Basement to surface expressions and critical factors in the genesis of unconformity-related deposits

Eric Potter[1] and TGI-4 researchers[2]

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Targeted Geoscience Initiative 4 (TGI-4)

TGI-4 is a ***collaborative*** federal geoscience program that provides industry with the ***next generation of geoscience knowledge and innovative techniques***, which will result in more effective targeting of buried mineral deposits.

TGI-4 Uranium Collaborations

TGI 4 Ore Systems

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TGI-4 Uranium

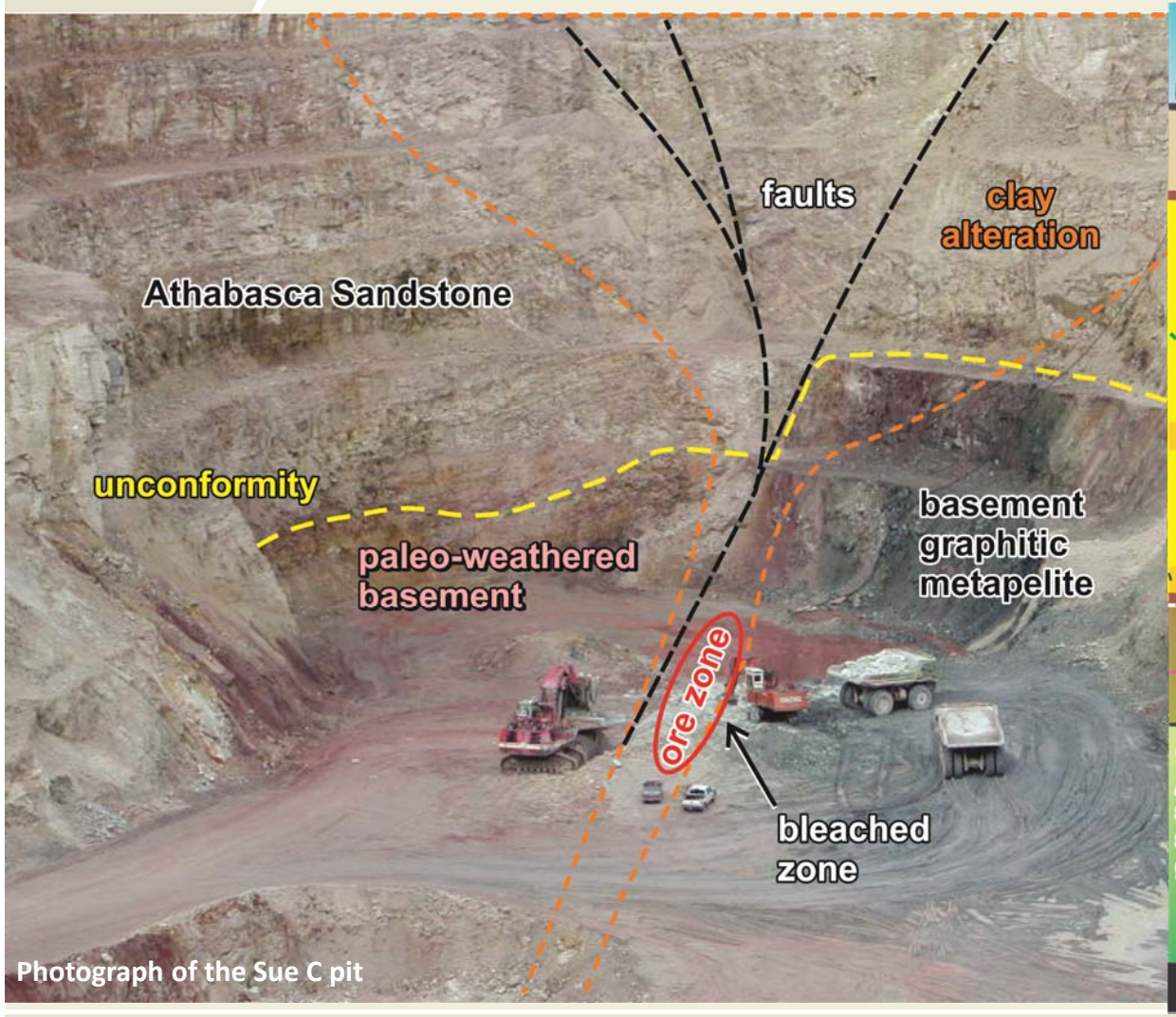
TGI 4 Ore Systems

Two subprojects:

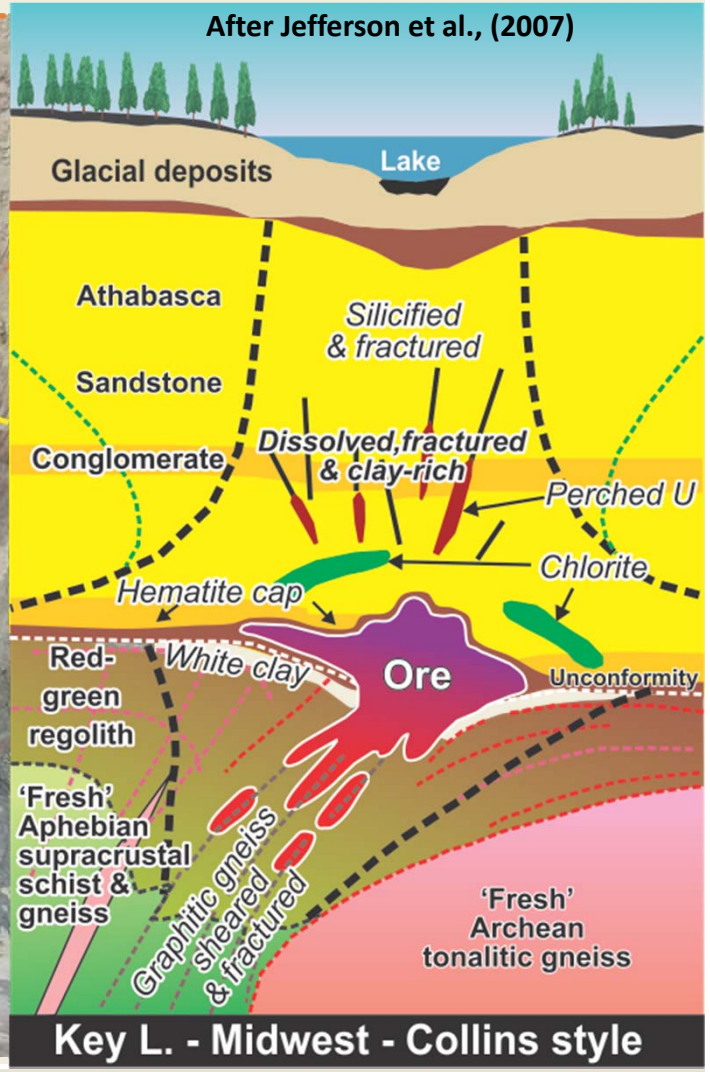
1) **Basement to surface expressions of deep mineralization and refinement of critical factors leading to the genesis of <u>unconformity-related</u> uranium deposits; and**

