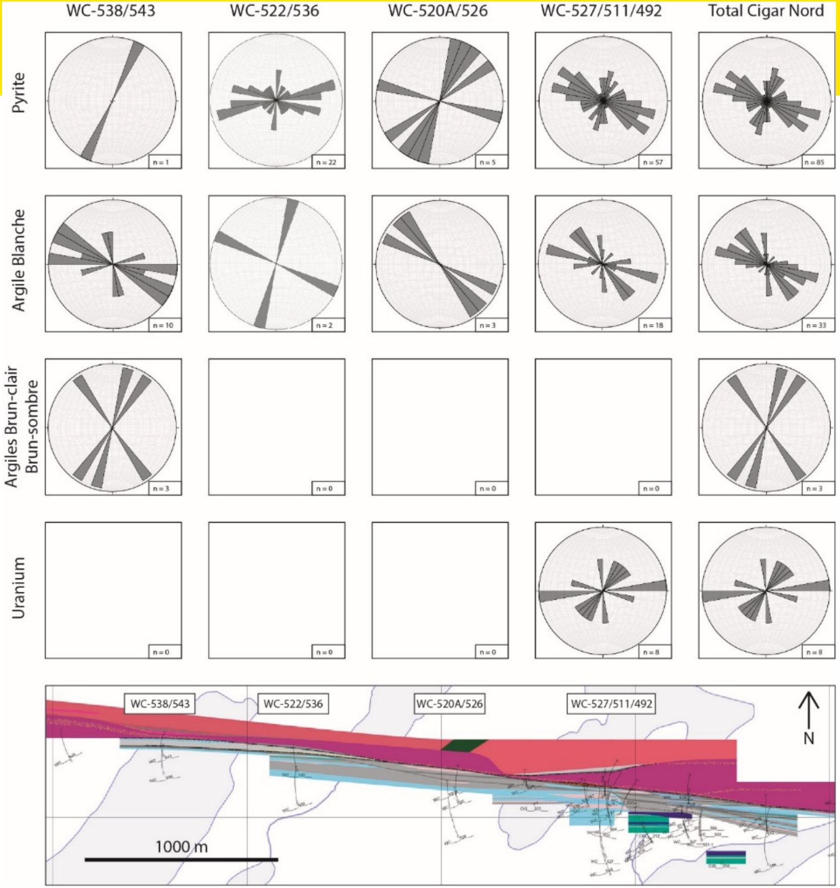
Structural evolution

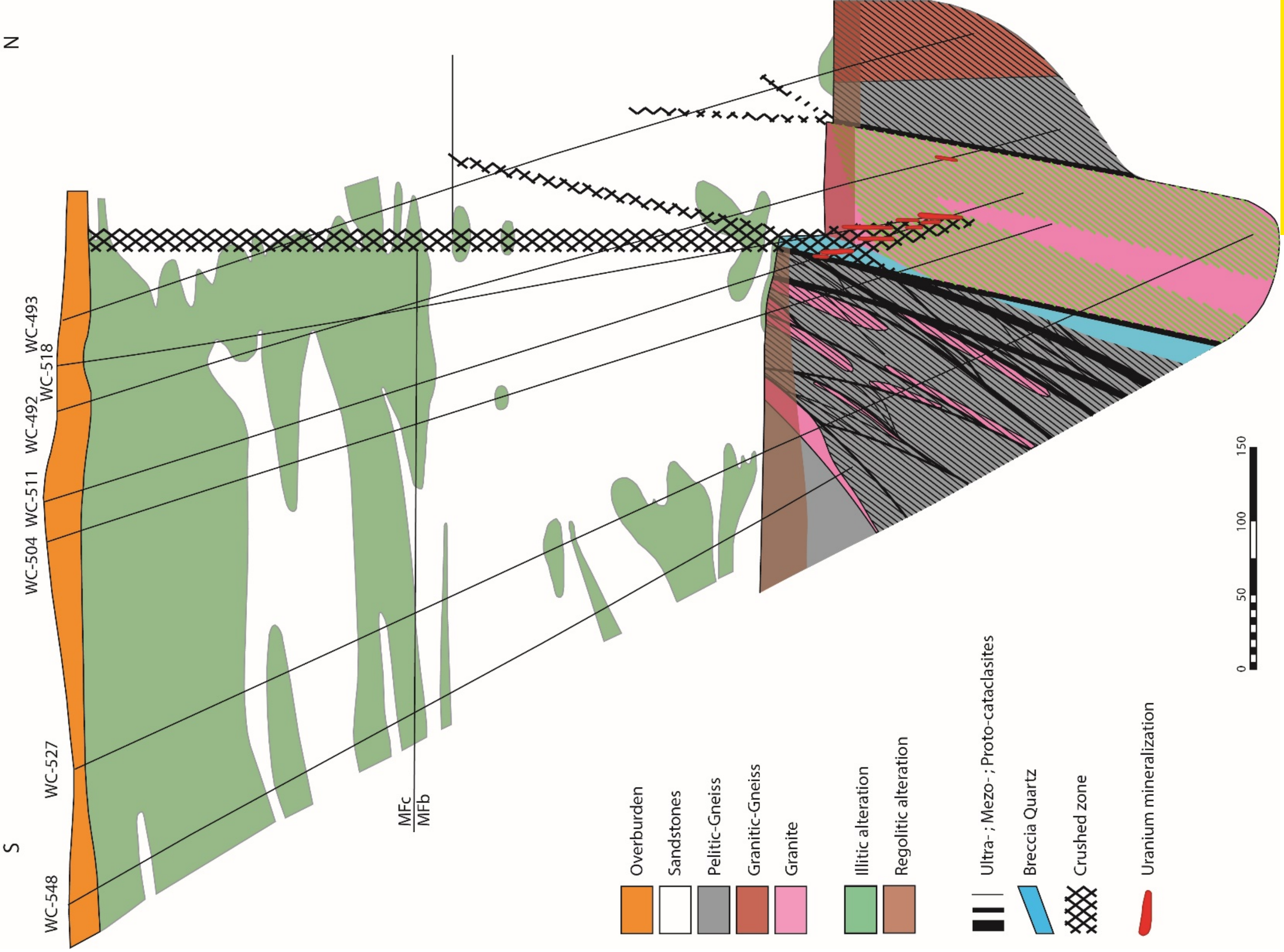
Reuse of previous structural orientations

