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Fault Architecture, Associated Structures and Uranium Mineralization, Eastern Athabasca Basin: ~~A Provisional Empirical Classification~~

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Cameco Exploration

cameco.com





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► Fault Architecture, Associated Structures and Uranium Mineralization



Theme

Improving understanding
faults and their role in the
formation of unconformity
associated uranium deposits,
Athabasca Basin

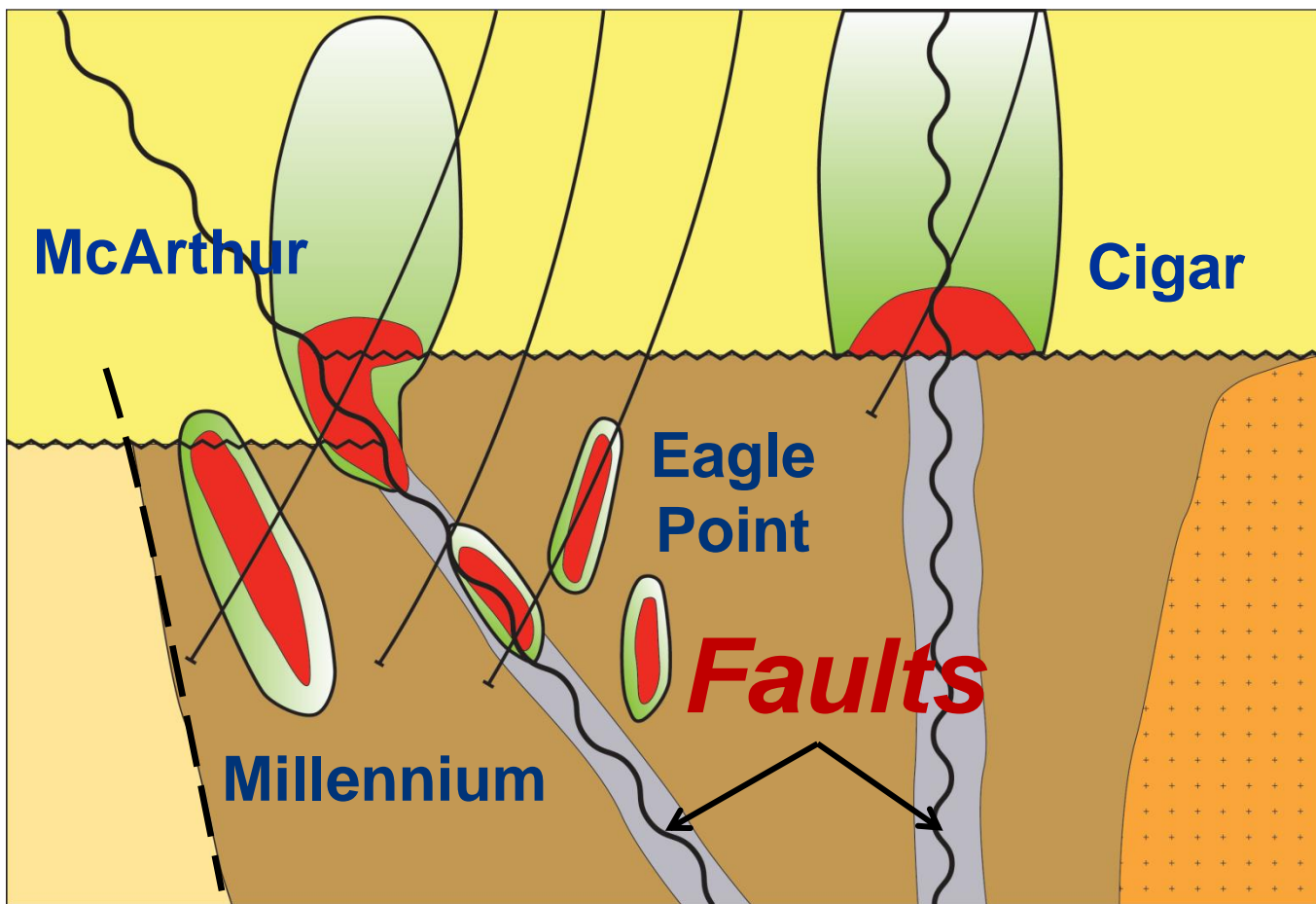
► Fault Architecture, Associated Structures and Uranium Mineralization



P2 Fault, McArthur River, underground exposure. Dip slip slickenlines on massive graphitic fault gouge.

- **Describe elements of faults**
 - More completely
 - More accurately
 - Consistent terminology
- **Synthesize / Interpret**
 - Temporal
 - Geometric
 - Kinematic
 - Fluid flow
- **Predictive models: guide prospect generation and drill targeting**

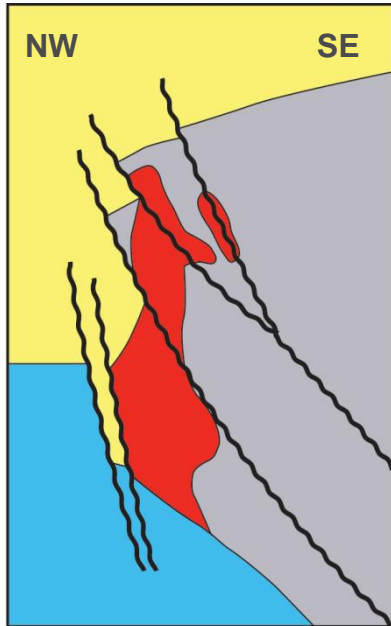
▶ Athabasca Unconformity Uranium Model



- Uranium mineralization
- Alteration halo
- Athabasca sandstone
- Qtzitic / arkosic gneiss
- Pelitic gneiss (graphitic)
- Pelitic gneiss
- Archean "granite" gneiss