2) **Recognition of uranium ore system alteration signatures in complex terranes: IOCG vs albite-hosted uranium vs volcanic-hosted uranium.**

TGI-4 Uranium: unconformity-related systems



Photograph of the Sue C pit



TGI-4 Uranium

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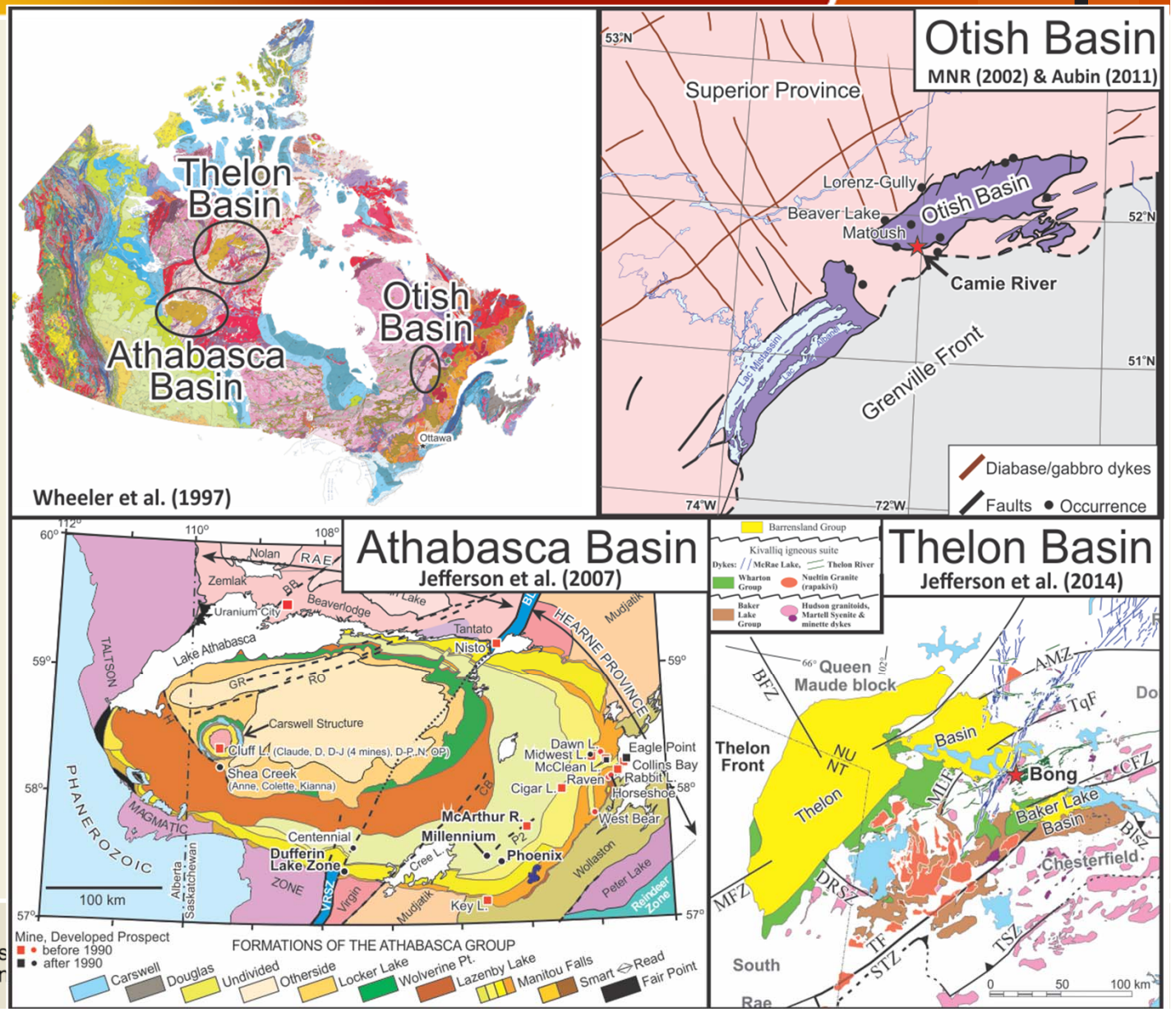