- Lithological contacts for quartz-hematite breccia
- Lithological contacts and breccia for cataclasites
- A new trend for illite-quartz veins



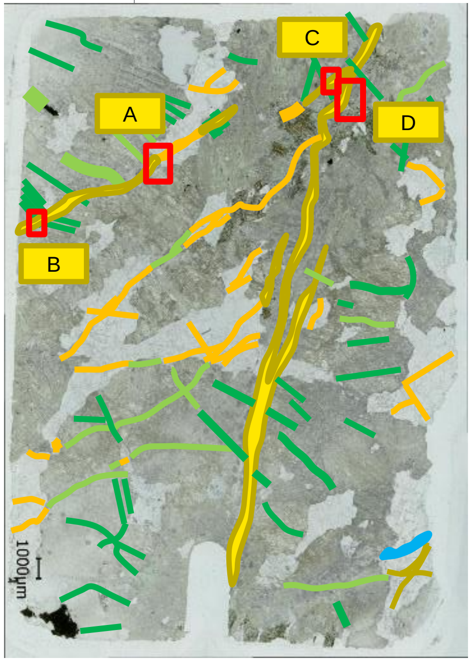

WC-538/543
WC-522/536
WC-520A/526
WC-527/511/492
Total Cigar Nord
Tout remplissages
Gaphite
Illite
Quartz
Carbonates
Hématite
n = 113
n = 490
n = 247
n = 685
n = 1535
n = 32
n = 214
n = 112
n = 159
n = 517
n = 38
n = 67
n = 45
n = 220
n = 370
n = 7
n = 30
n = 13
n = 144
n = 194
n = 17
n = 115
n = 59
n = 53
n = 244
n = 4
n = 40
n = 10
n = 23
n = 77

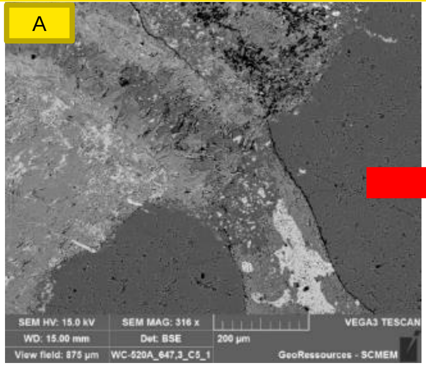

WC-538/543
WC-522/536
WC-520A/526
WC-527/511/492
Total Cigar Nord
Pyrite
Argile Blanche
Argiles Brun-clair Brun-sombre
Uranium
n = 1
n = 22
n = 5
n = 57
n = 85
n = 10
n = 2
n = 3
n = 18
n = 33
n = 3
n = 0
n = 0
n = 0
n = 3
n = 0
n = 0
n = 0
n = 8
n = 8
WC-538/543
WC-522/536
WC-520A/526
WC-527/511/492
N
1000 m