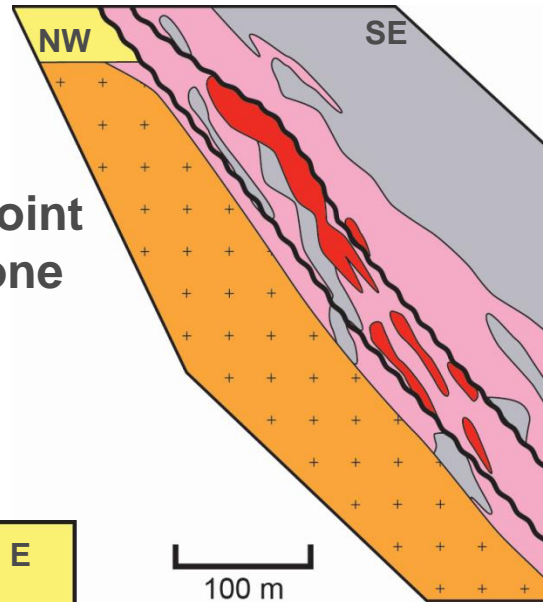
► Uranium Deposits – Cross Sections

**McArthur
Zone 2**



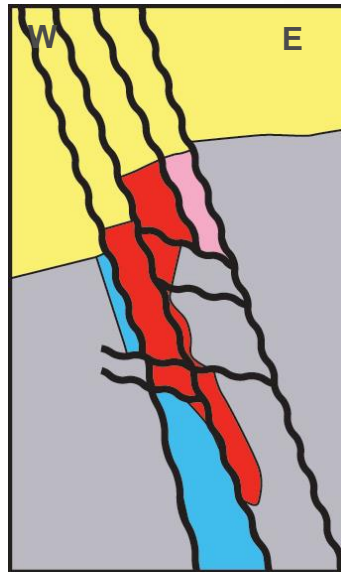
20 m

**Eagle Point
144 Zone**



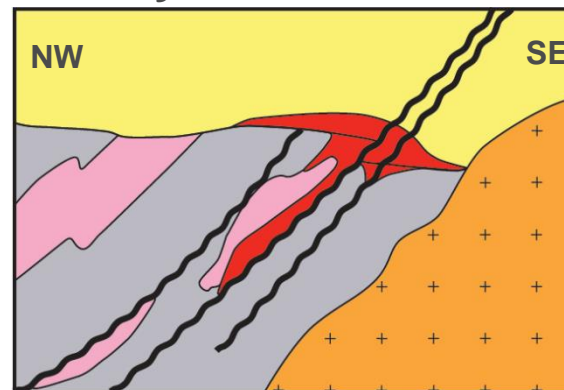
100 m

Sue - C

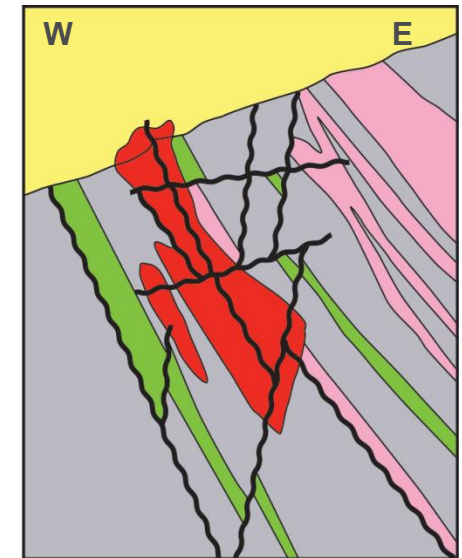


50 m

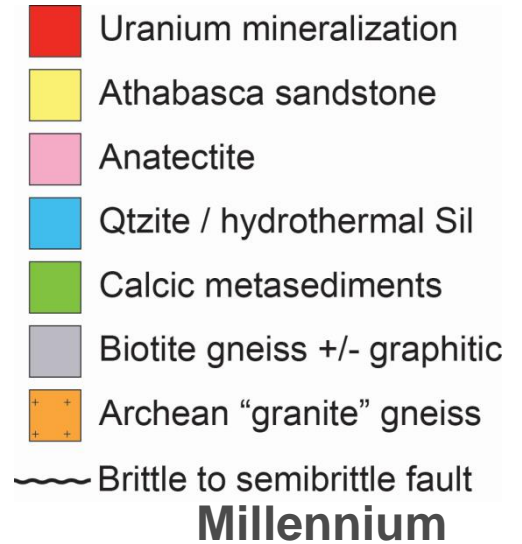
Key L – Deilmann



100 m



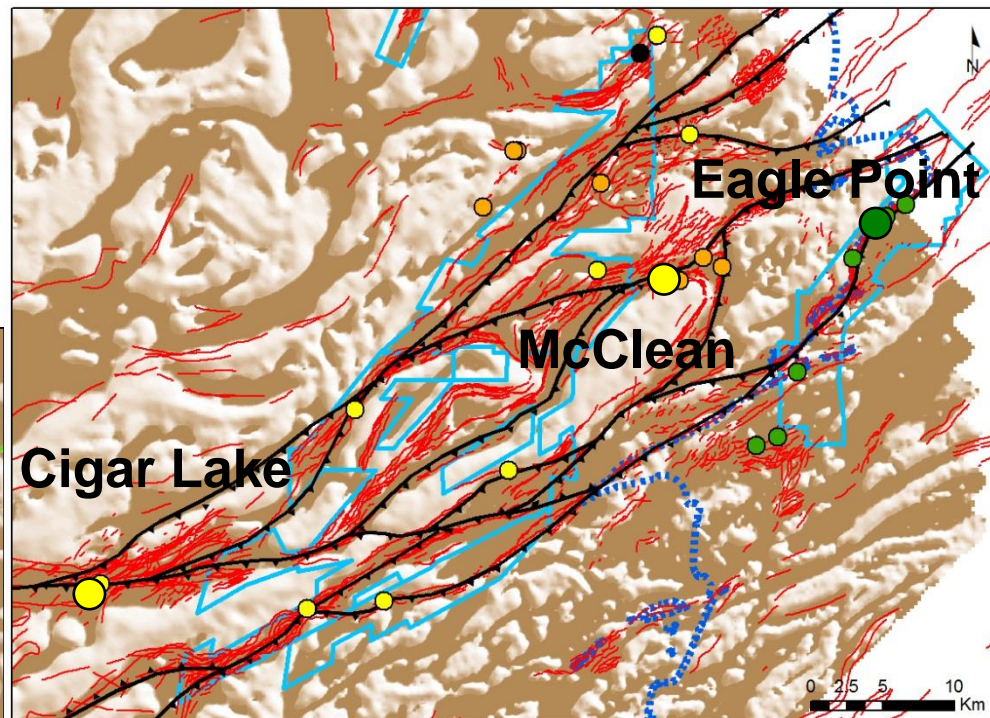
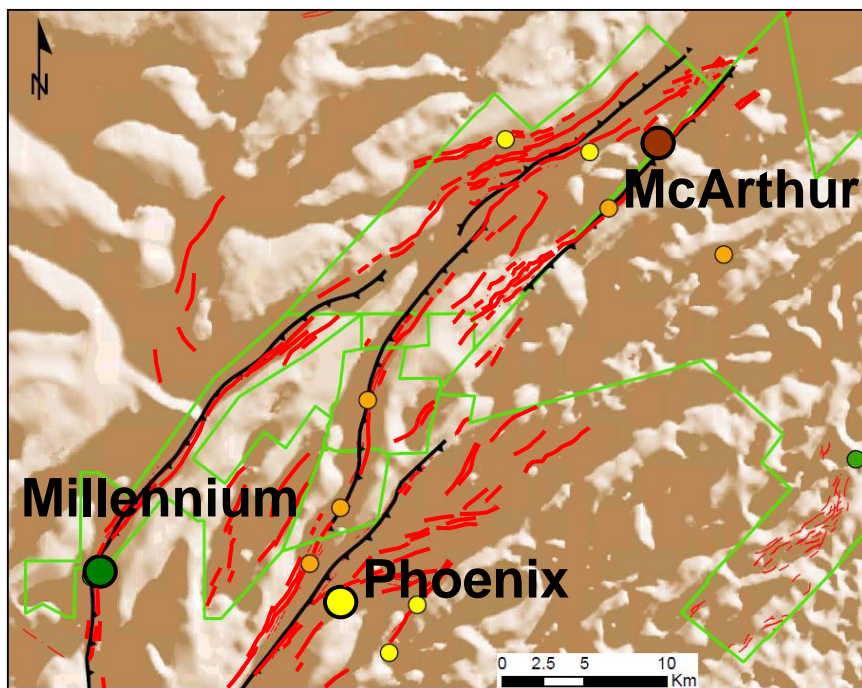
50 m



► Uranium Deposits, Faults and Conductors

Deposit Type

- Unconformity
- UC / Bsmt
- Basement



**Conductors
proxy \approx
Basement Faults**

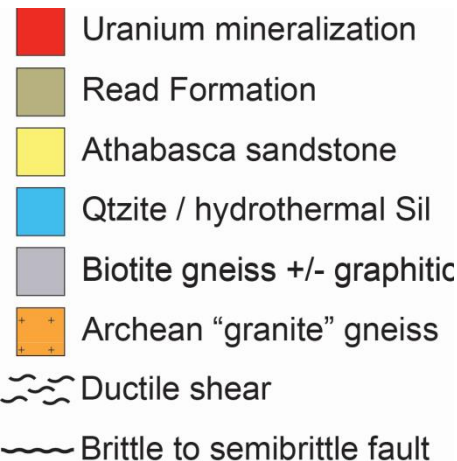
► Unconformity Uranium and Faults



Pre-Athabasca

Syn-Athabasca

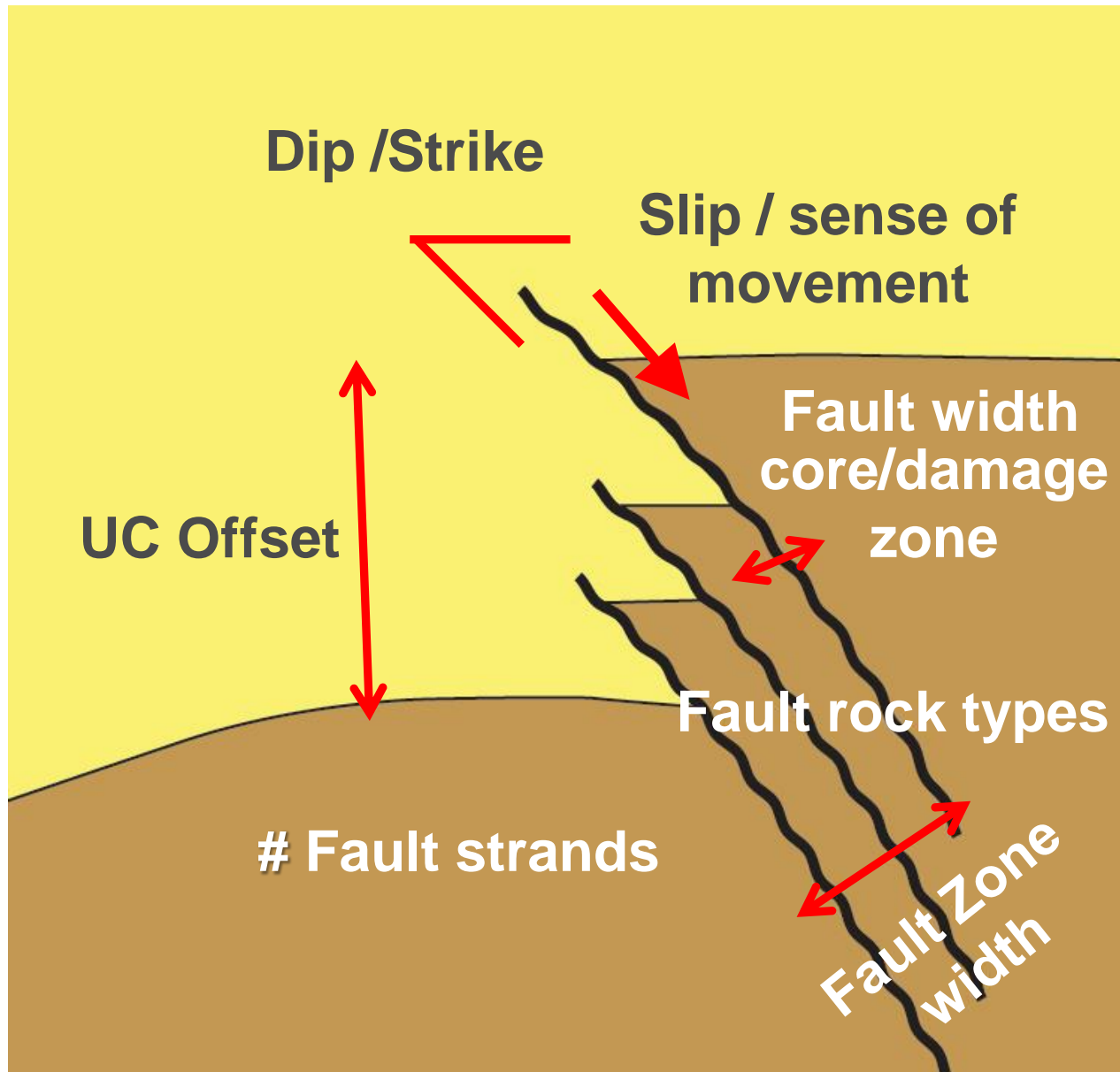
Post-Athabasca



Syn/Post-Mineral

- Pre- Athabasca faults...**ductile**
- Post-Athabasca faults ...**brittle**
- Caution! ...complex history..
 - Protracted seismic reactivations; changing stress fields; contrasting rheological properties
 - Variations strain rates and varying P, T fluid conditions

► Fault Architecture – Basic Elements

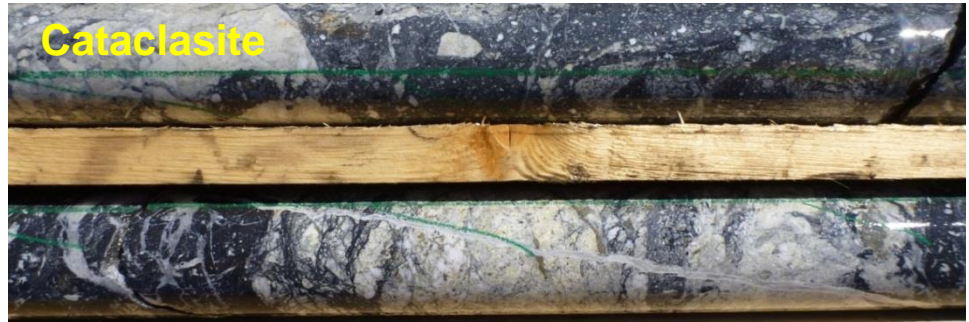


Athabasca Basin Faults

Incohesive breccia



Cataclasite



Fracture desilicification



Cataclasite and ultraclataclasite



Sheeted deformation bands



Phyllonite



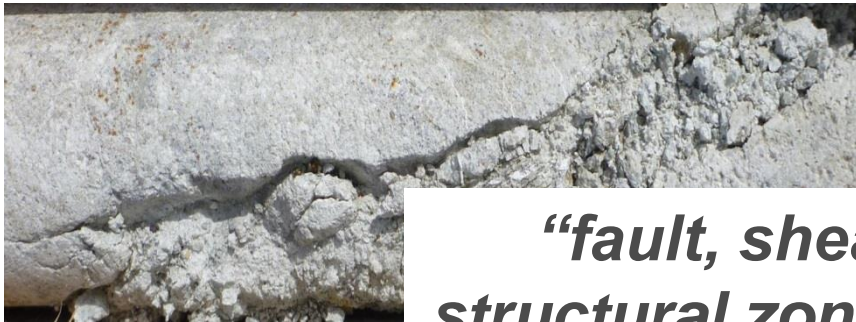
chaotic fault breccia / gouge



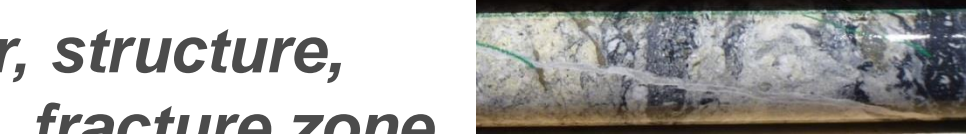
Mylonite



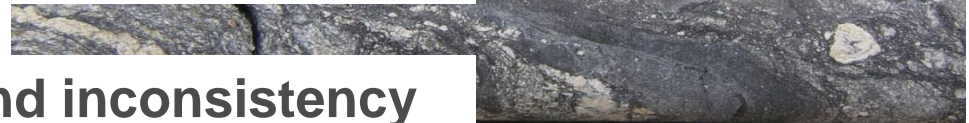
► Athabasca Basin Faults



***“fault, shear, structure,
structural zone, fracture zone,
broken core,
breccia, gouge, cataclasite”***



**Lack of clarity and inconsistency
in the use**



► Fault Zone Architecture – Rock Types

		non-foliated	foliated	
>30% large clasts >2 mm	75-100% large clasts (>2 mm)		fault breccia crackle breccia mosaic breccia chaotic breccia	
	60-75% large clasts (>2 mm)			
	30-60% large clasts (>2 mm)			
<30% large clasts >2 mm	incohesive ¹		fault gouge	
	cohesive	glass or devitrified glass	pseudotachylyte	
		0-50% matrix (<0.1 mm)	protocataclasite	protomylonite
		50-90% matrix (<0.1 mm)	(meso)cataclasite	(meso)mylonite
		90-100% matrix (<0.1 mm)	ultracataclasite	ultramylonite
		pronounced grain growth		blastomylonite ²