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TGI-4 Uranium

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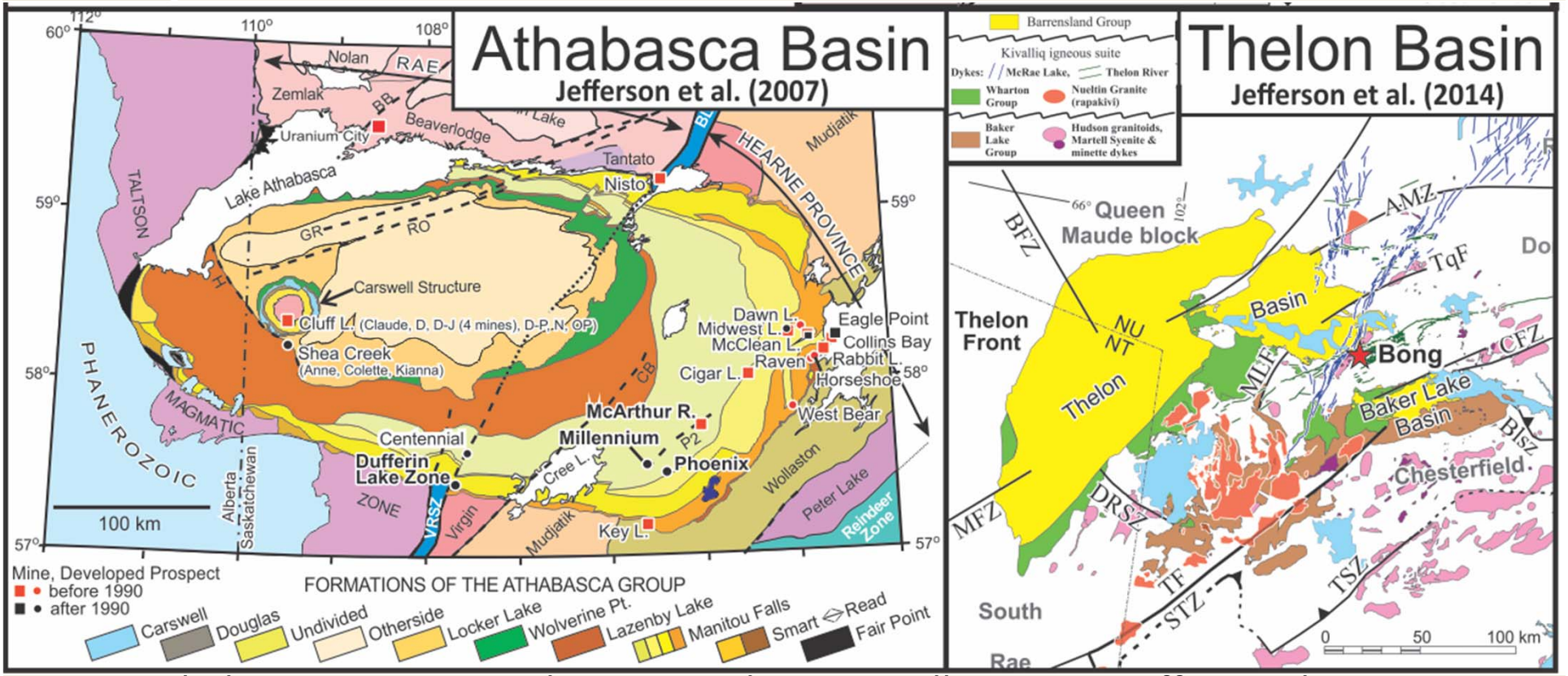


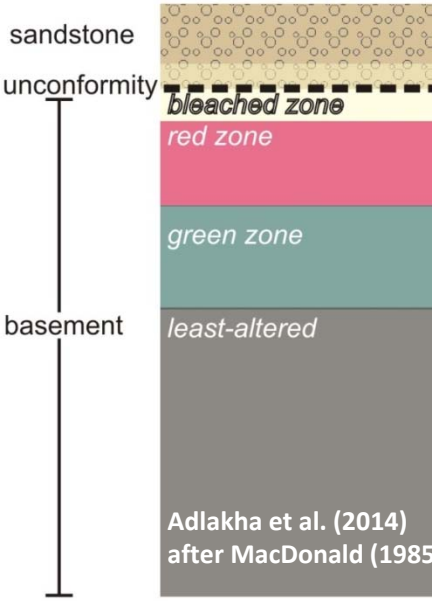
Athabasca sites: McArthur River, Phoenix, Millennium, Dufferin Lake.

