Deformation in mafic protoliths: Impacts from late faults on Ni-Cu-PGE Mineralization at Lac des Iles Mine, Canada

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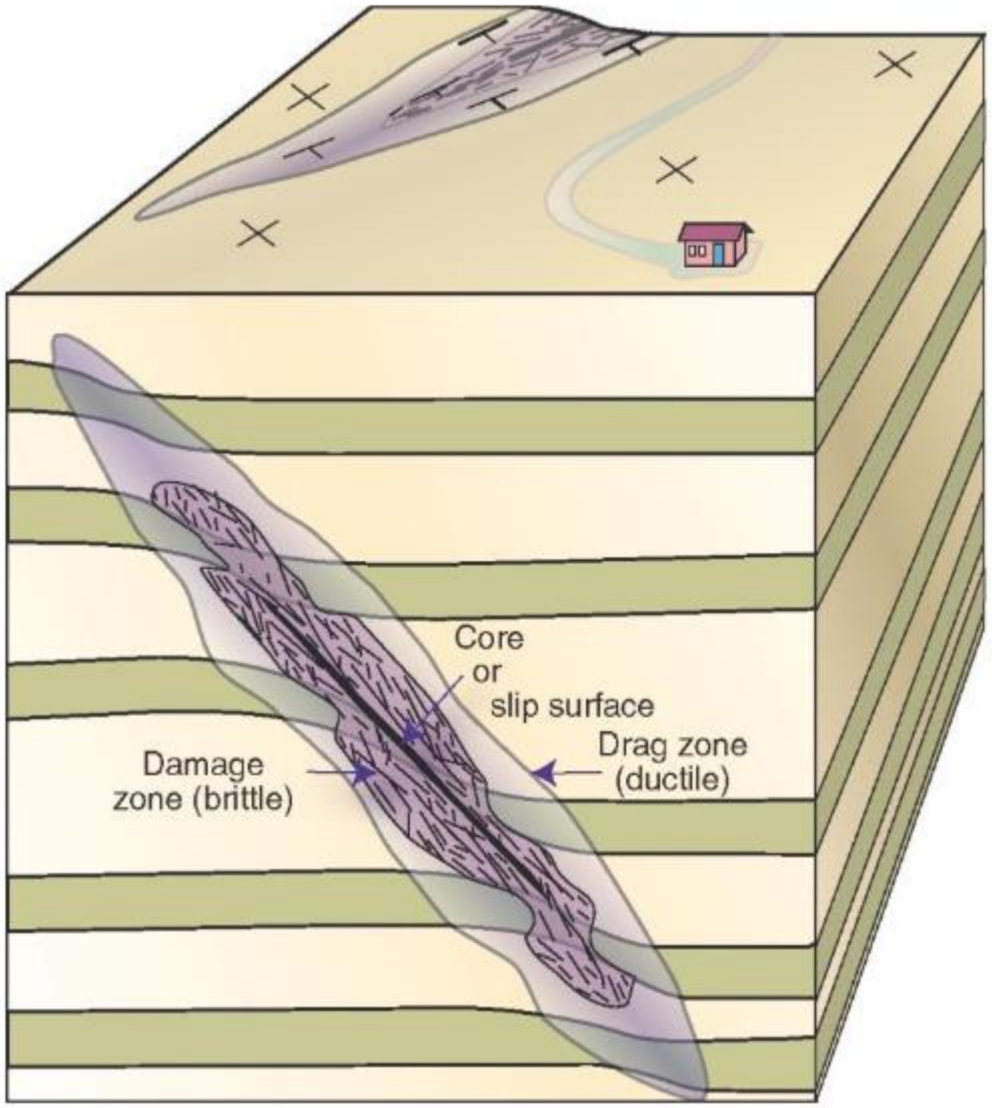
Faults and Fault Structure

- Complex structures that can serve as permeable pathways through the upper crust
- Often hosted within anisotropic and discontinuous lithologies, where physical and chemical properties can change over short distances
- At shallow depths, pressure-dependent processes (brittle fracturing and cataclasis) control deformation
- Both high fluid pressure and the presence of clay minerals play a role in the weakening of fault zones



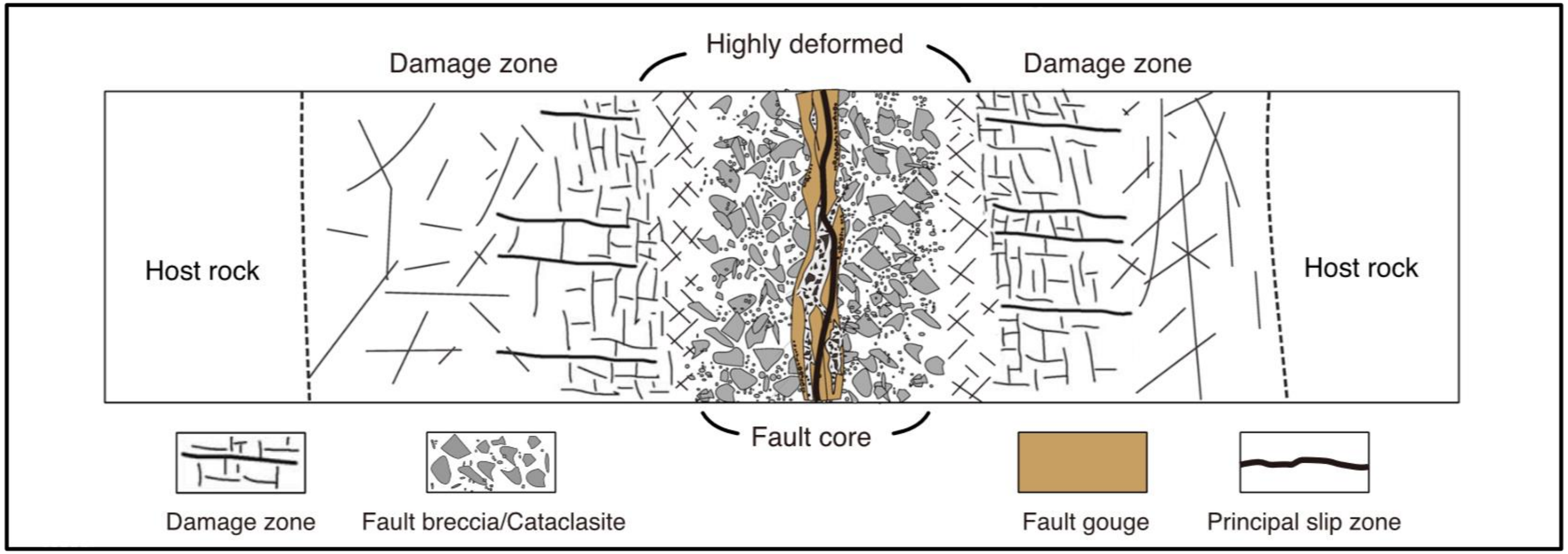
(Fossen, 2016)

Typical Fault Zone Architecture

1) Protolith – host rock, typically (or ideally) unaltered
   - *Least altered / fractured, country rock*

2) Damage zone – zone of high permeability and fluid flow, with increased fracture density
   - *Fault breccia, abundant mode one fractures, increased alteration*

3) Fault core(s) – where the most slip was accommodated (high strain, low permeability)
   - *Gouge, cataclasite, principal slip surface, highest amount of localized shear*



(Yang et al., 2020)

1. How does late faulting and associated fluids affect PGE mineralization?

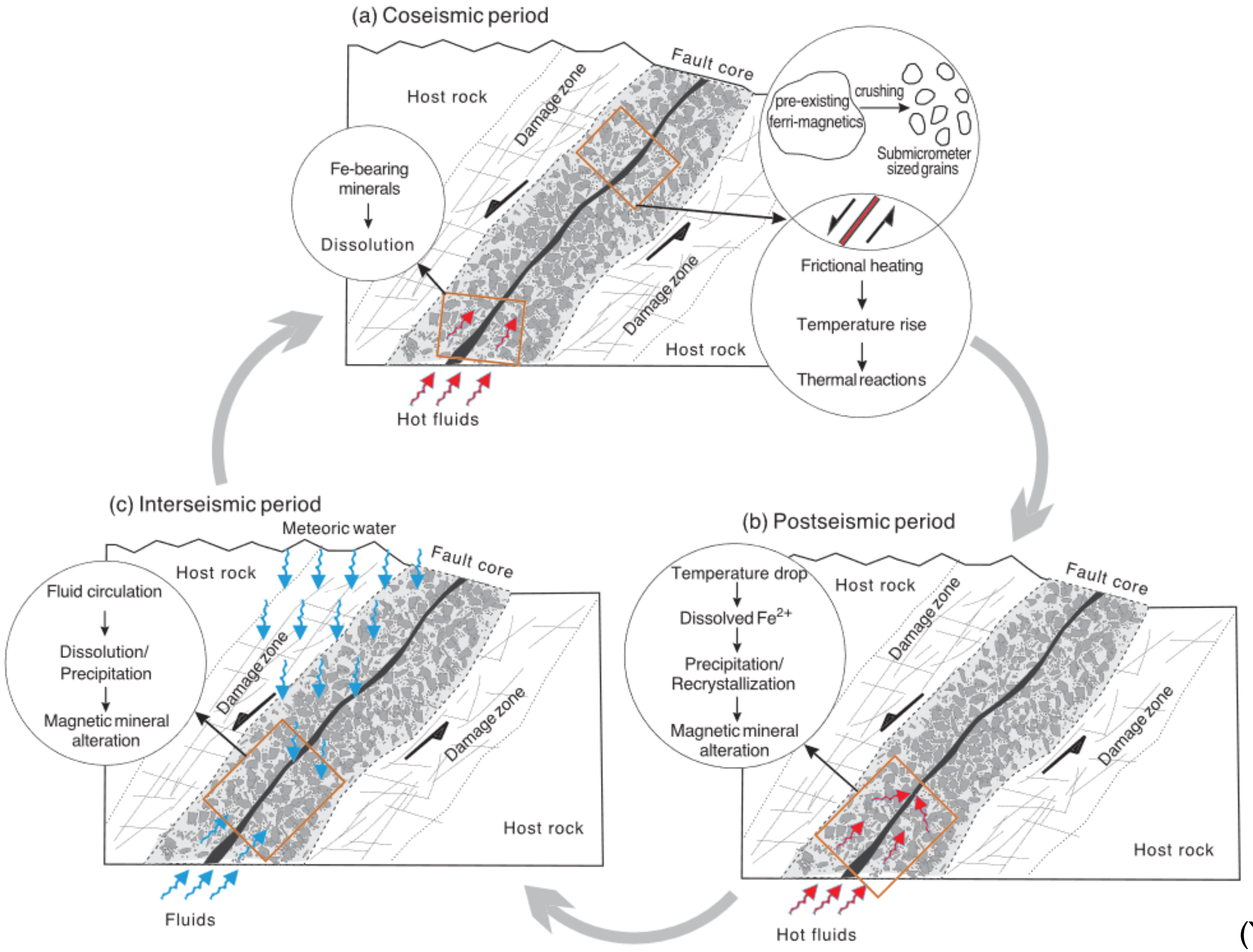
2. How does a fault zone structure vary with respect to the protolith?