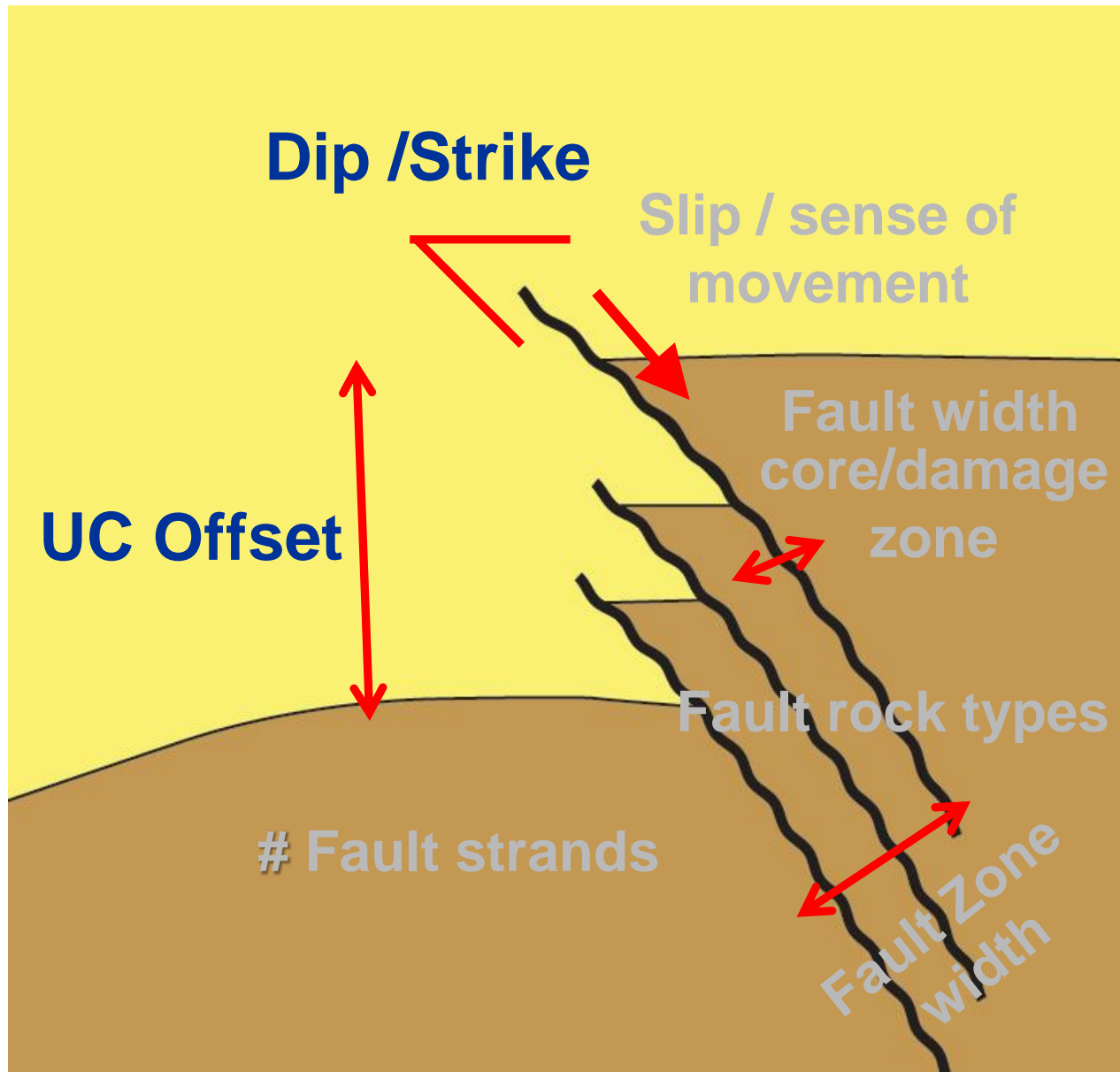
¹incohesive at present outcrop

²some blastomylonites have >30% large porphyroclasts

(after Woodcock and Mort, 2008)

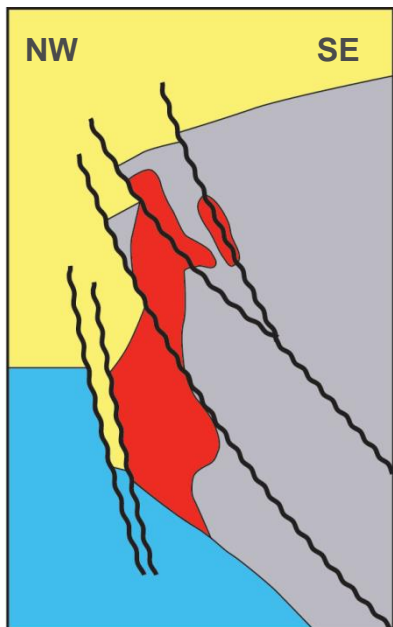
...use standard
fault rock
classifications
and be rigorous
in application

► Fault Architecture – Basic Elements

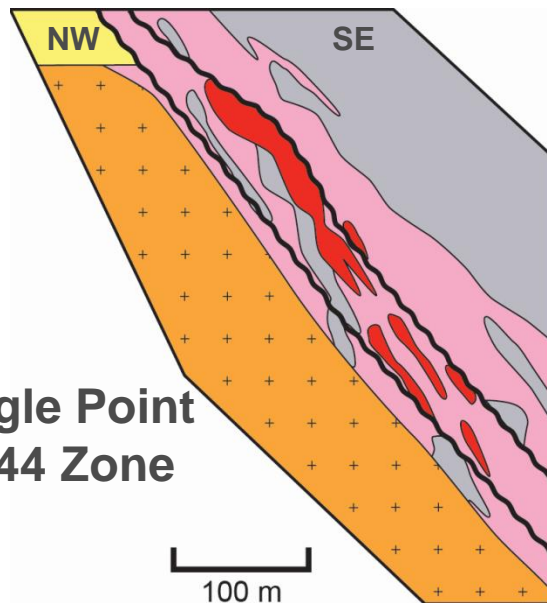


► Post Athabasca Faults – Dip

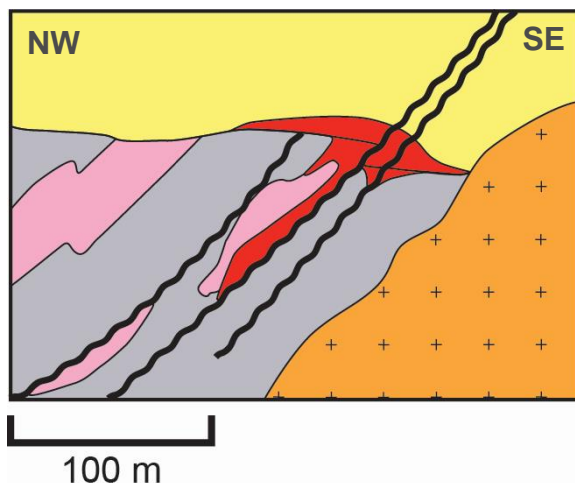
McArthur
Zone 2



Eagle Point
144 Zone



Key L – Deilmann



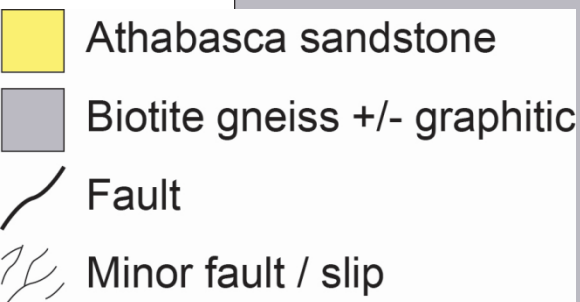
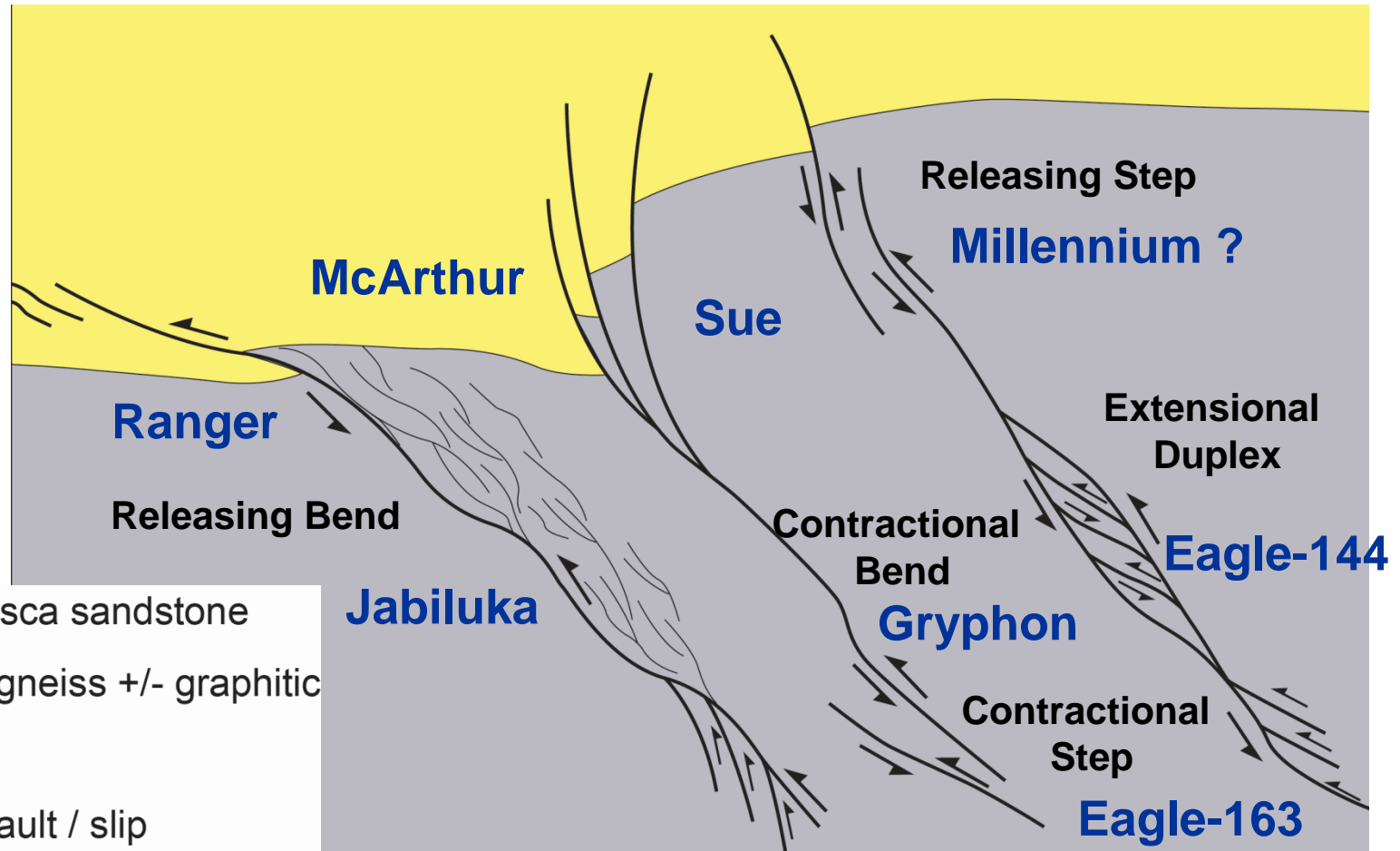
- **Post-Sst basement faults**
 - Range 50°- 85°...
- **Flatten or steepen in sst**
 - broad zones of fracturing and quartz dissolution
 - correlation of discrete faults on sections problematic
- **Variations in dip and strike create prospective structural settings**
 - Segment flexures, segment steps, termination splays