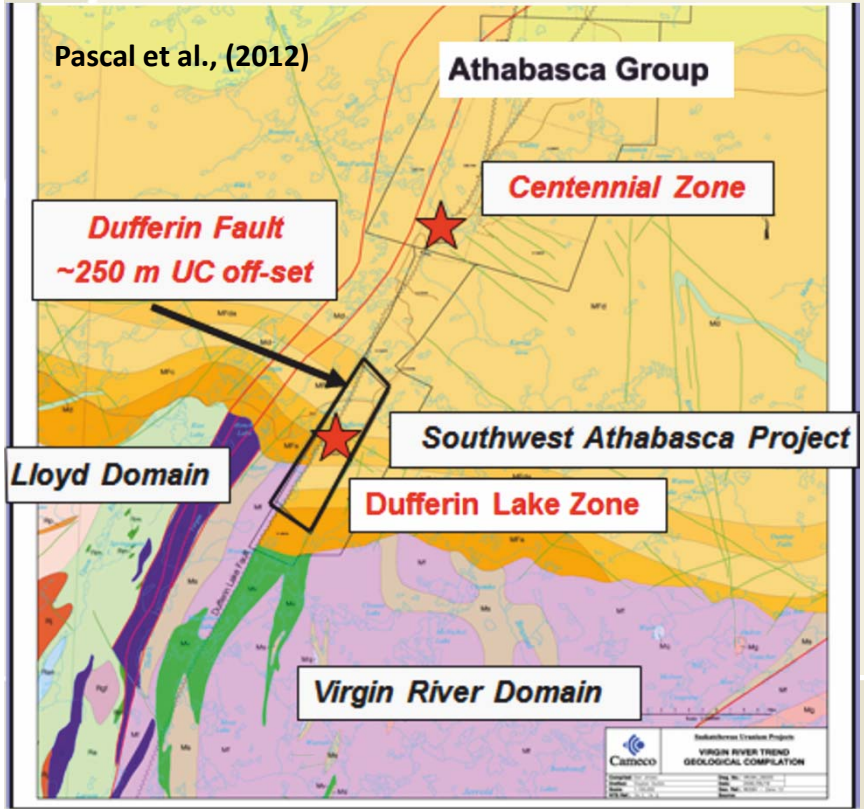
Thelon: Bong

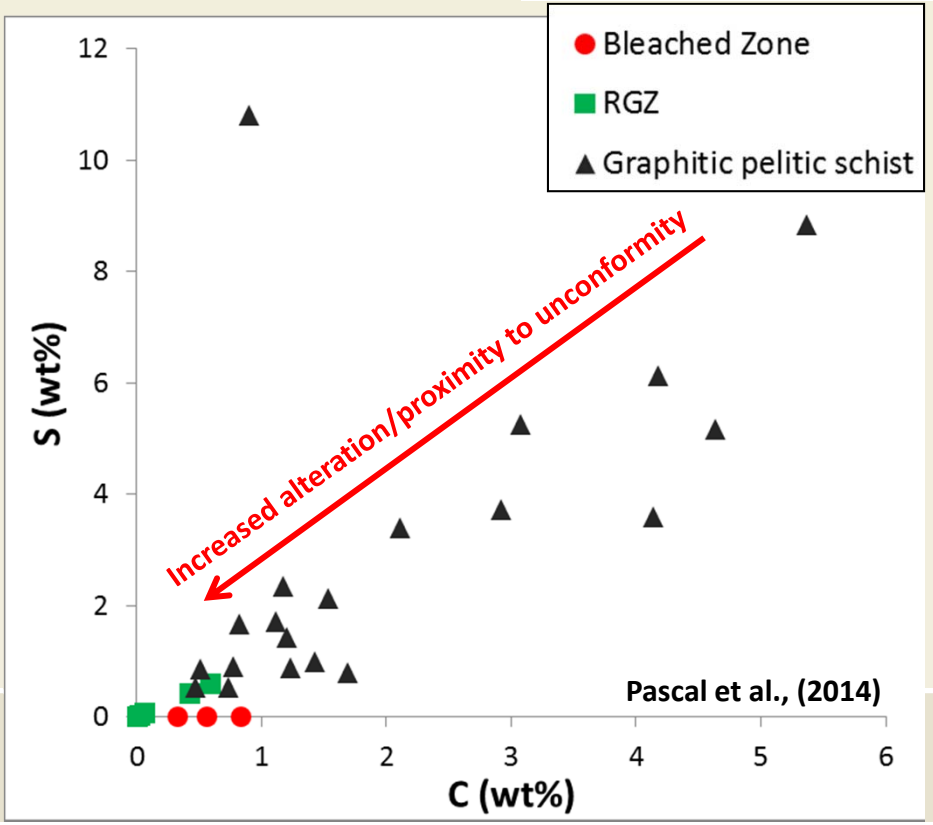
Graphite-depletion in basement rocks at the Dufferin Lake Zone

Marjolaine Pascal, Kevin Ansdell, Irvine Annesley

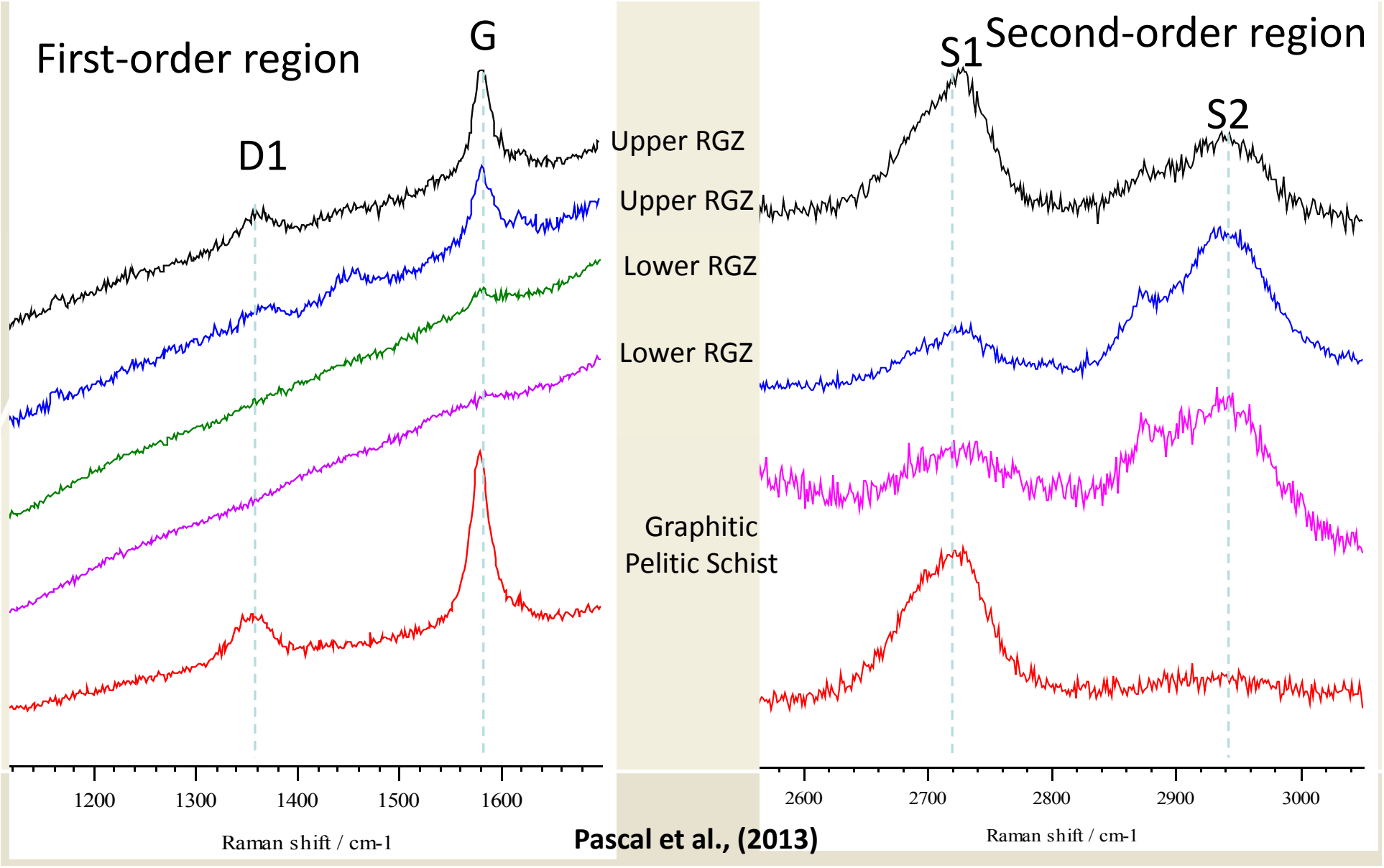
- Dufferin Lake zone, South of Centennial deposit.
- Presence of graphite-depleted rocks immediately below the mineralized zone.
- GSC Open File# 7258, Goldschmidt 2012, 2013 & SGA 2013