I. Structural study on faulting in mafic and felsic protoliths

- Are there variations in damage zone structure and what are the conditions of faulting?

II. Geochemical patterns and alteration styles

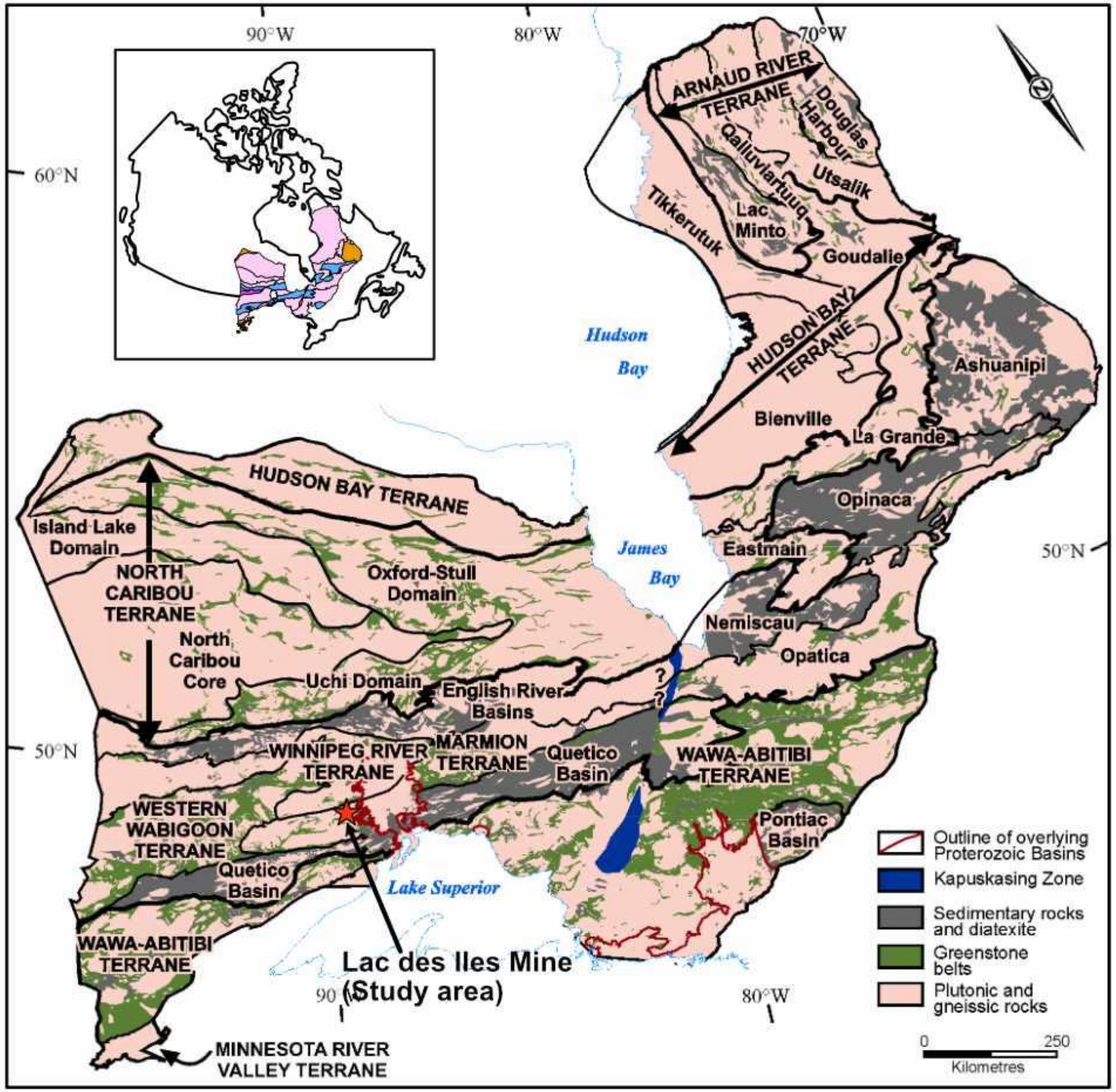
- Understanding fault zones and fluid remobilization of PGE's



(Yang et al., 2020)

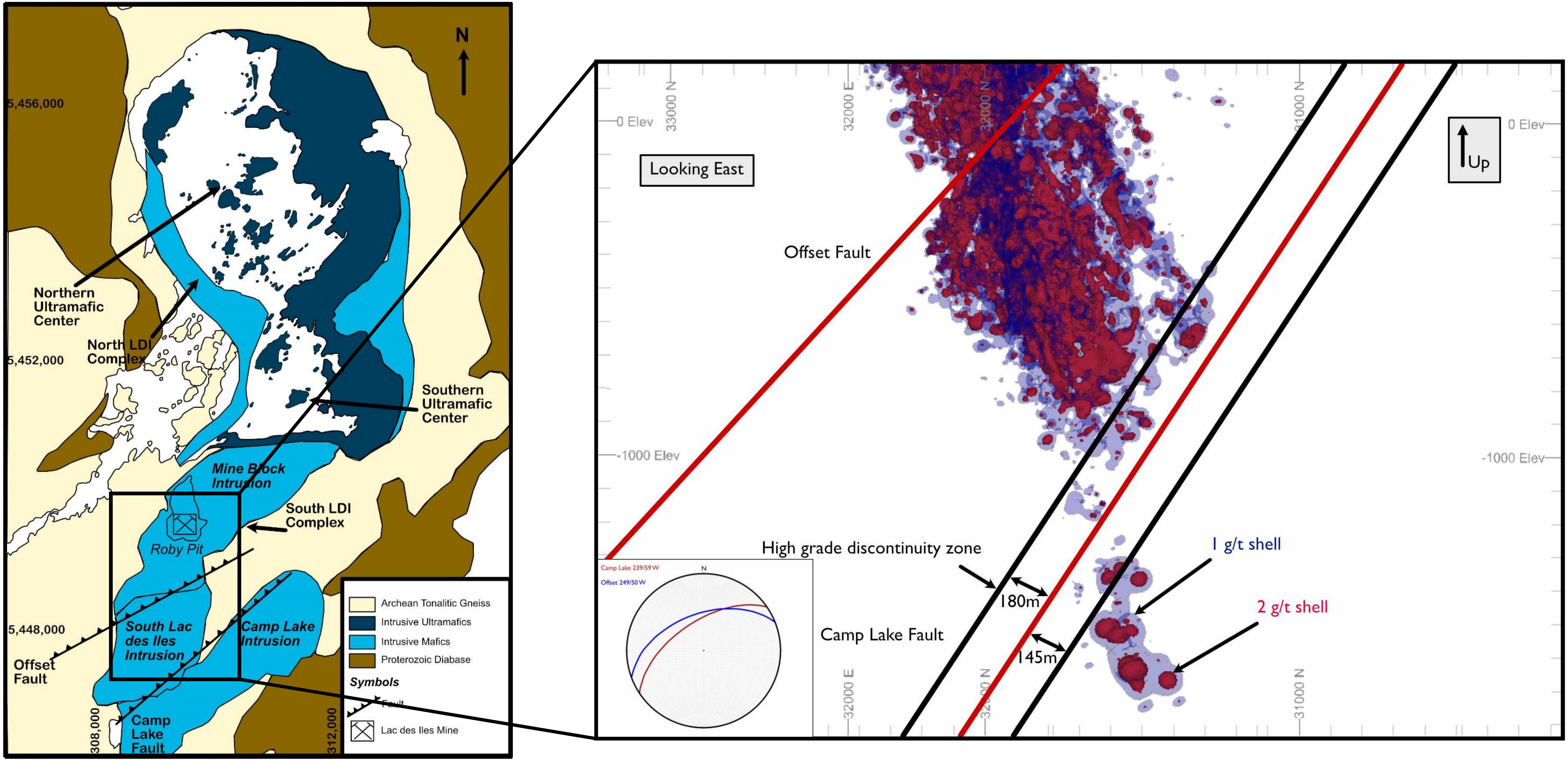
Lac des Iles Mine

- We can answer these questions by using Lac des Iles as a natural laboratory
- Location in the Marmion terrane of the Superior Province, 80 km north of Thunder Bay, ON
- The abundance of drilling and underground exposure provides an ideal study area to focus on faults in mafic protoliths