► Post Athabasca Faults – Dip / Strike

Plan

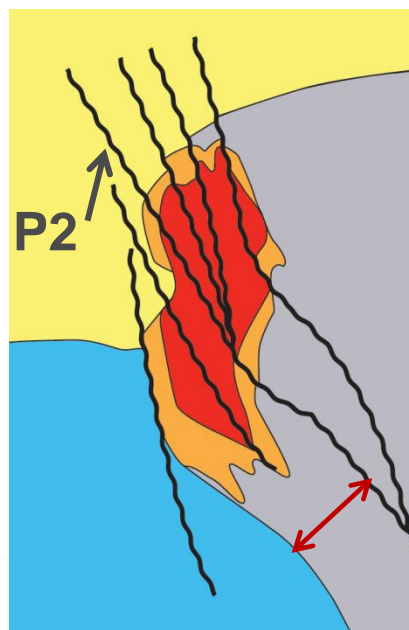
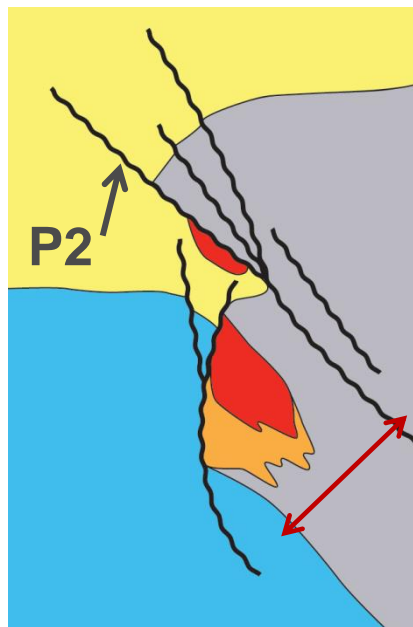


Section

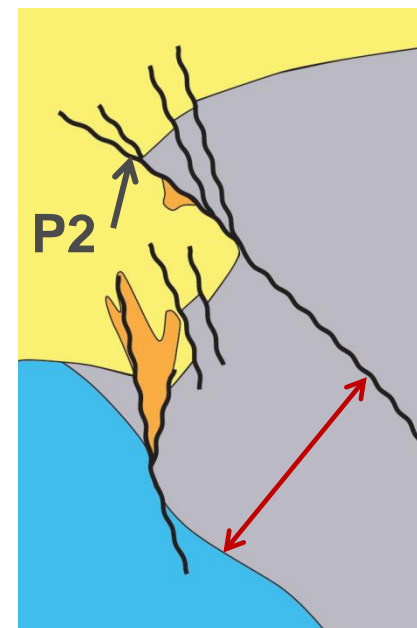
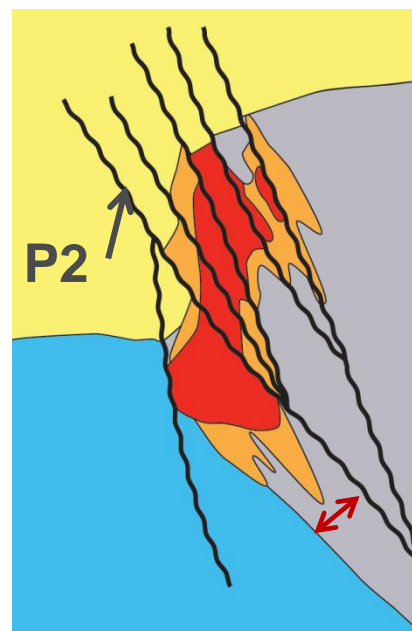


► McArthur – Zone 2

NE

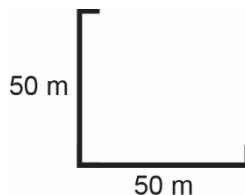


110 m



SW

- High grade uranium
- Low grade uranium
- Athabasca sandstone
- Qtzite / hydrothermal Sil
- Biotite gneiss +/- graphitic
- Brittle to semibrittle fault



After Thomas (2000)

Cameco

► McArthur – Zone 2

NE

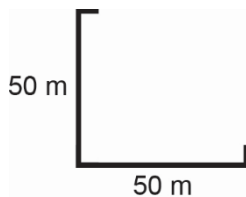
110 m

SW

Increased fracturing ≈ permeability
Multiple fault strands ≈ fluid flux

- High grade uranium
- Low grade uranium
- Athabasca sandstone
- Qtzite / hydrothermal Sil
- Biotite gneiss +/- graphitic

~ Brittle to semibrittle fault

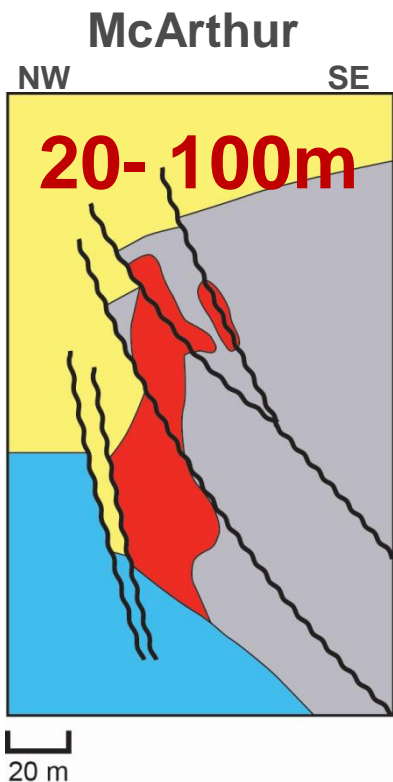


After Thomas (2000)

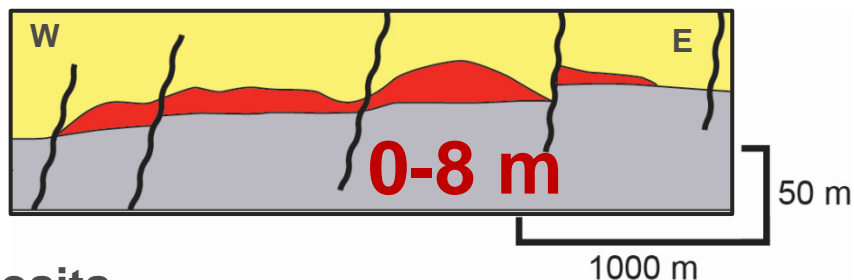
Cameco

► Unconformity Offset

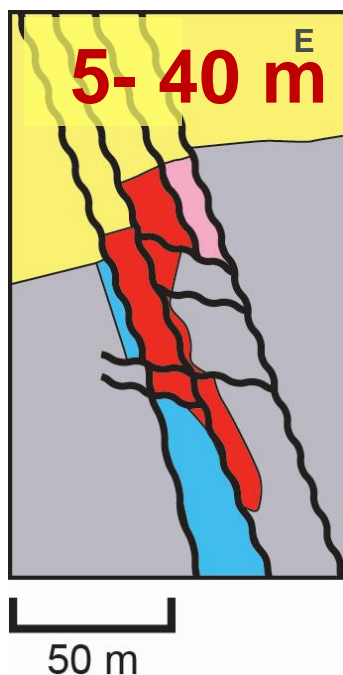
- Cumulative U.C. offset \approx size of deposit?



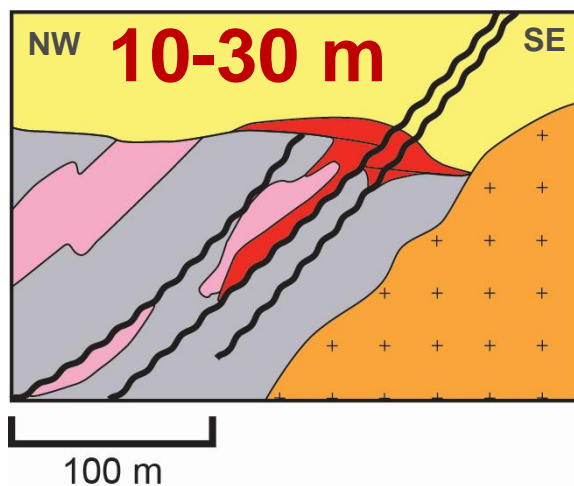
Cigar L (longitudinal section)