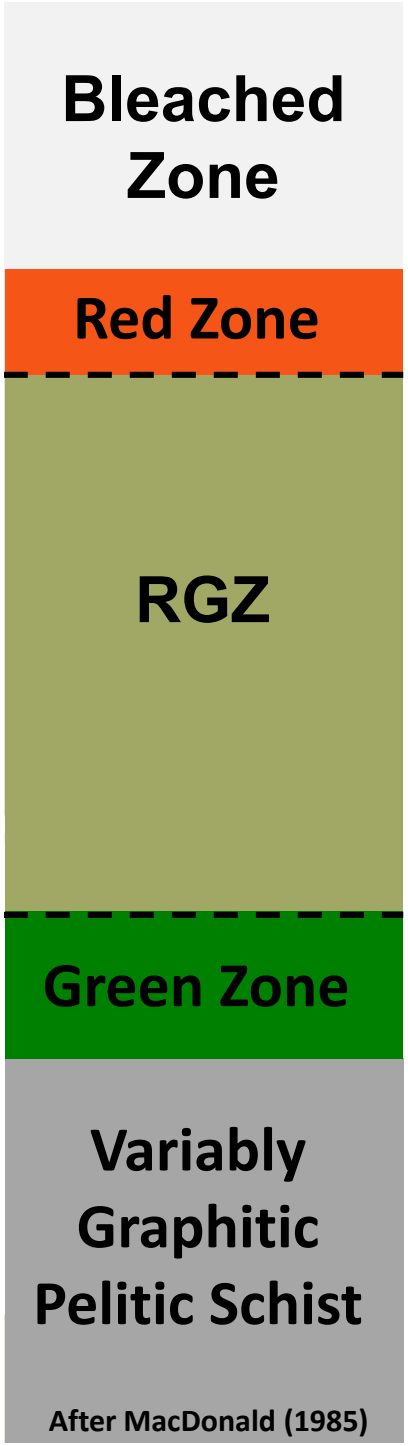




Different Raman spectra of carbon species in the different zones at Dufferin Lake



Pascal et al., (2013)



- No recognized carbon species (C & S consumption/depletion)
- Most highly altered with enrichments in Al, Na, K, B, and U
- Quartz and hematite dissolution, dravite formation
- Important fluid-rock interactions

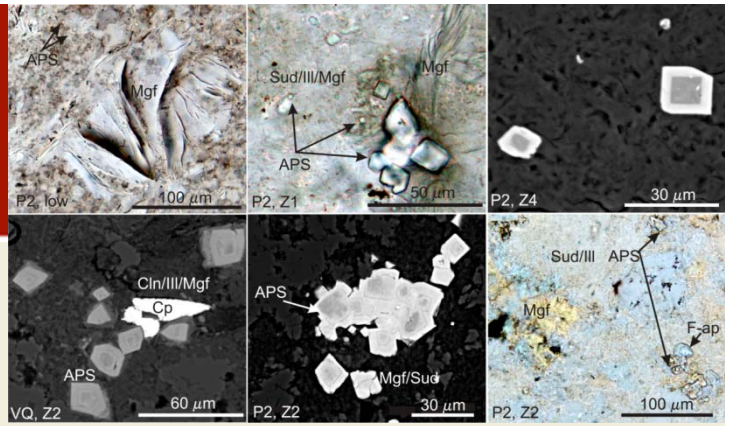
- Variable loss of carbon (+ sulfide) confirmed macroscopically, petrographically, and geochemically
- Carbon species present, but in very low quantities
- Mainly amorphous carbon
- Similar major element composition with the graphitic pelitic schist
- Quartz ± hematite overprint the original fabric, and may be linked to the loss of graphite (exact timing unknown)
- Evidence for 2 brines:
  - The regional basinal fluid (Na-Ca-Mg brine)
  - An evolved brine possibly related to U mineralization (Na-Ca-Mg-Li brine)

- No fresh rocks (variably retrograded)
- Different kinds of mainly well-ordered carbon species
- Monophase vapor FI - Could be generated by the breakdown of graphite to **CH_4** and associated feldspars/micas to **NH_4** and **N_2/H_2**

<u>Three possible reductants for uranium precipitation</u>

Alteration along the P2 fault, McArthur River Deposit

Erin Adlakha, Keiko Hattori, Gerard Zaluski, Tom Kotzer, Eric Potter



APS=aluminum phosphate sulphate minerals

- Alteration similar to ore zone: sud ± ill, Mgf (magnesiofoitite), APS
- Spatial association and similar chemistry along the P2 suggests that APS plus Mgf were contemporaneous & formed by uraniferous oxidizing fluid – APS also contain trace amounts of U-
- Suggests the P2 fault it was conduit for uraniferous fluids
- However, the fluids did not form U deposits all along the P2.....the deposits required interaction with focused reduced media to precipitate uraninite.