(Modified from Stott et al., 2010)

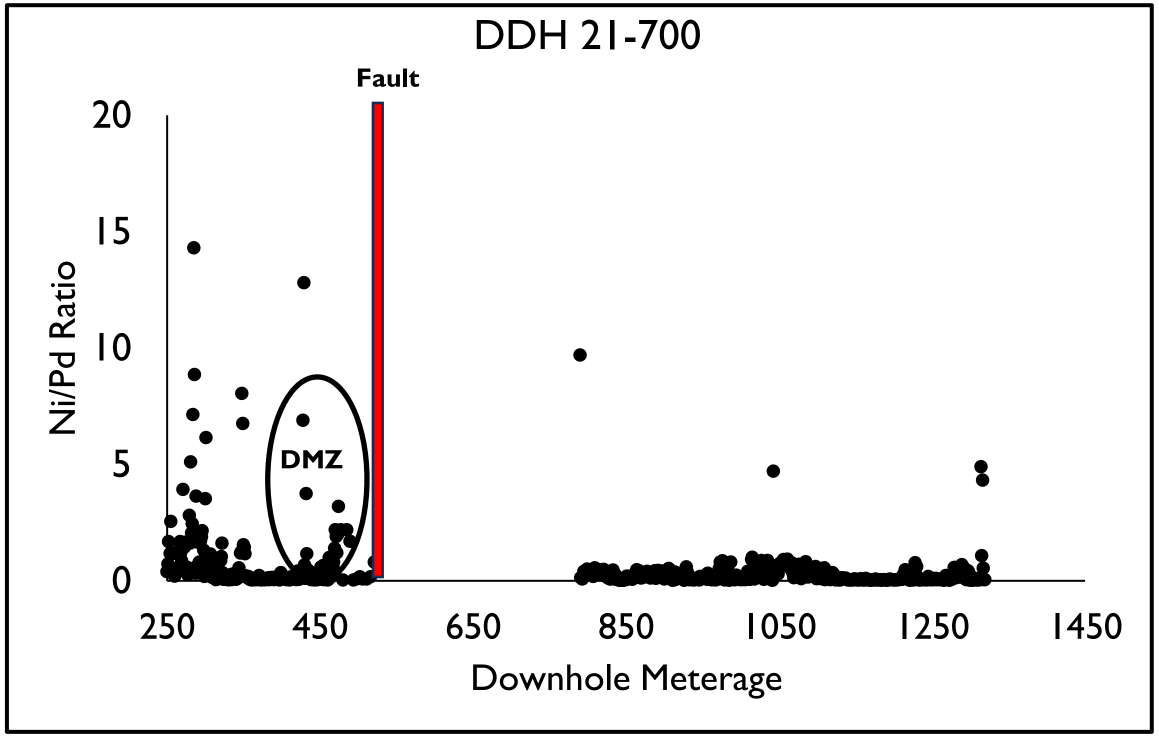
Study Area

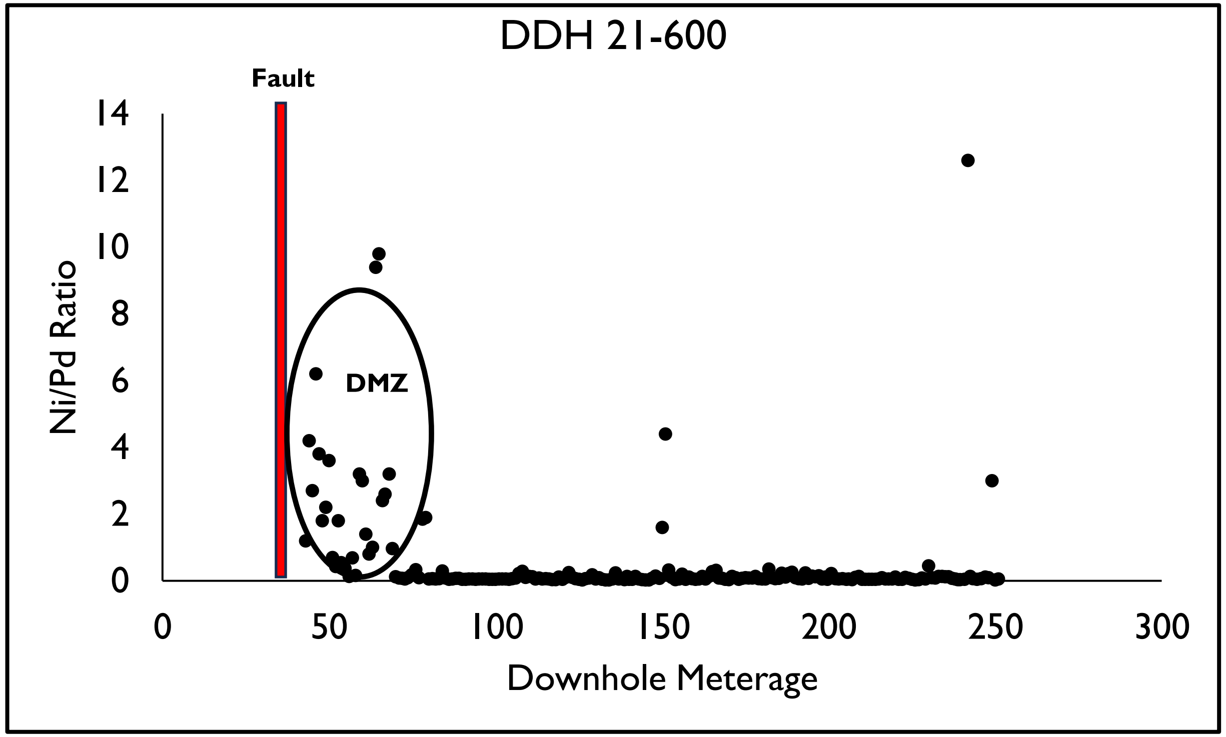


(Modified from Djon et al., 2018)

Was Pd present originally?

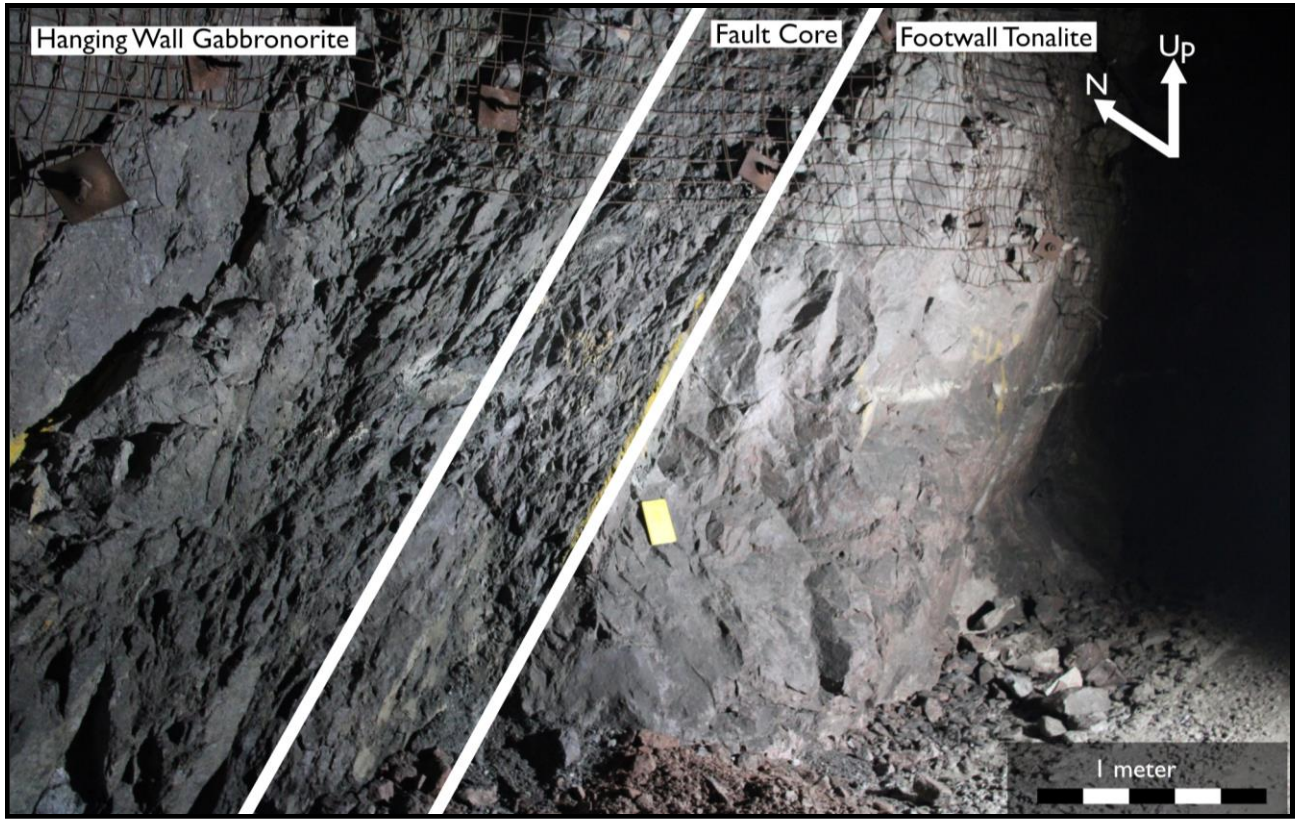
- In these systems, Ni and Pd often correlate and concentrate in pentlandite
- Increased alteration *should* increase Ni/Pd ratios (Ni immobile, Pd moderately mobile)
- If Pd was not originally present, these ratios would likely not change