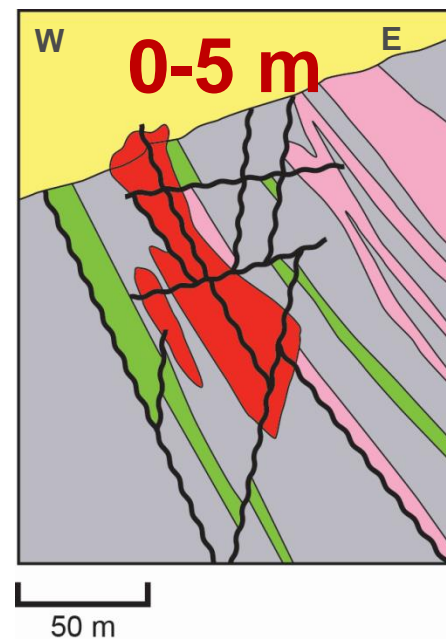
Sue Deposits



Key L – Deilmann

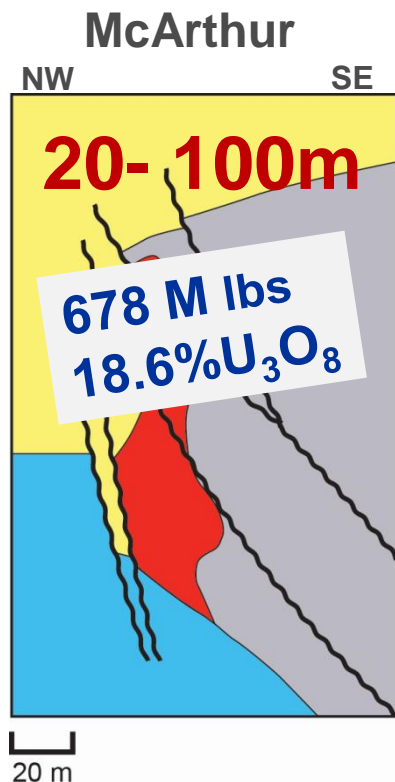


Millennium

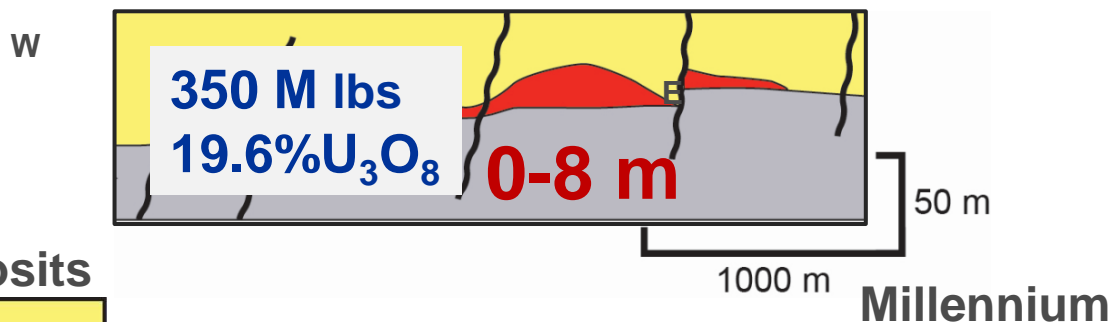


► Unconformity Offset

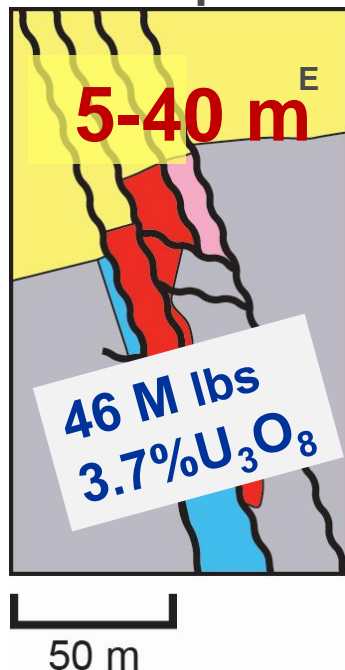
Cumulative U.C. offset \approx size of deposit?



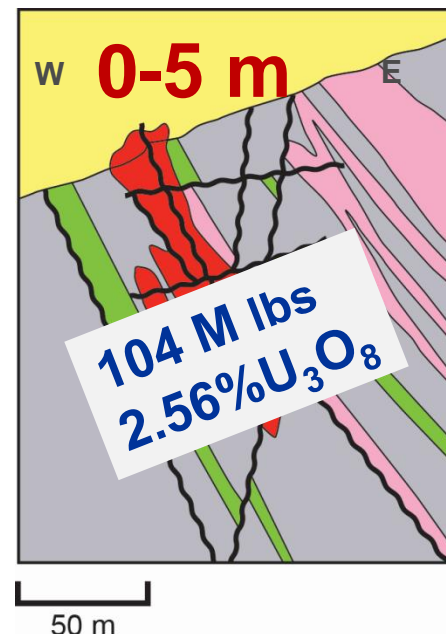
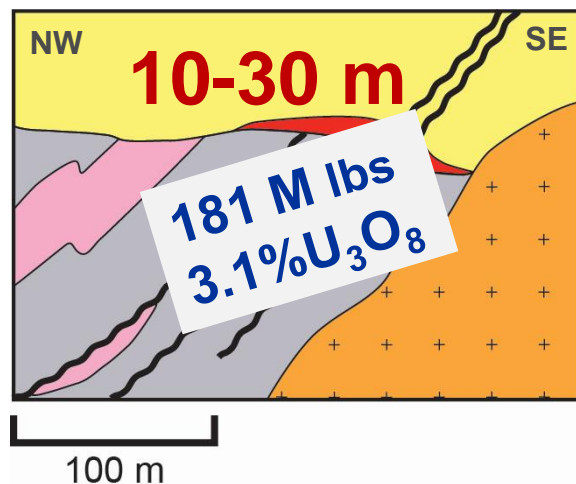
Cigar L (longitudinal section)



Sue Deposits

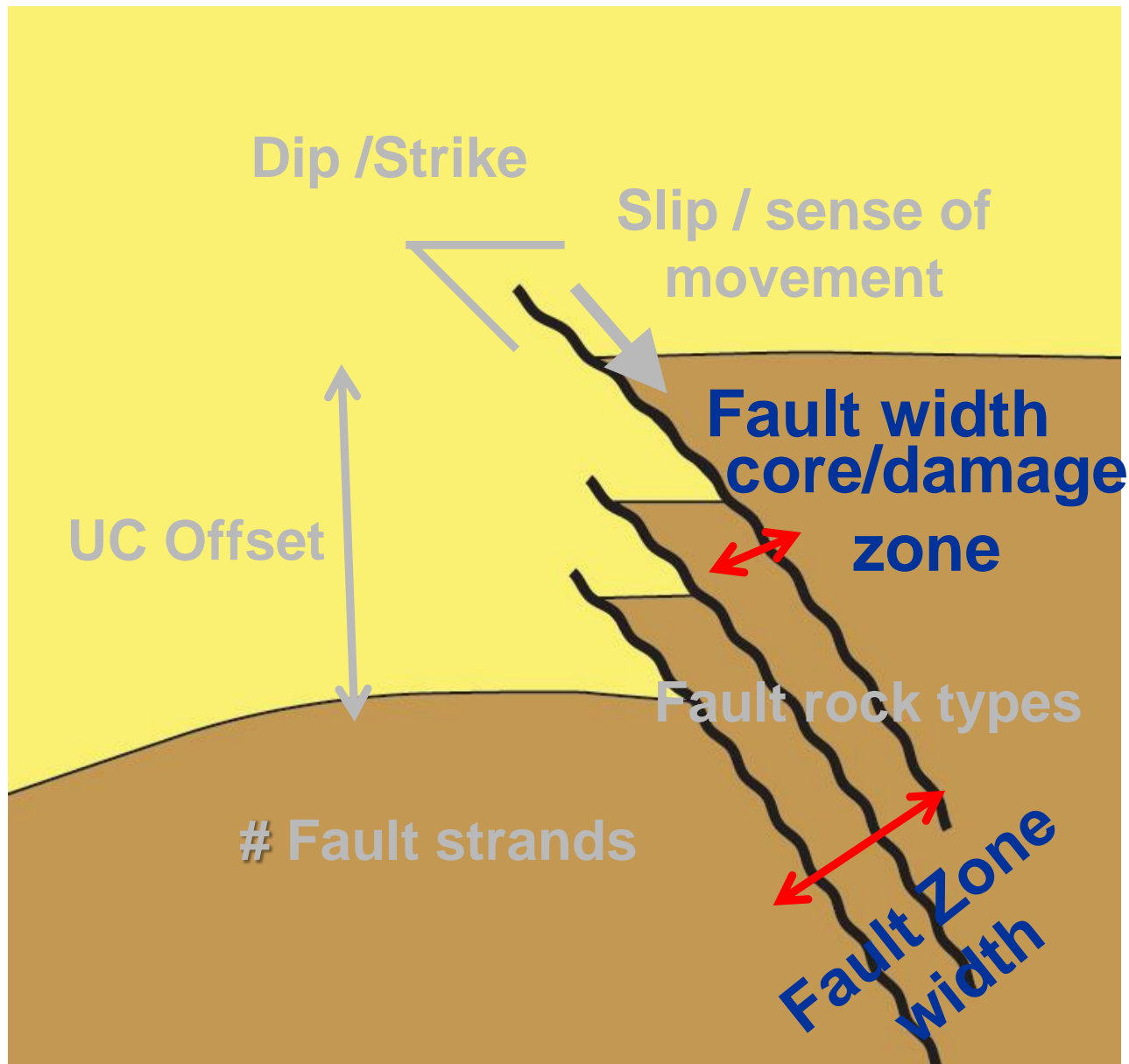


Key L – Deilmann



Sources: IAEA UDEPO and Cameco data, for illustrative purposes only, and not in accordance with CIM guidelines