GSC Open File Reports: 7365, 7462 (in press), Goldschmidt 2013, SGA 2013, GAC-MAC 2014

Iron and Magnesium isotopic signatures related uranium precipitation processes

Two components:

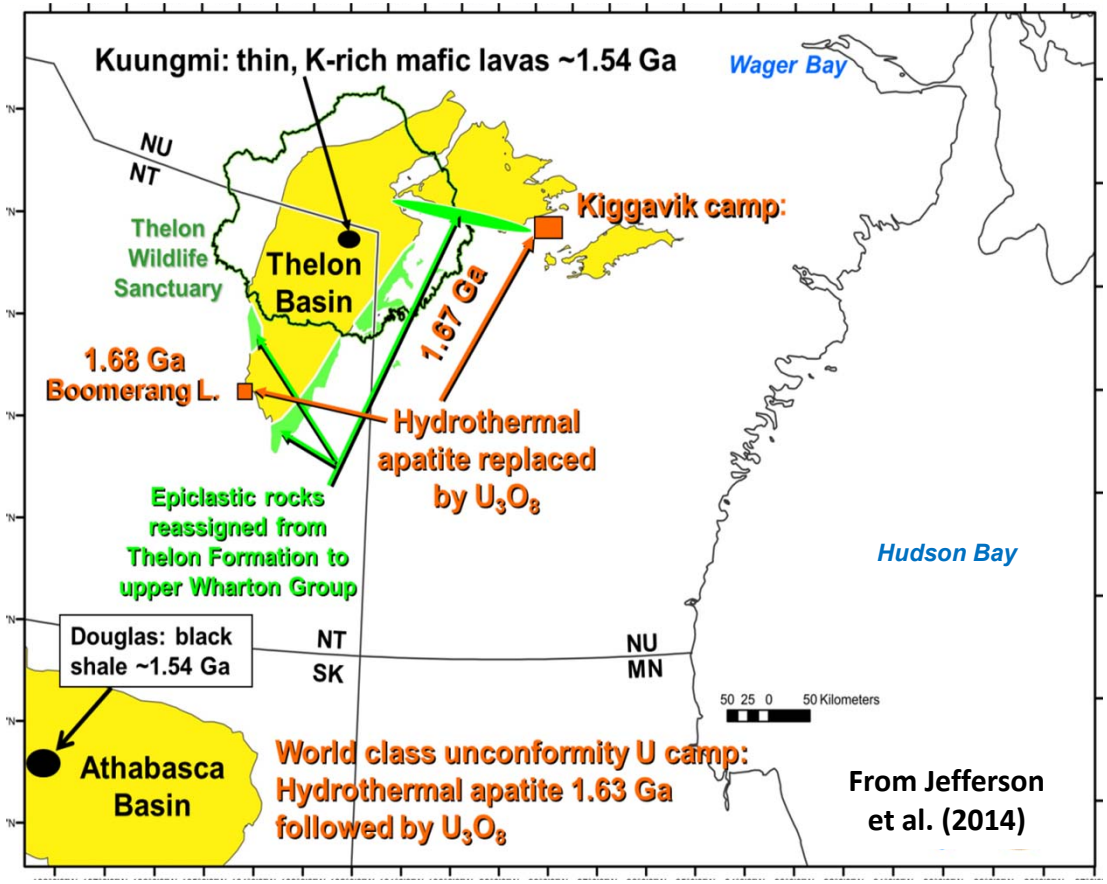
a) whole rock and clay-size fractions (Bong & McArthur River deposits; Potter et al.)

b) Clay (chlorite) fractions (McArthur River deposit; Kyser et al.)

Fractionation is temperature dependent and strongly influenced by redox reactions (cf. Dideriksen et al, 2010; Hill et al, 2010; Liu et al, 2010; Teng et al., 2010).

As a result, there is potential for distinct populations that reflect weathering, diagenetic, and hydrothermal/redox origins.

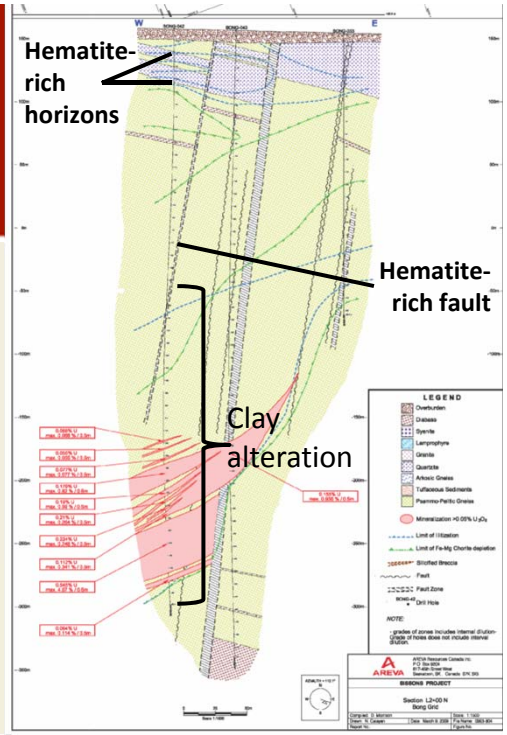
Outputs: Potter et al., GAC-MAC 2014; open file *in press*, Kyser et al., open file *in prep.*