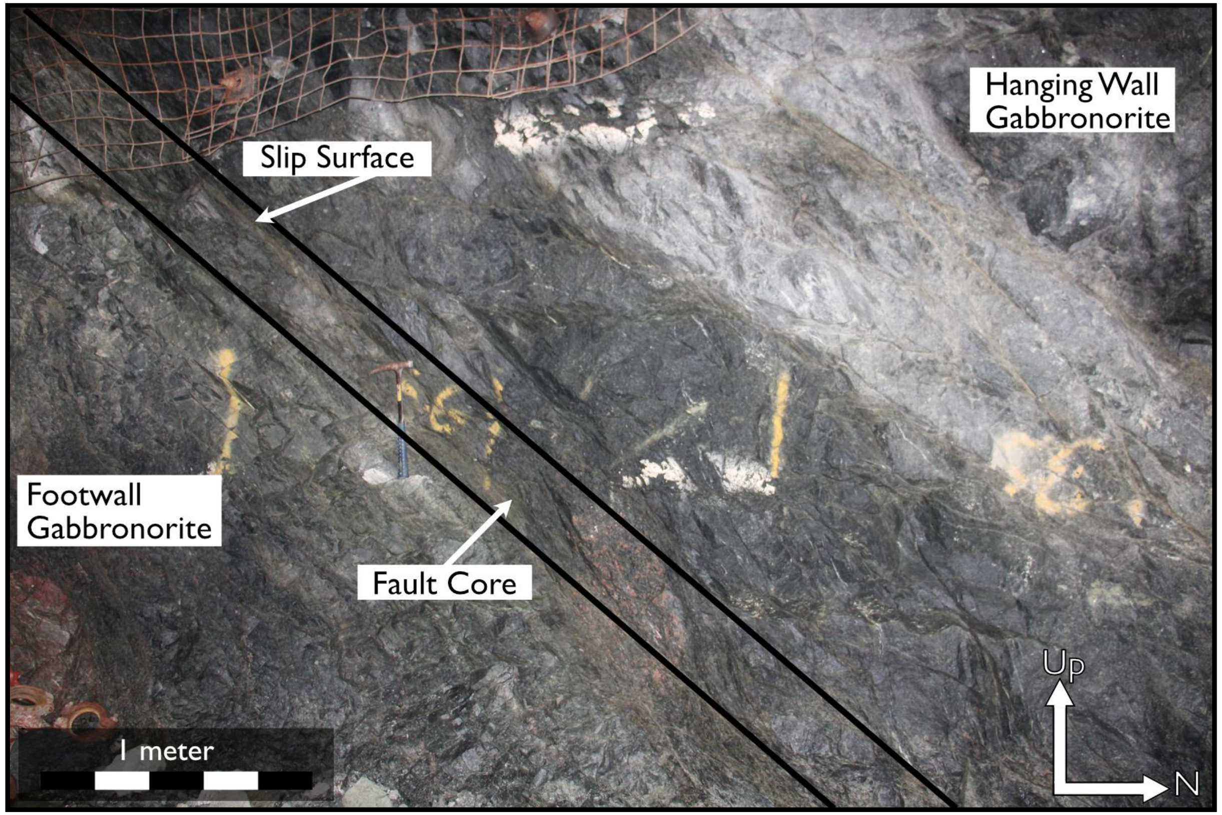


Field Observations

- Camp Lake Fault is a reverse fault displaced over 500 meters typically with the gabbronorite in fault contact with tonalite (Vektore, 2020)
- Offset Fault is a reverse fault with 200-300 meters of displacement, with variable lithologies in hanging wall and footwall



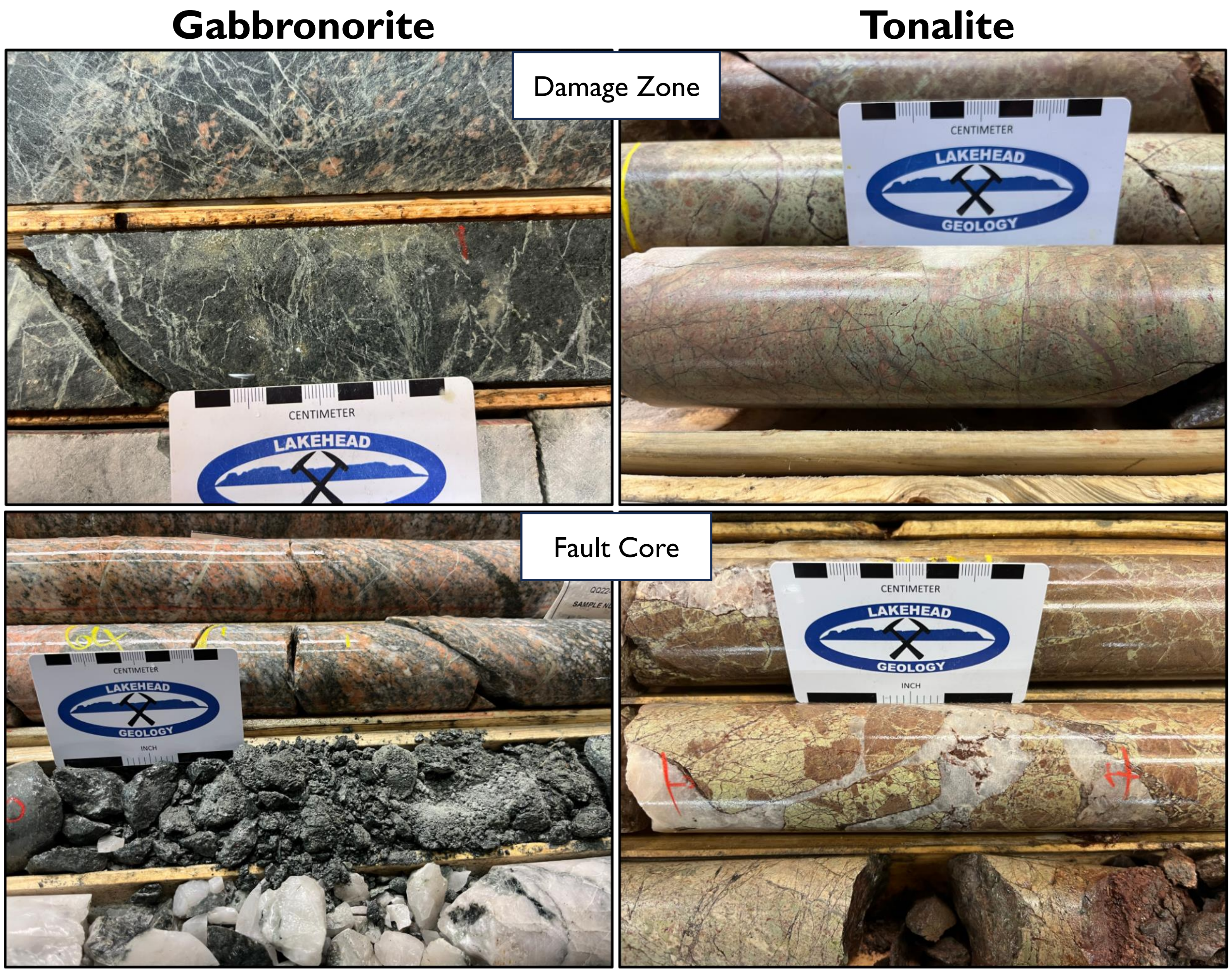
Camp Lake Fault (239/59)



Offset Fault (249/50)

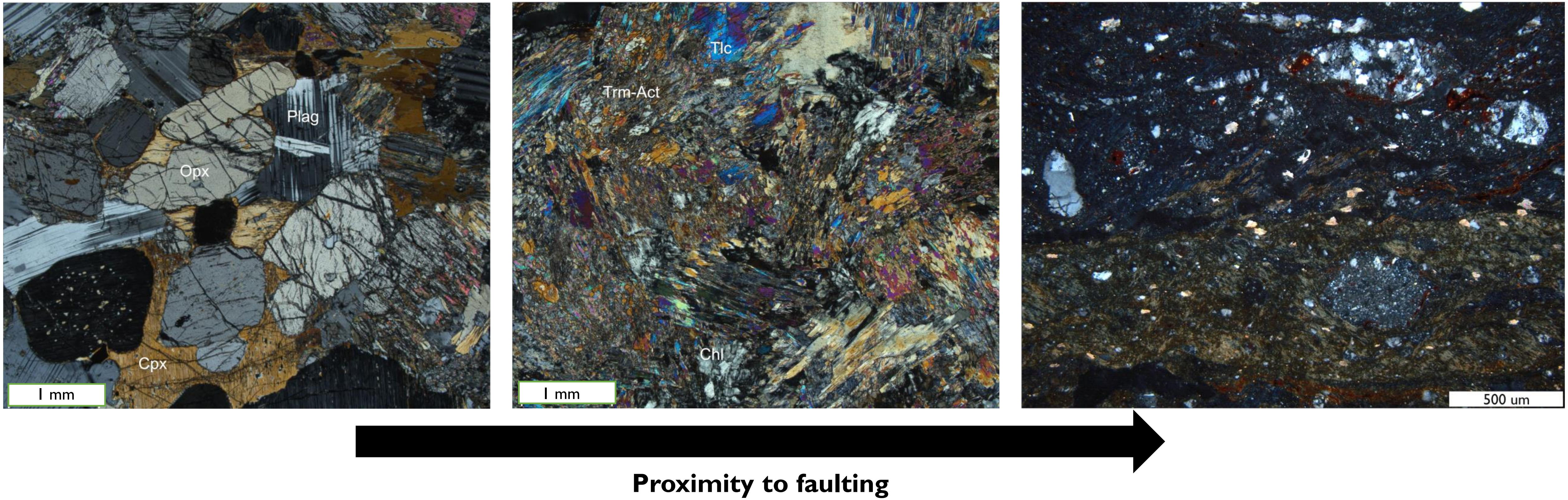
Core Logging – Observed Lithologies

- Detailed core logging observations show 3 distinct lithologies: tonalite, various gabbronorites, and chlorite-actinolite schist
- Alteration intensity increases with proximity to faulting
- Chlorite, tremolite, actinolite, talc, and minor sericite in the gabbronorites
- Potassium feldspar, epidote and sericite in the tonalites