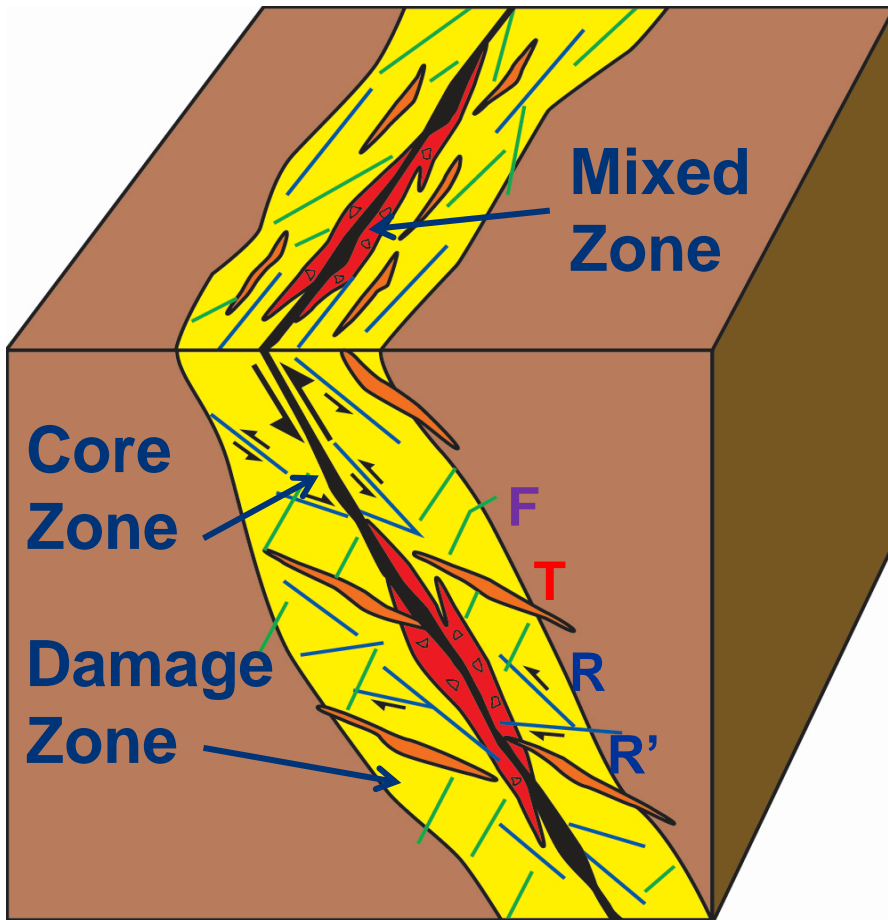
► Fault Architecture – Elements



► Fault Zone Architecture

Upper Crust

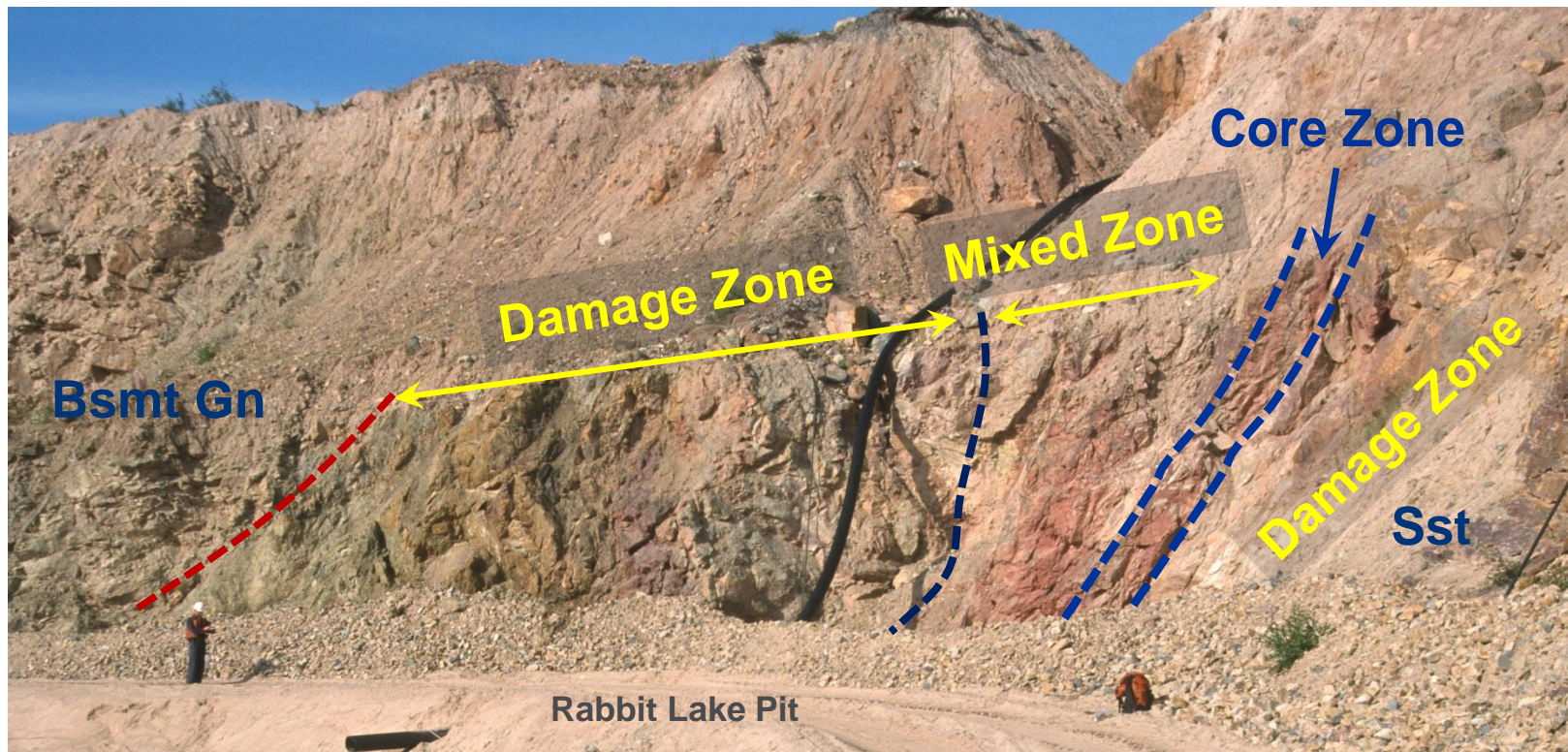
(<3 – 10 km depth)



- **Core Zone**
 - Zone of main movement
- **Damage Zone**
 - Bounding zones, symmetric/asymmetric
 - Extensive fractures, veins, small faults/slips, R-R'
- **Mixed Zone**
 - Between core and damage zone,
 - Intercalation of variably strained rocks; heterolithic fault breccia;
- **Wall rock**

After Caine, JS, Evans, JP and Forster CB (1996)

► Fault Zone Architecture – Rabbit L.



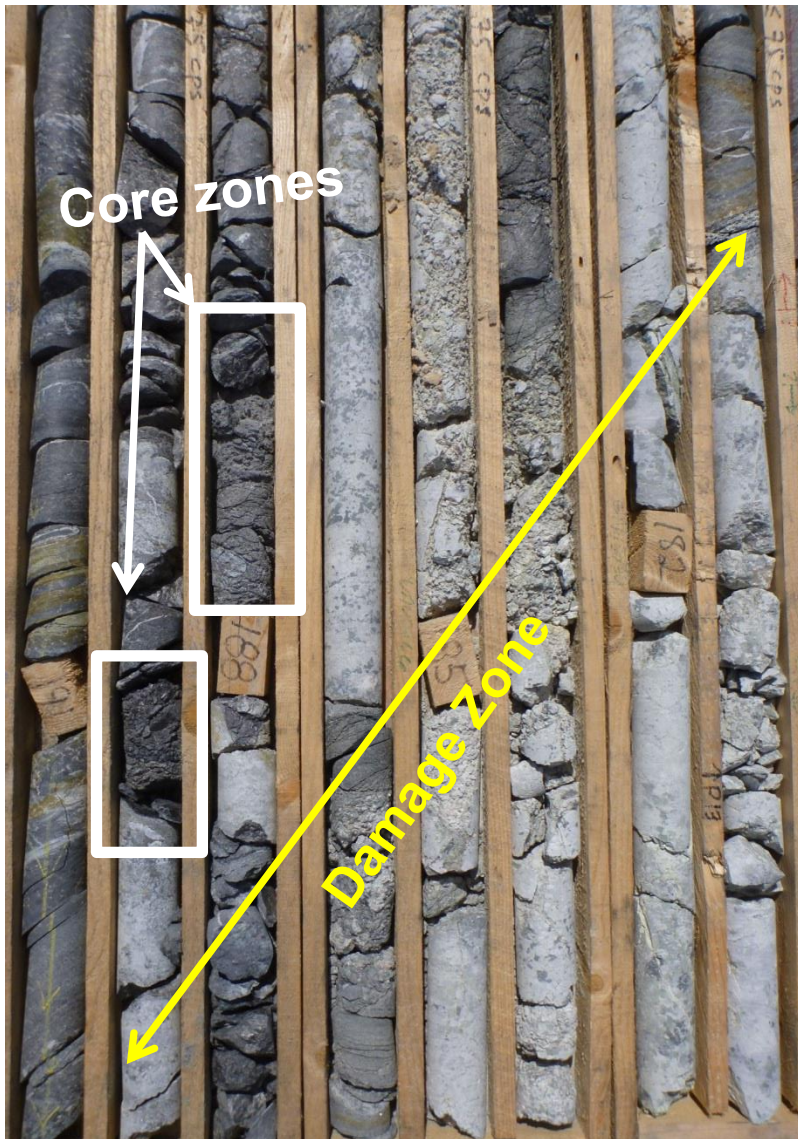
Damage Zone

- Outer structural zone
- Bedding/metamorphic layering intact
- Minor faults, extensive fracture / vein network
- Large-scale Riedel fractures

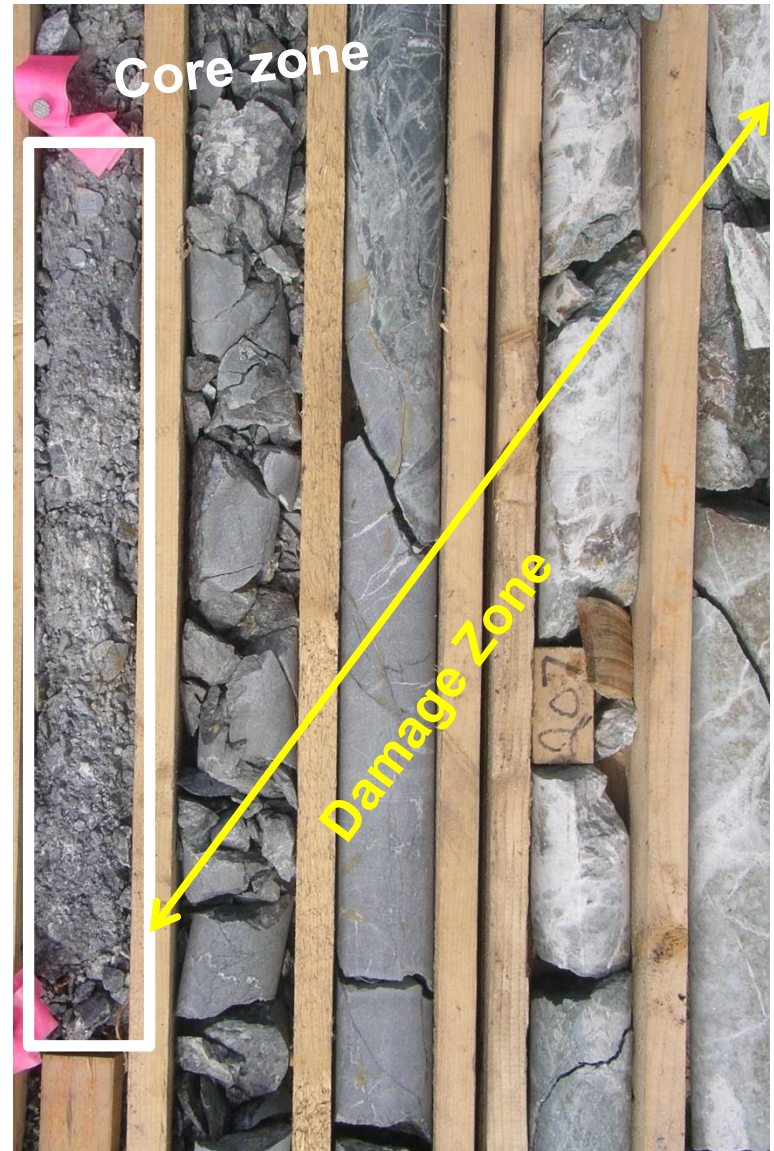
Core Zone

- Zone of main movement
- Bounding slip surfaces
- Significant grain size reduction
- Anastomosing slip surfaces
- Gouge, incohesive breccias, cataclasites

► Faults - Core / Damage Zones



Key Lake fault, Gartner deposit. SE-086

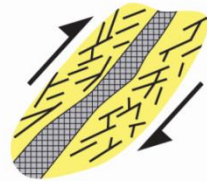


Thorburn Fault, Thorburn zone. Q14a-026

► Core and Damage Zones

Distributed Deformation

Composite Deformation



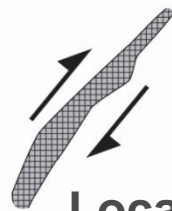
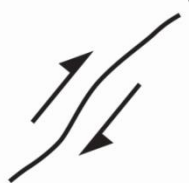
% core