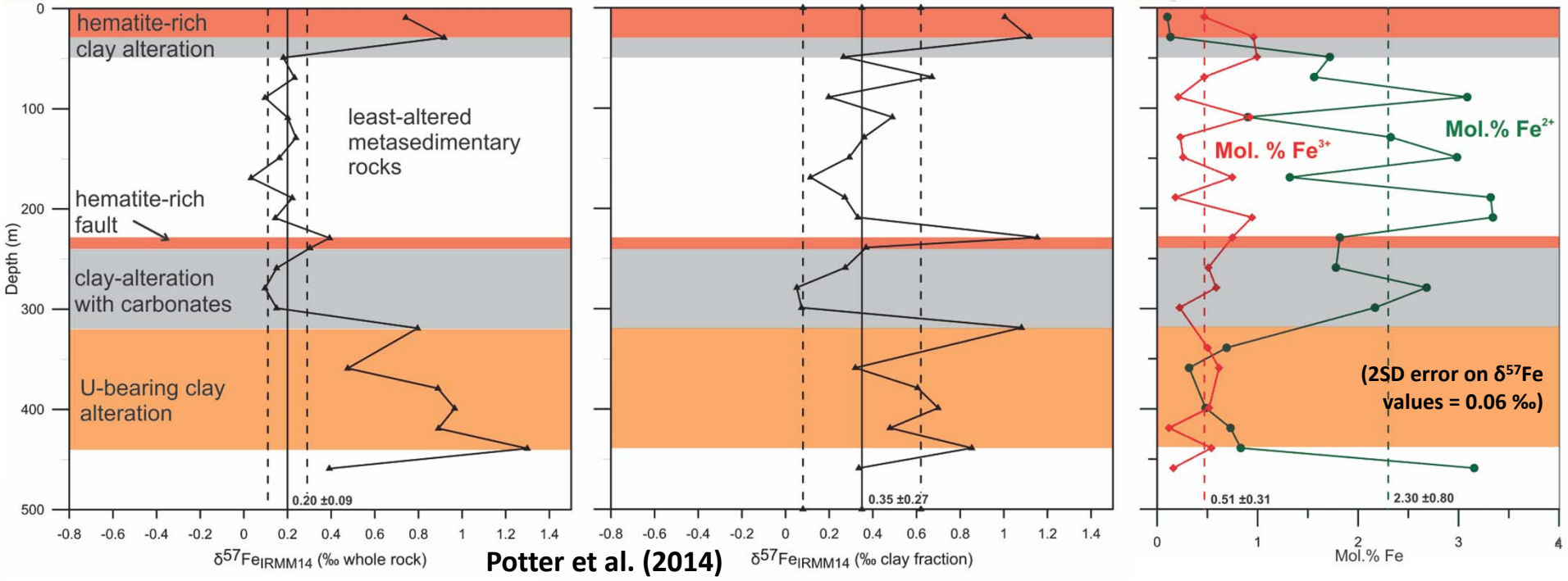


Whole-rock Fe & Mg isotopes: Bong deposit

Eric Potter, Ryan Sharpe, Isabelle Girard, Mostafa Fayek, David Quirt, John Robbins

- Elevated $\delta^{57}Fe$ values associated with the U-bearing clay alteration and hematite-bearing horizons - correlate with relatively **losses in Fe^{2+}**
- Whole-rock vs clay fractions: Fe isotopic shifts in hematite-rich horizons dominated by clay-size fraction **– low vs. higher temperature processes**

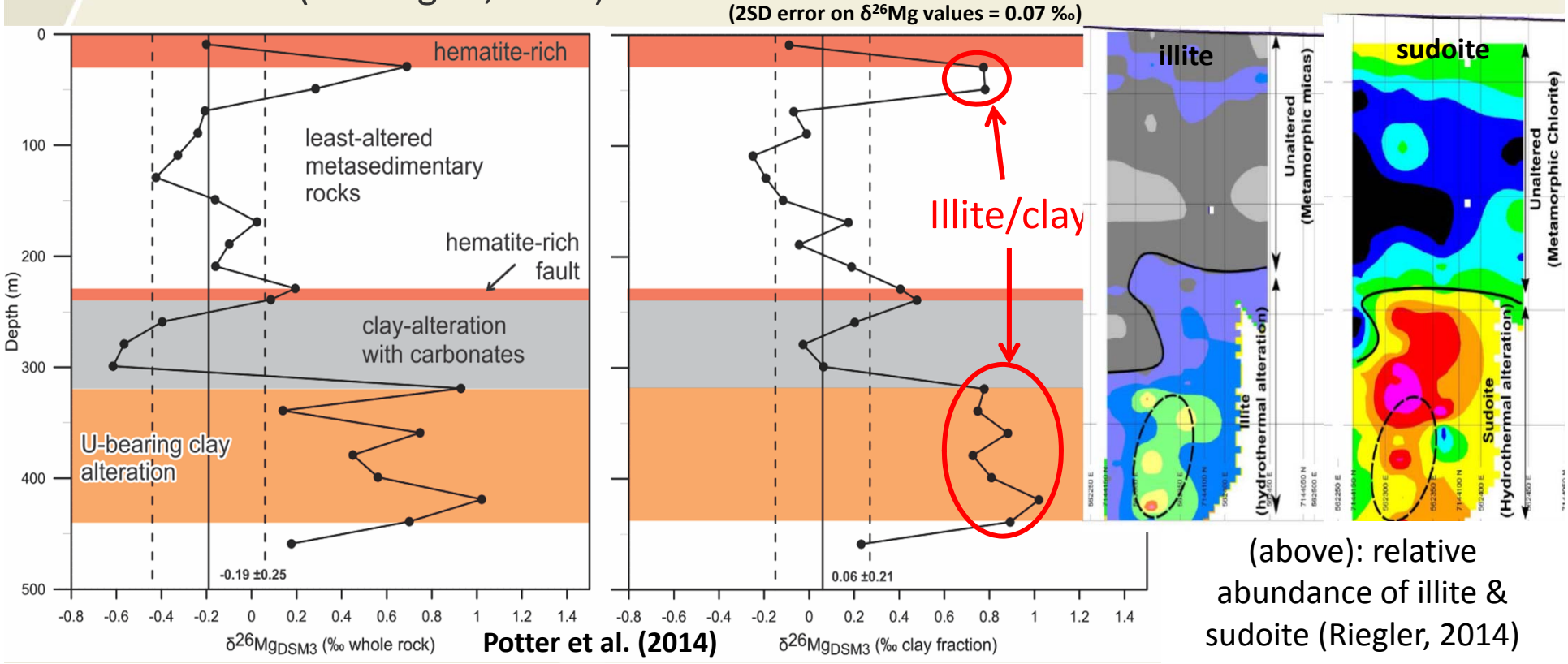




Potter et al. (2014)