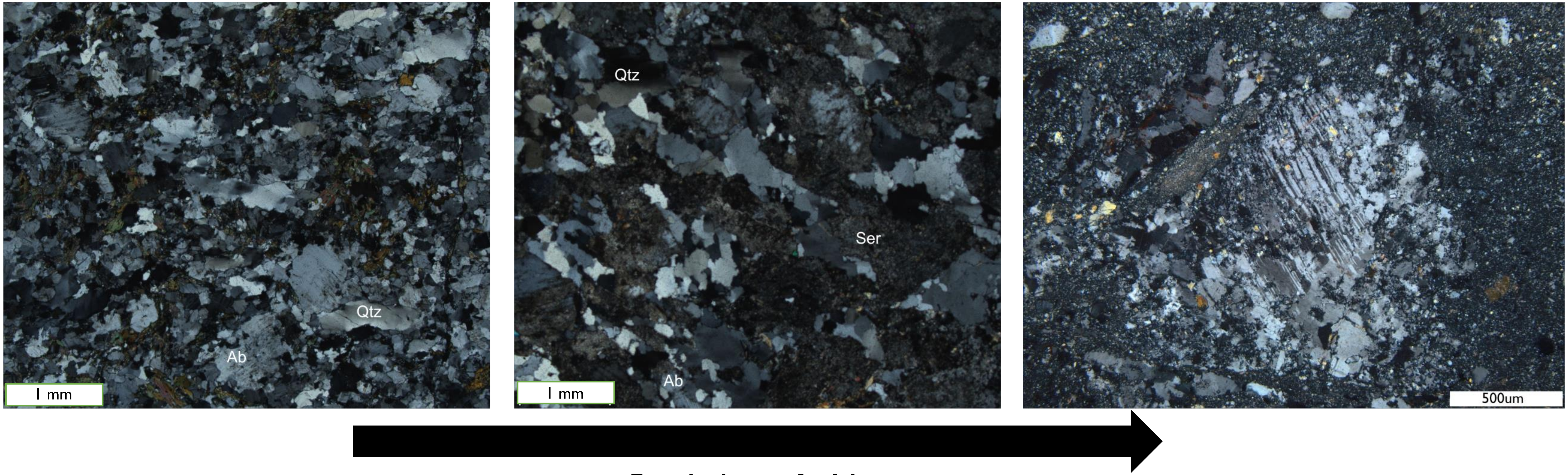
Petrography - Gabbronorite

- Primarily composed of plagioclase and pyroxene
- Strong chlorite, actinolite and talc alteration with proximity to faulting
- Fault core is dominated by chlorite (multiple varieties) and quartz



Petrography - Tonalite

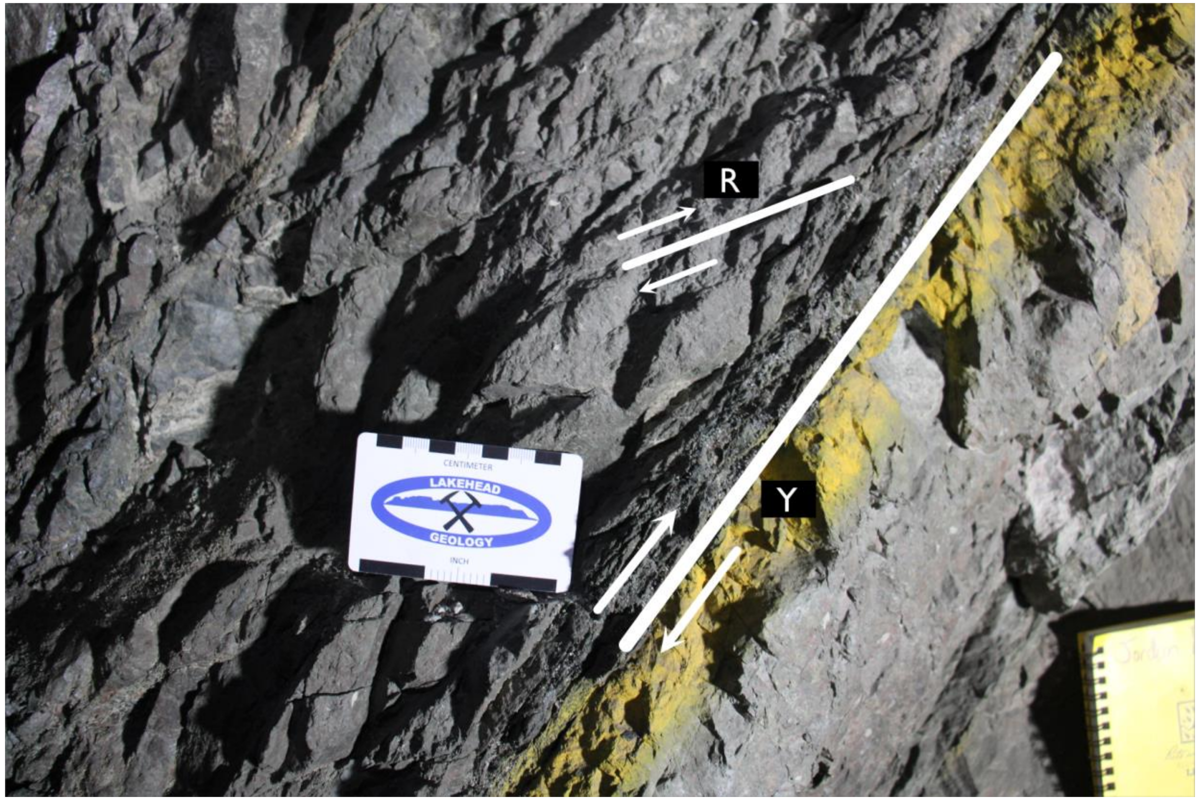
- Primarily composed of quartz, plagioclase, biotite, and pyroxene
- Variably foliated, display strong sericite and epidote alteration, and reduced in grain size when faulted
- Tonalite fault core is dominated by albite, quartz, epidote and sericite