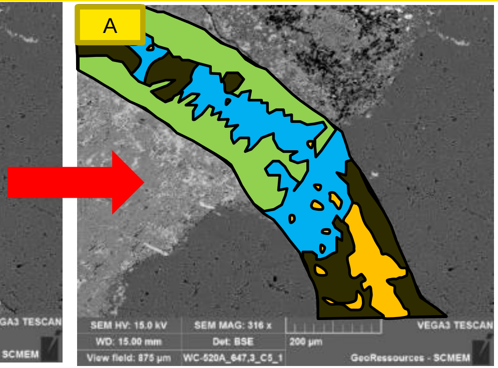

N
S
WC-493
WC-518
WC-492
WC-511
WC-504
WC-527
WC-548
MFc
MFb
Overburden
Sandstones
Pelitic-Gneiss
Granitic-Gneiss
Granite
Illitic alteration
Regolitic alteration
Ultra- ; Mezo- ; Proto-cataclasites
Breccia Quartz
Crushed zone
Uranium mineralization
0
50
100
150

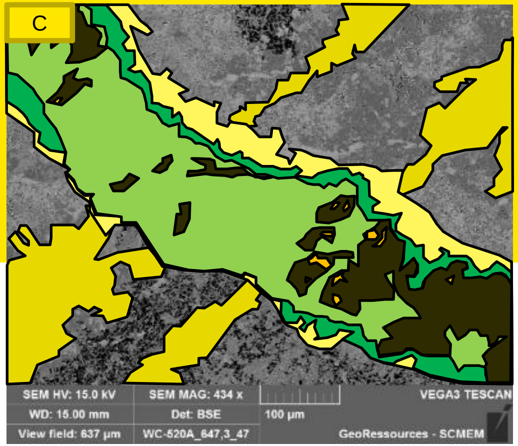
Thin section observations

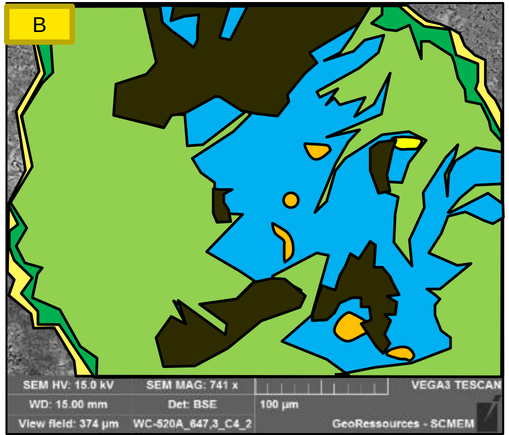
Analyse of the minerals cristallisation sequence in veins obsserved on SEM photographies from the thin section WC-520A_647,3. The minerals determination is based on opticals properties coupled with geochimical BSE analysis

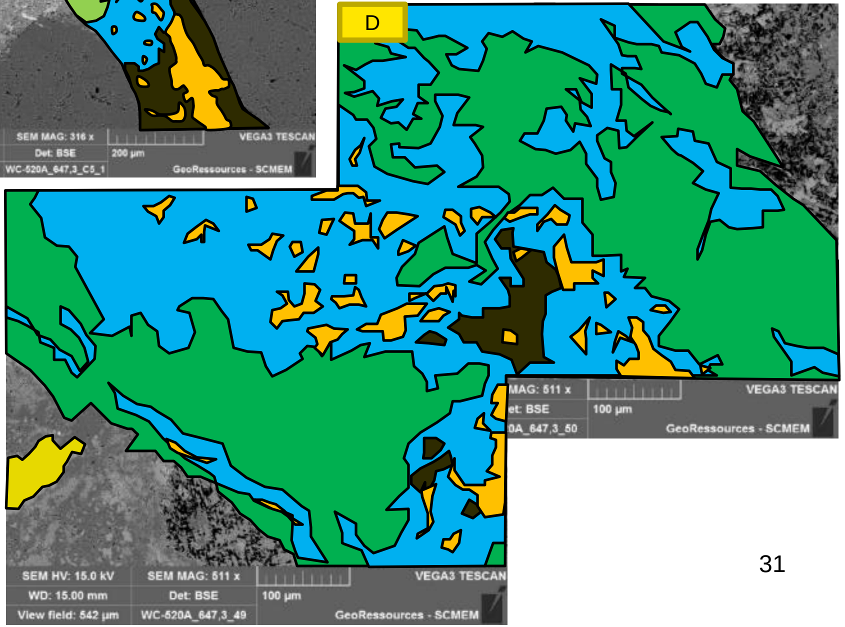












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