% damage zone

% damage zone

Fault Zone Architecture Styles

% core



Single Fracture Fault

Localized Deformation

- Hydrogeological units
- Fault zone permeability
 - % Core vs % Damage Zone
- Conduit, barrier or combined conduit- barrier

After Caine, JS, Evans, JP and Forster CB (1996)

Caine, JS, Bruhn, RL and Forster, CB (2010)

► Fault Zone Architecture- Permeability

Extensive Conduit

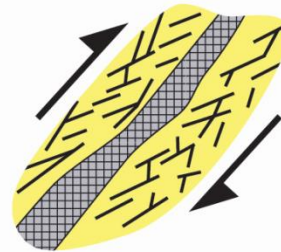
Distributed
Deformation



Cigar, McClean,
Phoenix

Combined Conduit-barrier

Composite
Deformation



McArthur, Eagle,
Rabbit, Key,
Sue

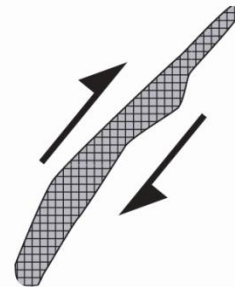
Eagle Point
(O2 O2N)

Single Fracture
Fault



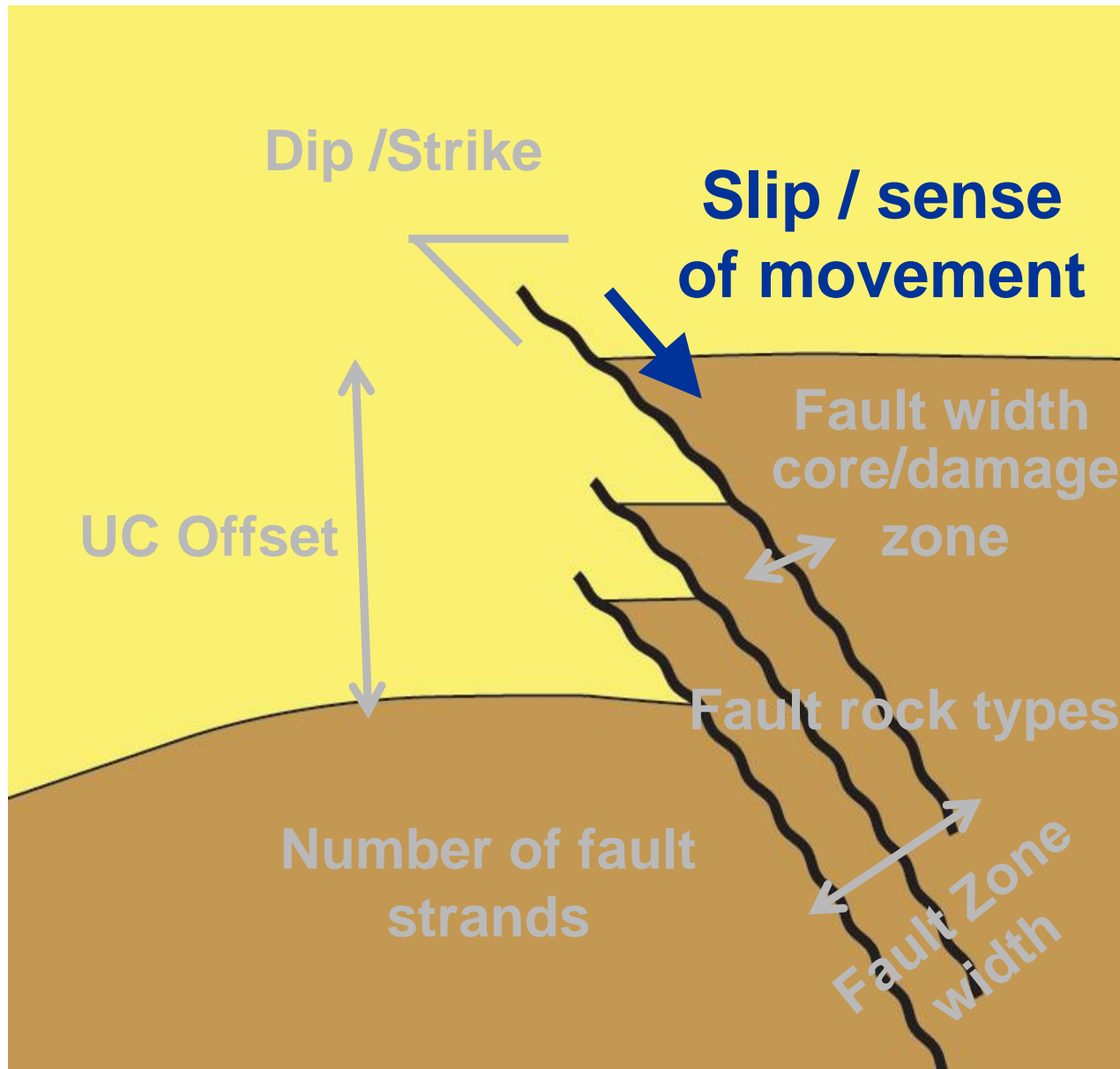
Restricted Conduit

Localized
Deformation



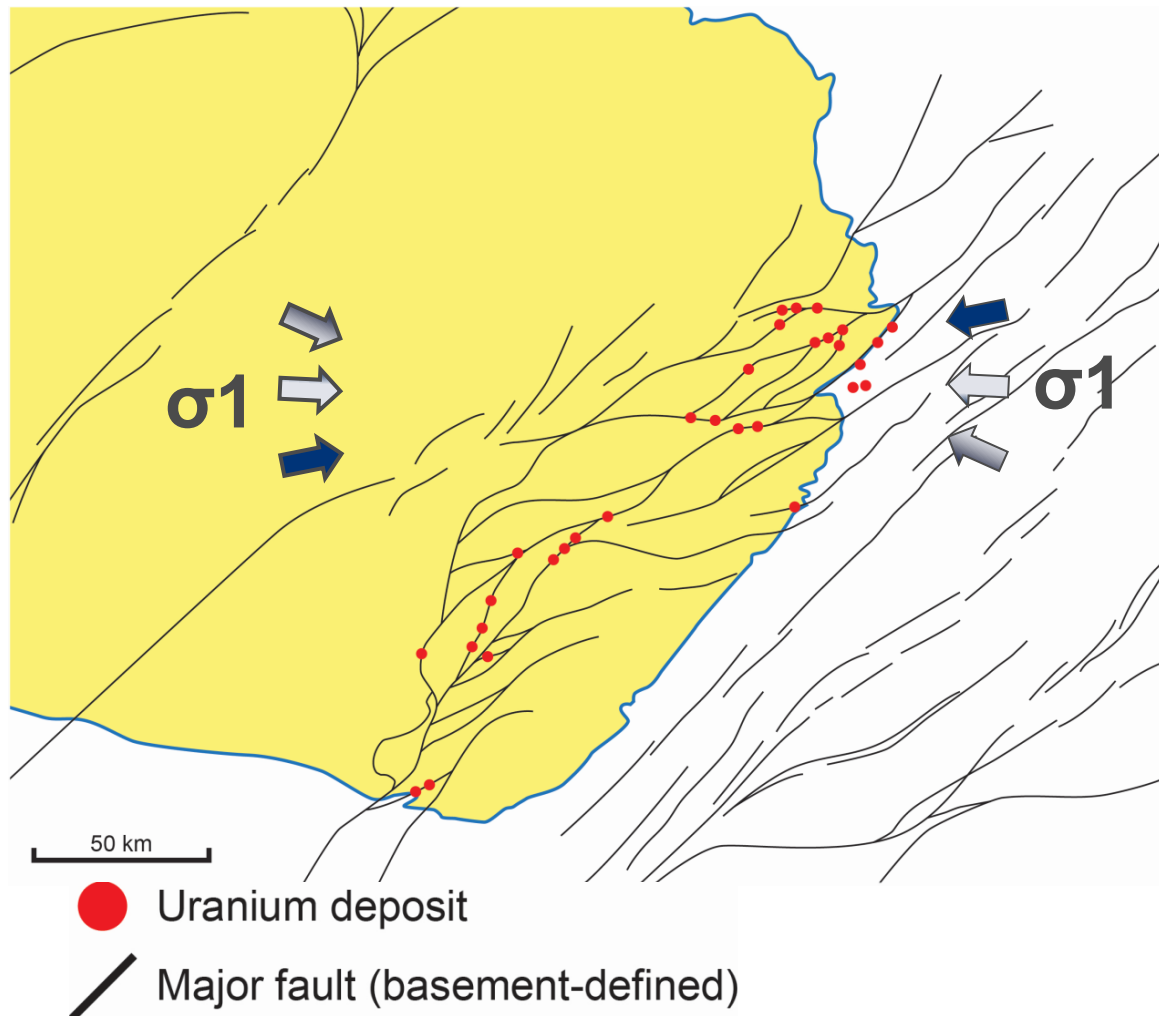
Barrier

► Fault Architecture – Elements



Fault Architecture - Kinematic

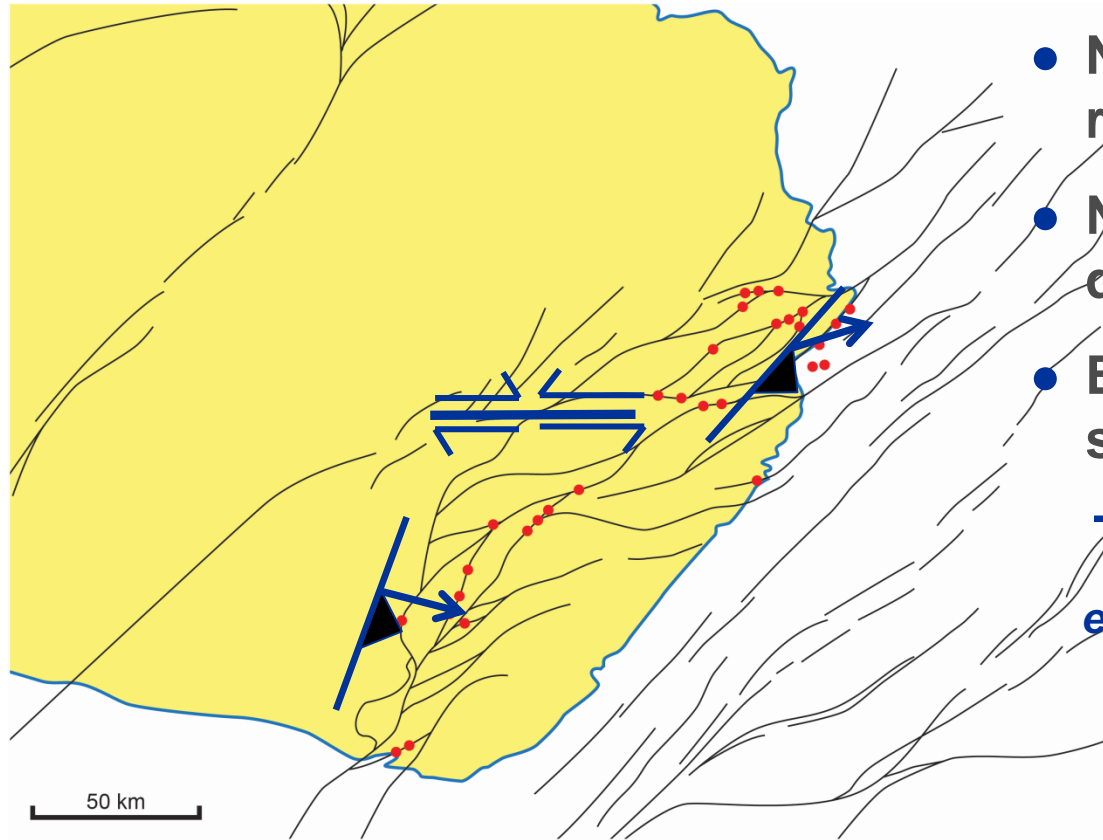
Uranium Deposits and Major Faults Eastern Athabasca Basin



- Faults associated with uranium mineralization
 - Dip slip - reverse
 - Oblique - reverse (transpressional)
 - Strike slip
- ENE through ESE shortening σ_1
- Syn-mineralization far field stress
 - ca. 1550-1600 Ma ?