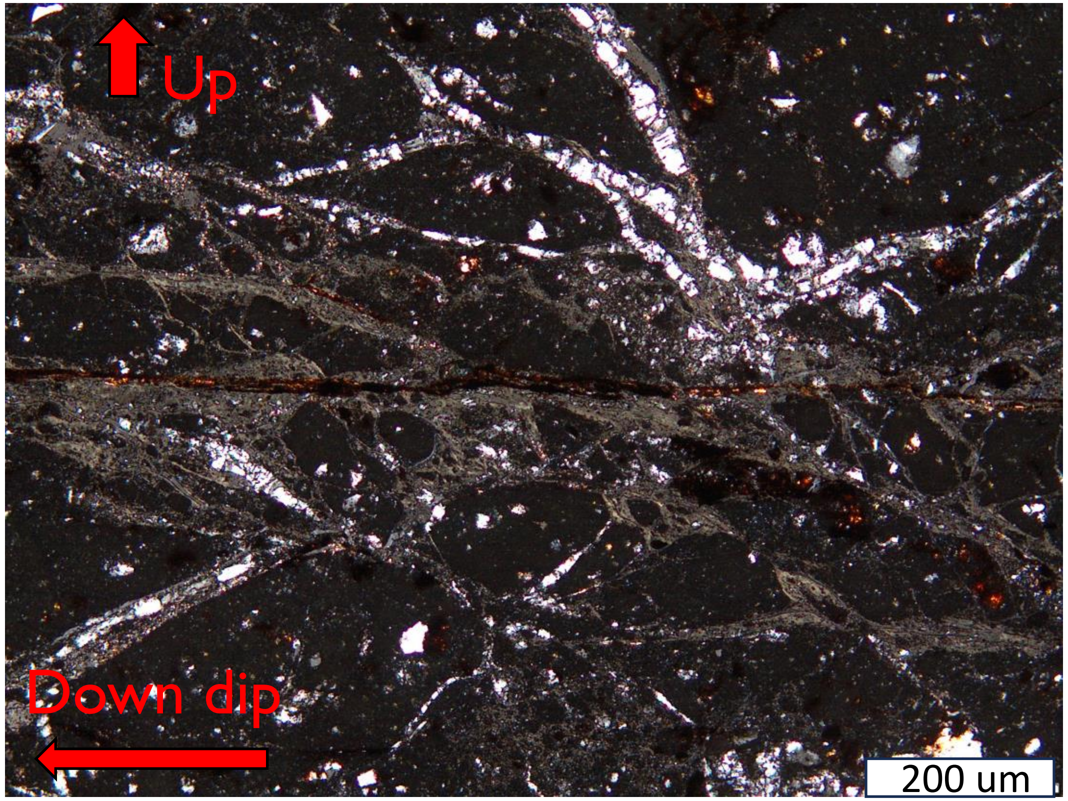


Proximity to faulting

Fault Rock Structures

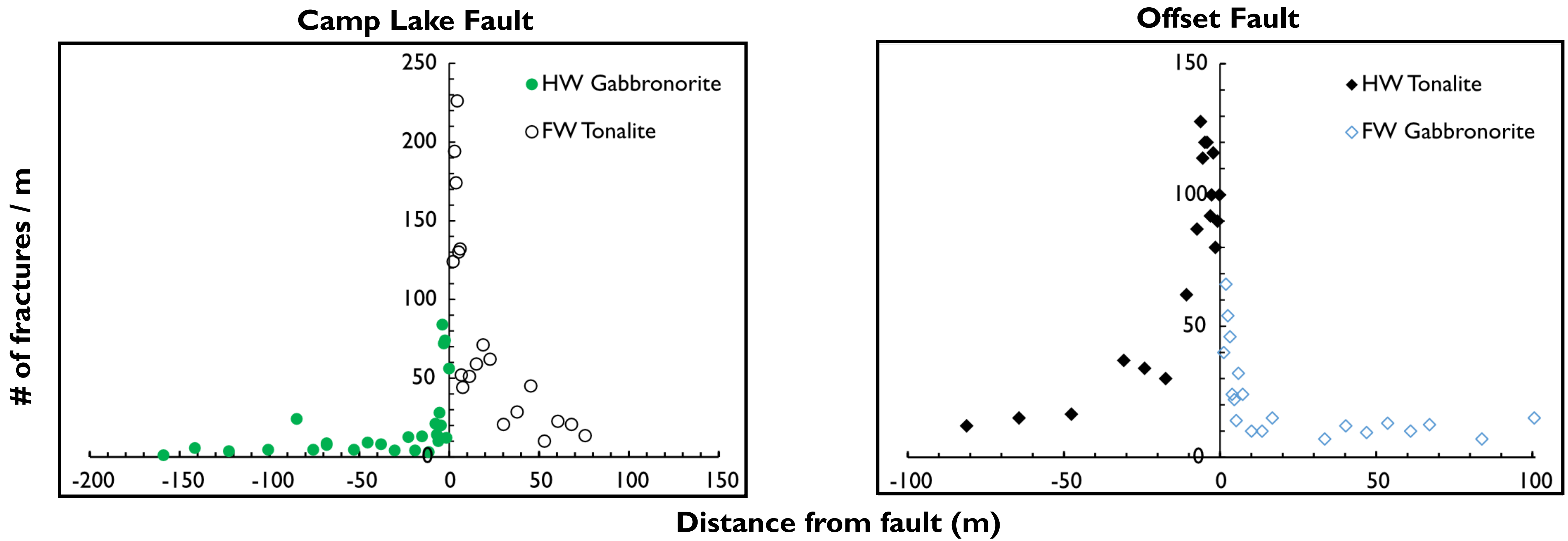
- The Camp Lake and Offset Faults are exposed parallel and normal to the fault slip surface
- Both have a discrete principal slip surface and well-defined fault core of 5-10cm
- Minor faulting is observable on the mm to cm scale, appearing to be consistent with the hypothesized kinematics





Fracture Density

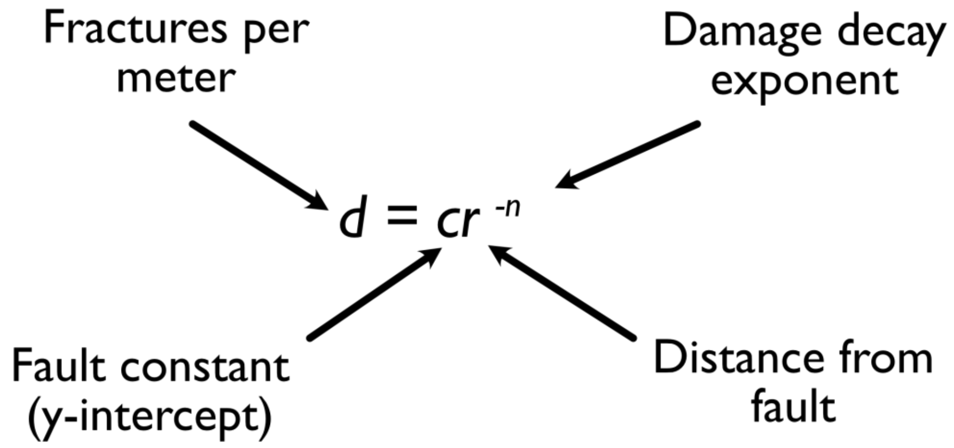
- Systematic study conducted on damage zone to analyze fracture density with proximity to fault core
- 8 drill holes studied
- Density is averaged to fractures / meter

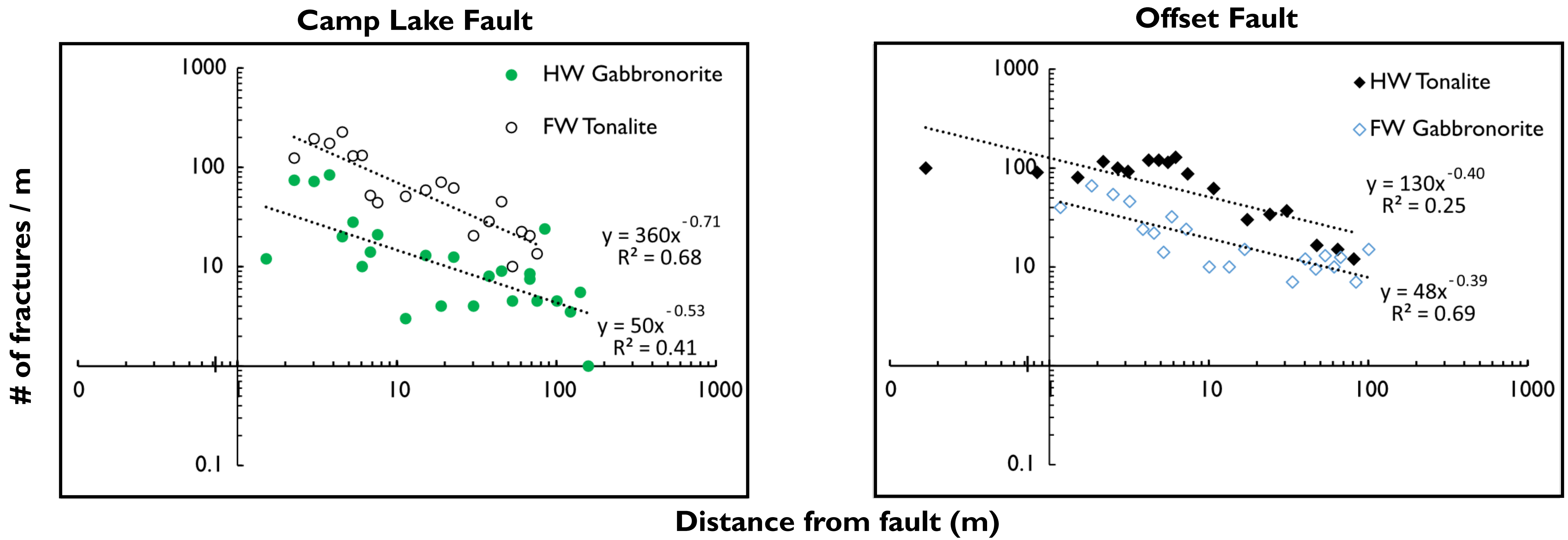


Fracture Density

- Plotted in log-log space to observe what type of trend is seen in the data

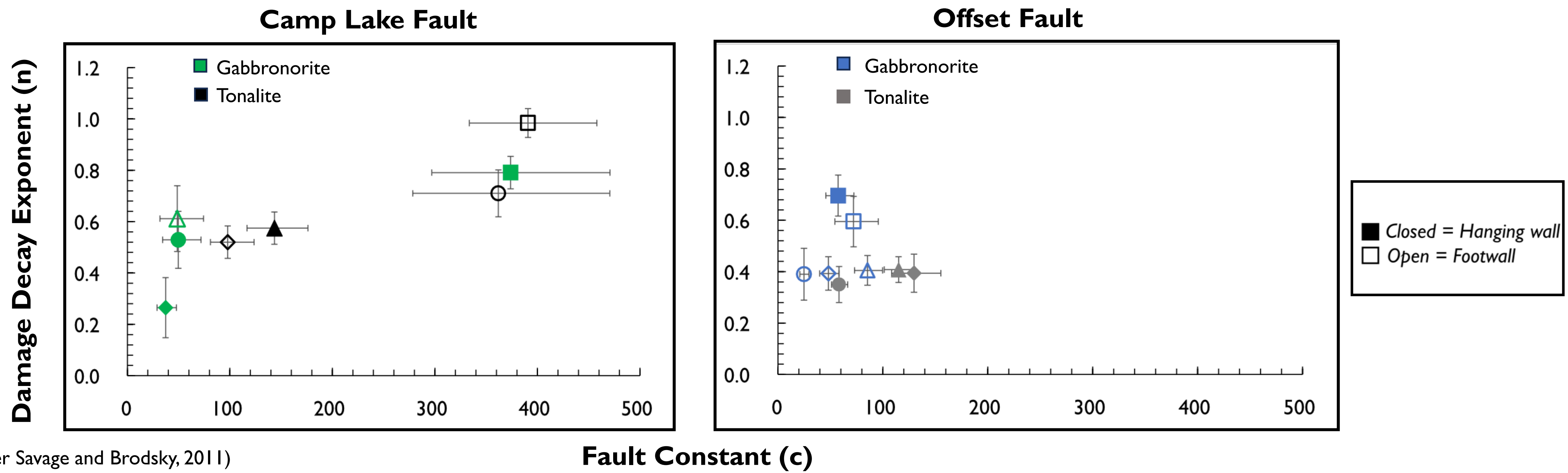
- To quantify the damage decay exponent, we fit a power law to the data as a function of distance from the fault ($d = cr^{-n}$)