Fault Architecture - Kinematic

Uranium Deposits and Major Faults Eastern Athabasca Basin



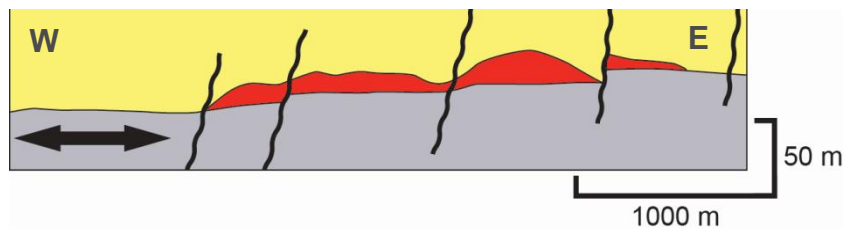
- N-S structures \approx high angle reverse
- NE structures \approx oblique dextral reverse
- E-W structures \approx sinistral/dextral strike slip

These are generalizations!
e.g. Gryphon zone ..steep sinistral transpressional

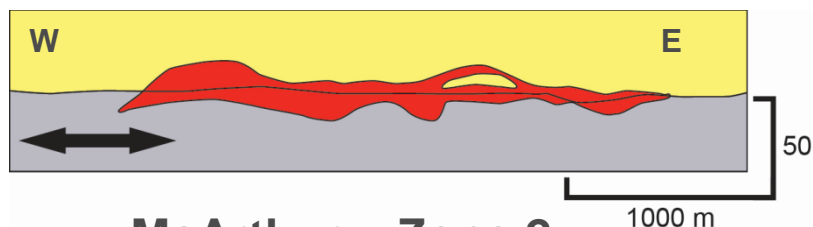
- Uranium deposit
- Major fault (basement-defined)

► Fault Architecture – Longitudinal Sections

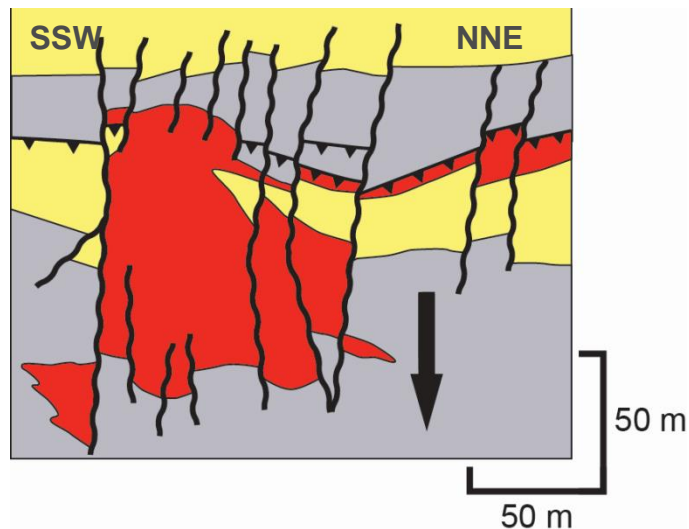
Cigar



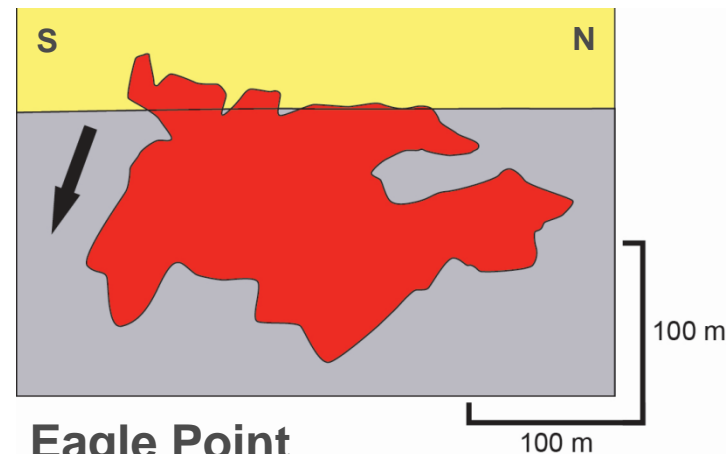
McClellan North- Pod 1



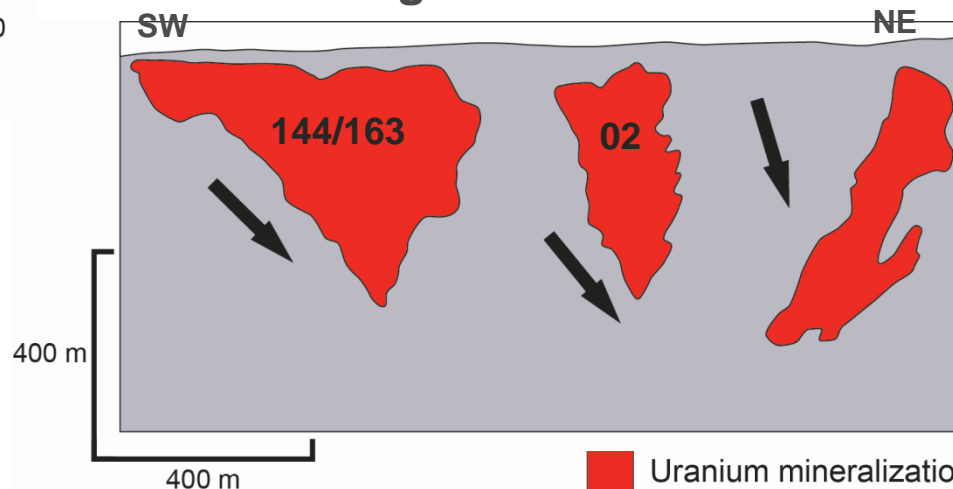
McArthur – Zone 2



Millennium



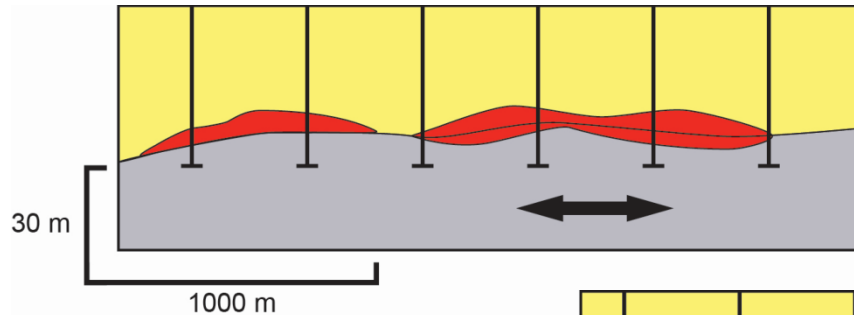
Eagle Point



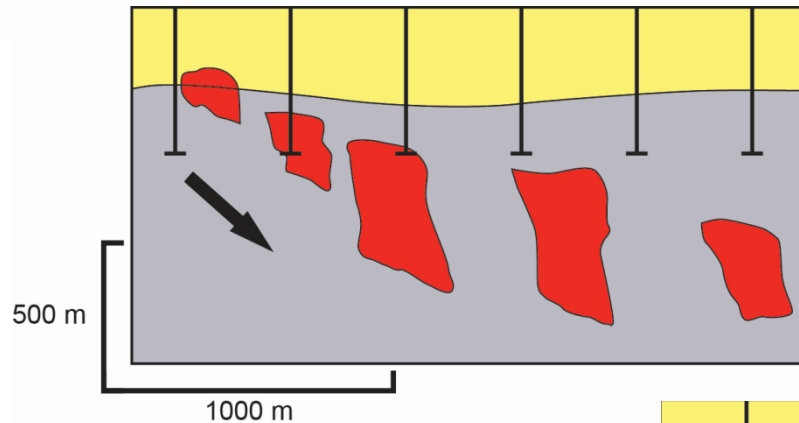
- Uranium mineralization
- Athabasca sandstone
- Basement gneiss
- Fault slip

► Ore System Geometry/Orientation

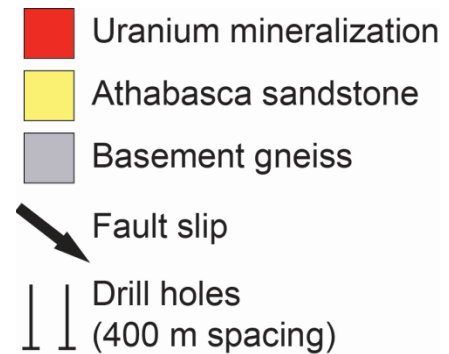
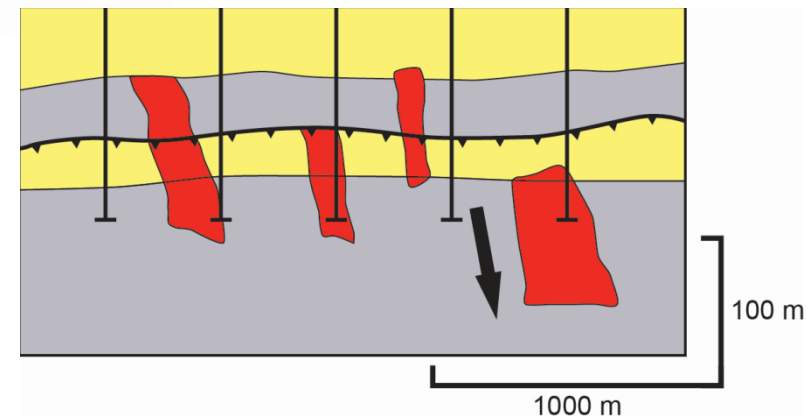
Cigar, McClean, Tamarack, J Zone, Phoenix



*Eagle Point, Key Lake,
Dawn Lake*



*McArthur, Millennium
Roughrider, Gryphon*



- Drill hole spacing
- Depth of drill holes
- Test along strike
- Test down-dip

► Athabasca Uranium and Faults: Summary