Fracture Density

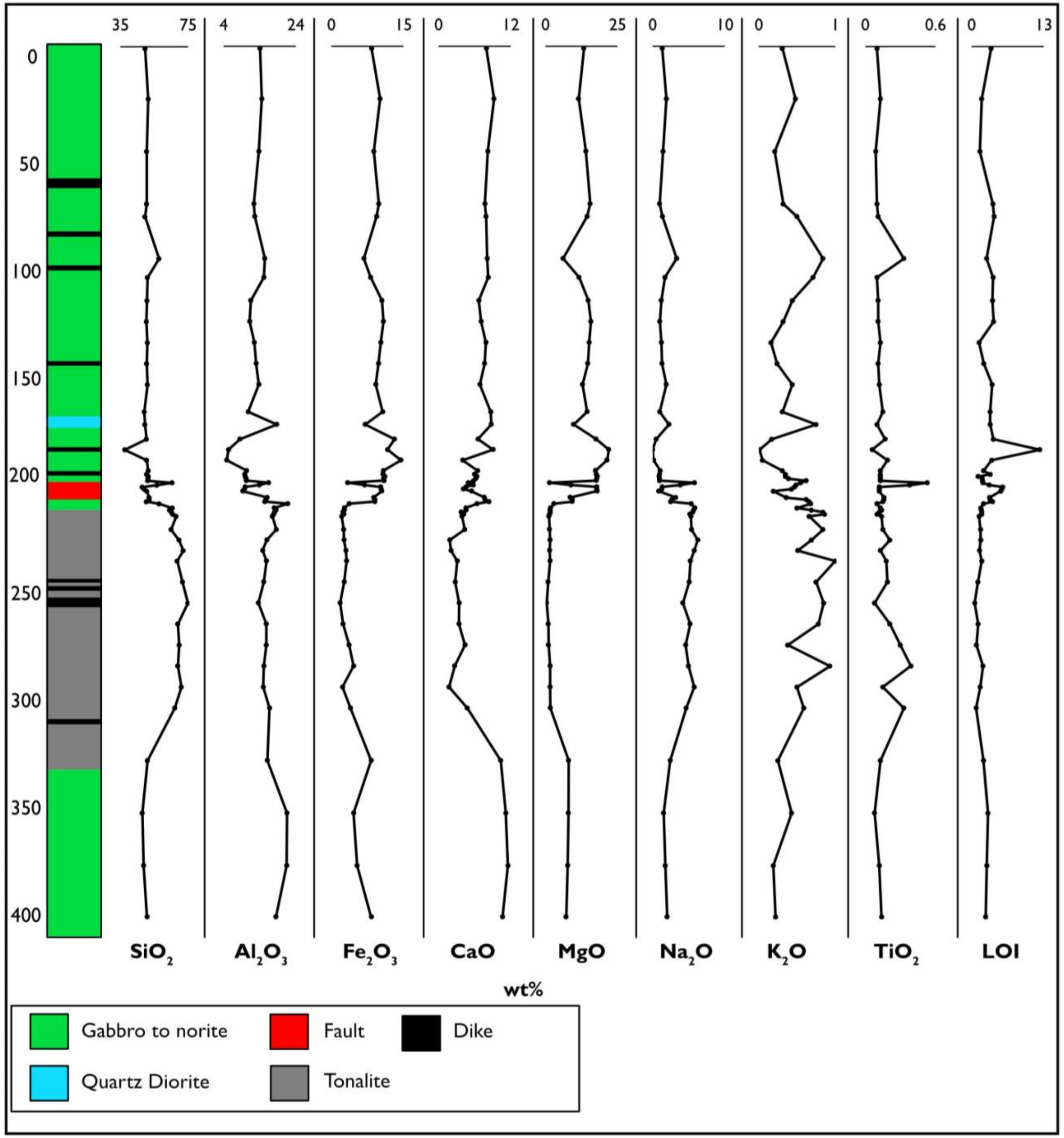
- All drill holes, within error, display a larger damage decay exponent in tonalites than the gabbronorites
- Takeaway being that tonalites decay at a faster rate than the gabbronorites



(After Savage and Brodsky, 2011)

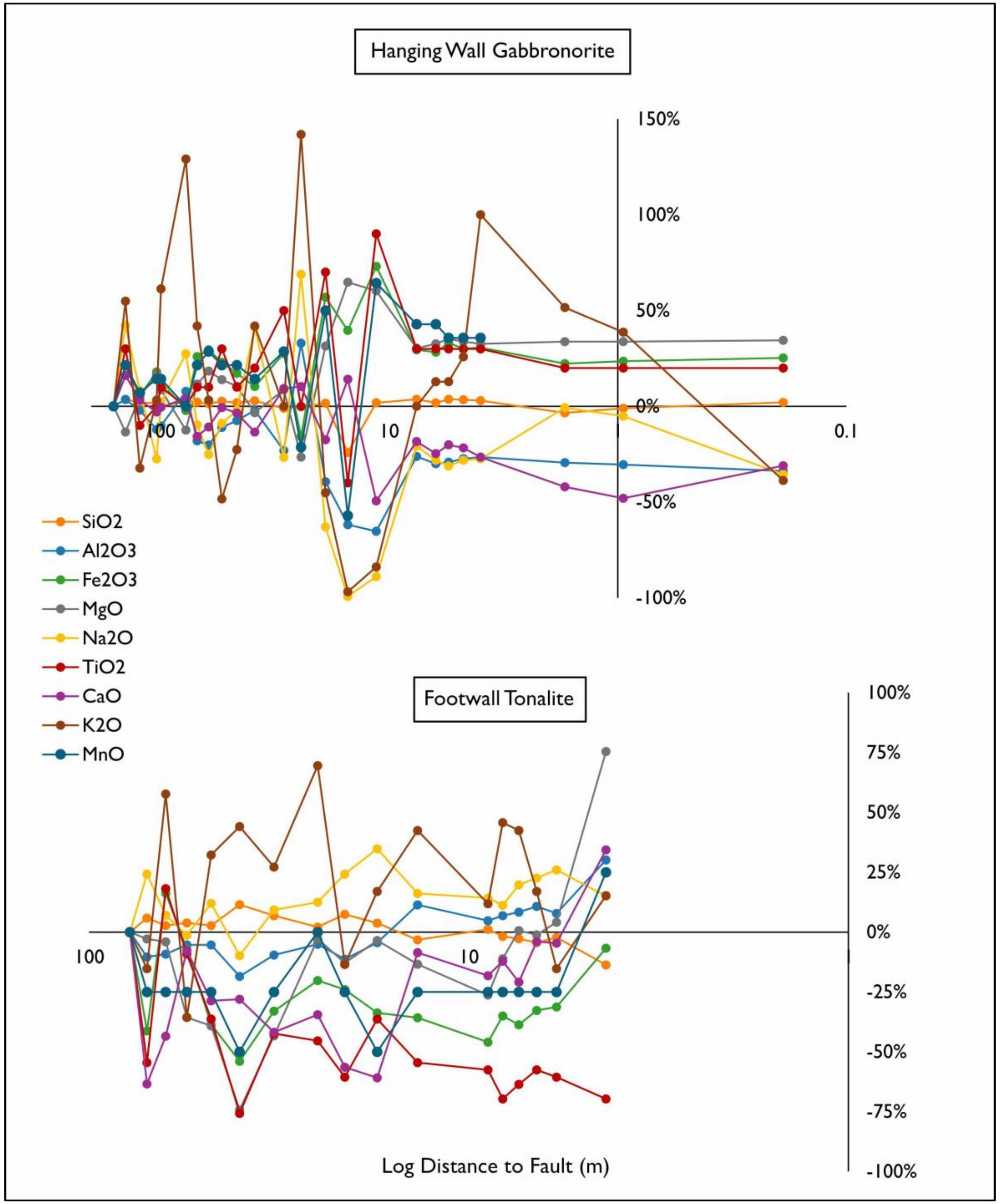
Geochemistry

- Downhole plots display that the greatest variation in major element oxides are observable in the damage zone (~180m)
- Following the expected trend as observed in fracture density data
- As expected, elements such as Na and K are mostly variable in tonalites



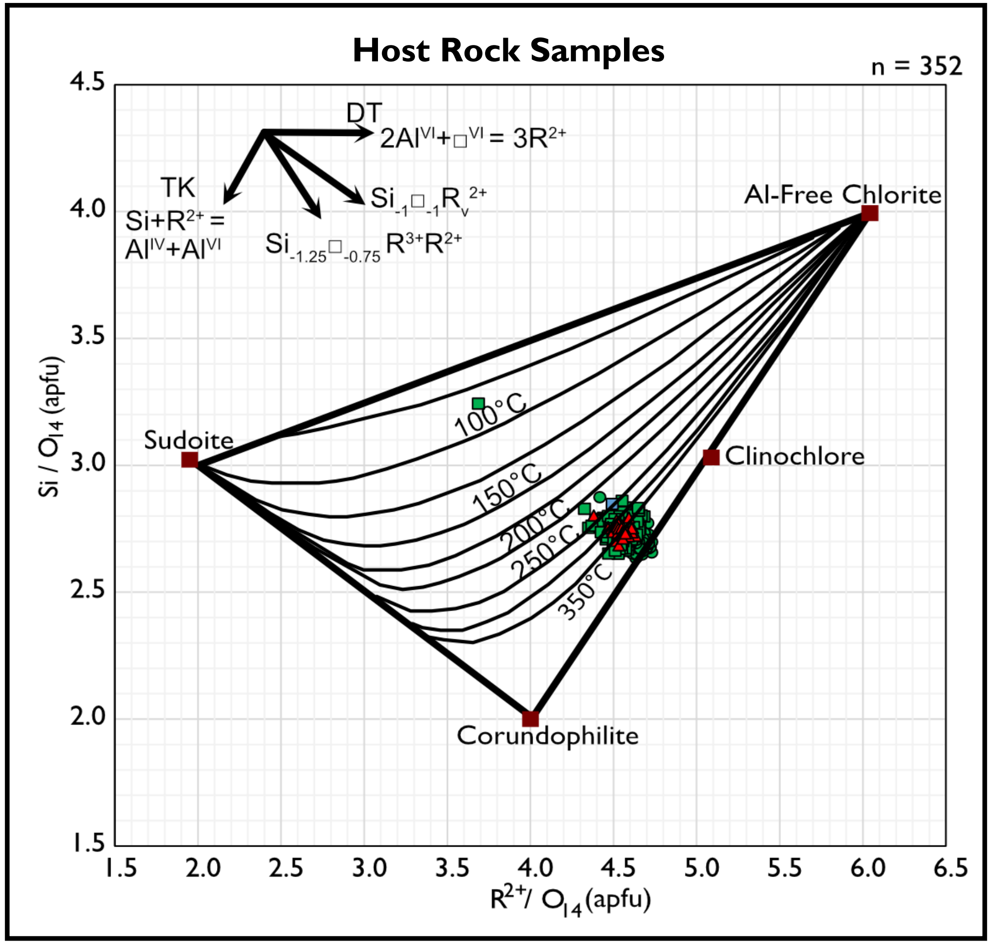
Alteration Geochemistry

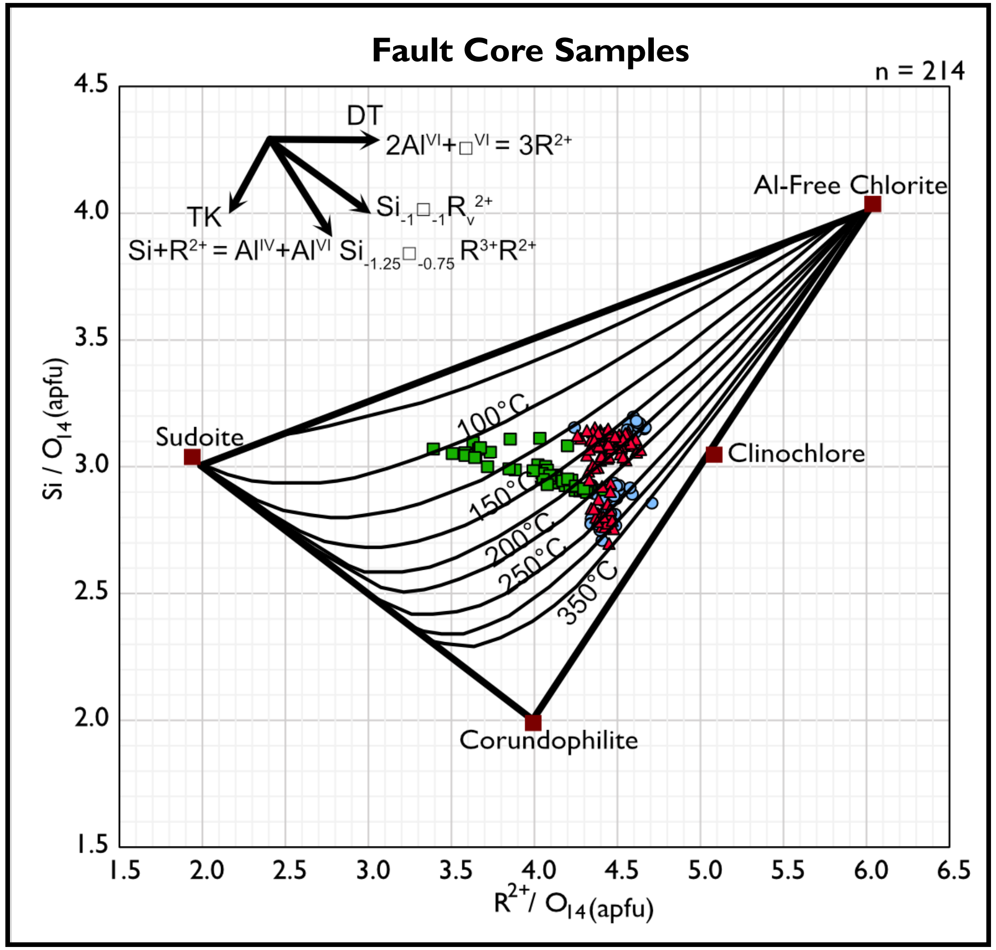
- Alteration plots exhibit percentage change referenced to the most distal (least altered) sample
- Gabbronorites show positive concentration changes in SiO_2, TiO_2, MnO, MgO, and Fe_2O_3, and average losses in CaO, Na_2O, and Al_2O_3
- Tonalites exhibit relatively consistent SiO_2 and Na_2O, enriched K_2O, and negative Al_2O_3, TiO_2, CaO, MgO and Fe_2O_3



Chlorite Thermometry

- Host rock chlorite range from >350 C° to 250 C°
- Fault core chlorite appears to form at 200 C°, with late meteoric chlorite at 100 C° to 200 C°





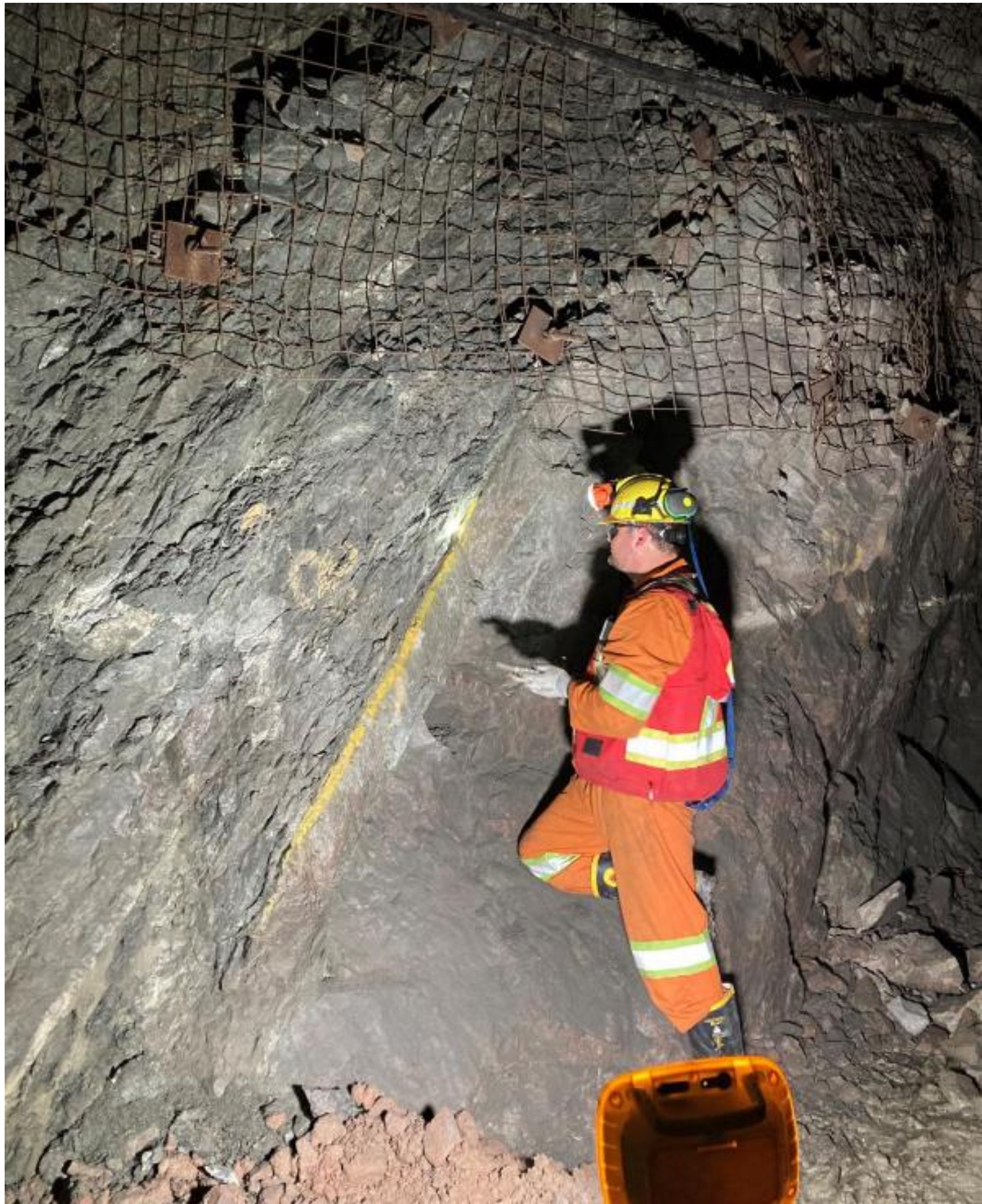
(Wiewiora & Weiss, 1990; Bourdelle and Cathelineau, 2015)

What does this mean?

1. Late faulting and fluids likely remobilized Pd during faulting

2. Fault zone structure varies a great deal with respect to protolith

3. Chlorite precipitation in the fault core likely resulted in the impeded development of a wider damage zone in the gabbronorites



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Questions?

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