Whole rock Mg isotopes: Bong deposit

- Elevated $\delta^{26}Mg$ values associated with the U-bearing clay alteration and the lower unit of the upper hematite-bearing horizons - reflecting presence of illite-rich alteration (cf. Wimpenny et al., 2014).....
- However, clay-altered zone above the U-bearing clay alteration yielded negative values, which may reflect presence of carbonate minerals or relative sudoite-chlorite abundances (cf. Riegler, 2014)

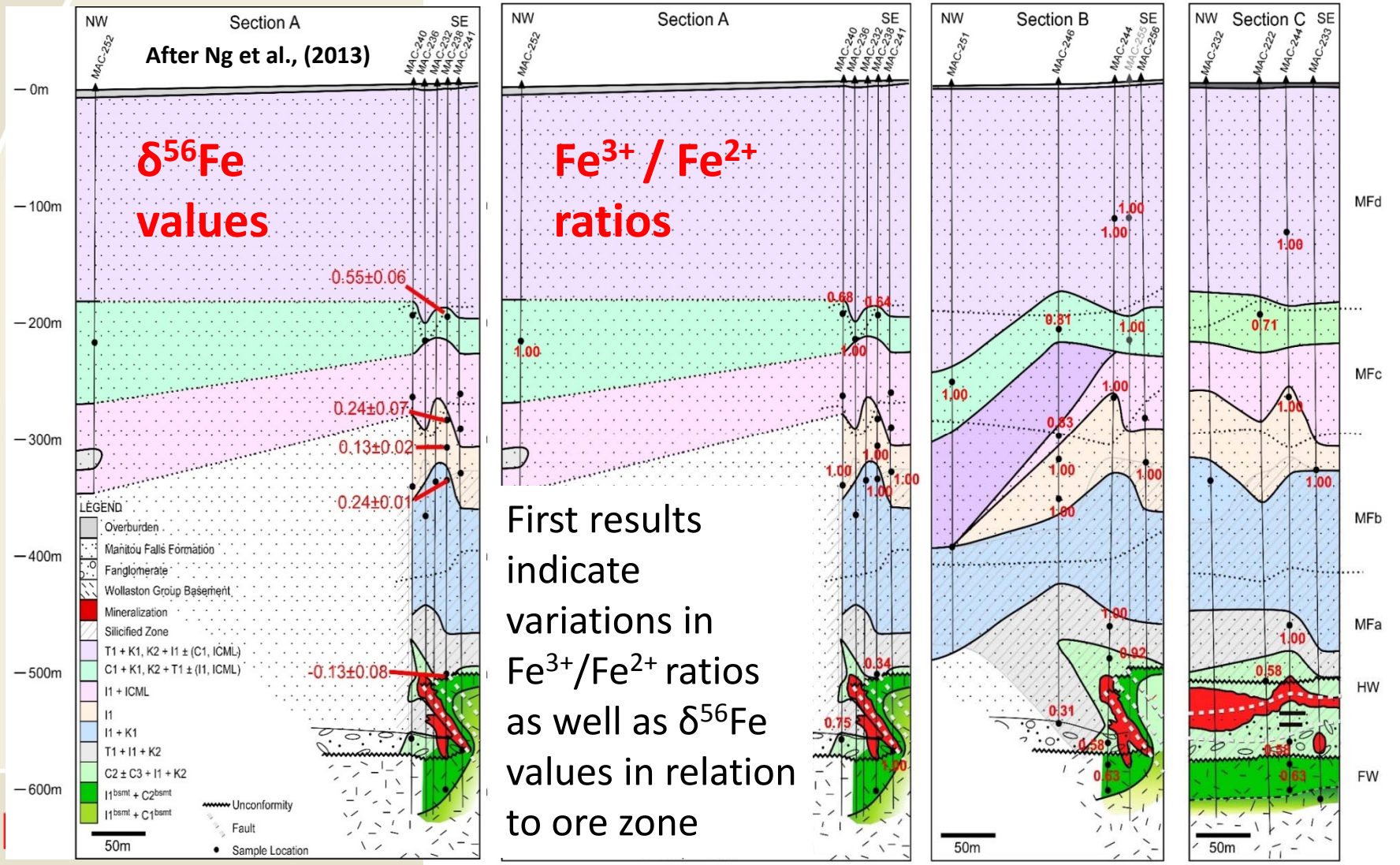


Potter et al. (2014)

(above): relative abundance of illite & sudoite (Riegler, 2014)

Fe and Mg isotopic composition of clay minerals from McArthur River

Kurt Kyser, Andrés Acevedo, Urmidola Raye, Don Chipley



First results indicate variations in Fe^{3+}/Fe^{2+} ratios as well as $\delta^{56}Fe$ values in relation to ore zone

Geochemical Anomalies in host rocks: Phoenix Deposit

Jack Dann, Keiko Hattori, Eric Potter, Chad Sorba

- Elevated concentrations of U, B, Pb and, Ni, Co, Cu, As, Y and REEs in sandstones over 400 meters above the uranium deposit and along the WS shear zone at the Phoenix Deposit.
- Y (+HREE) & W show vertical chimneys from deposit to the surface
- **GSC Open File Reports: 7366 & 7463**

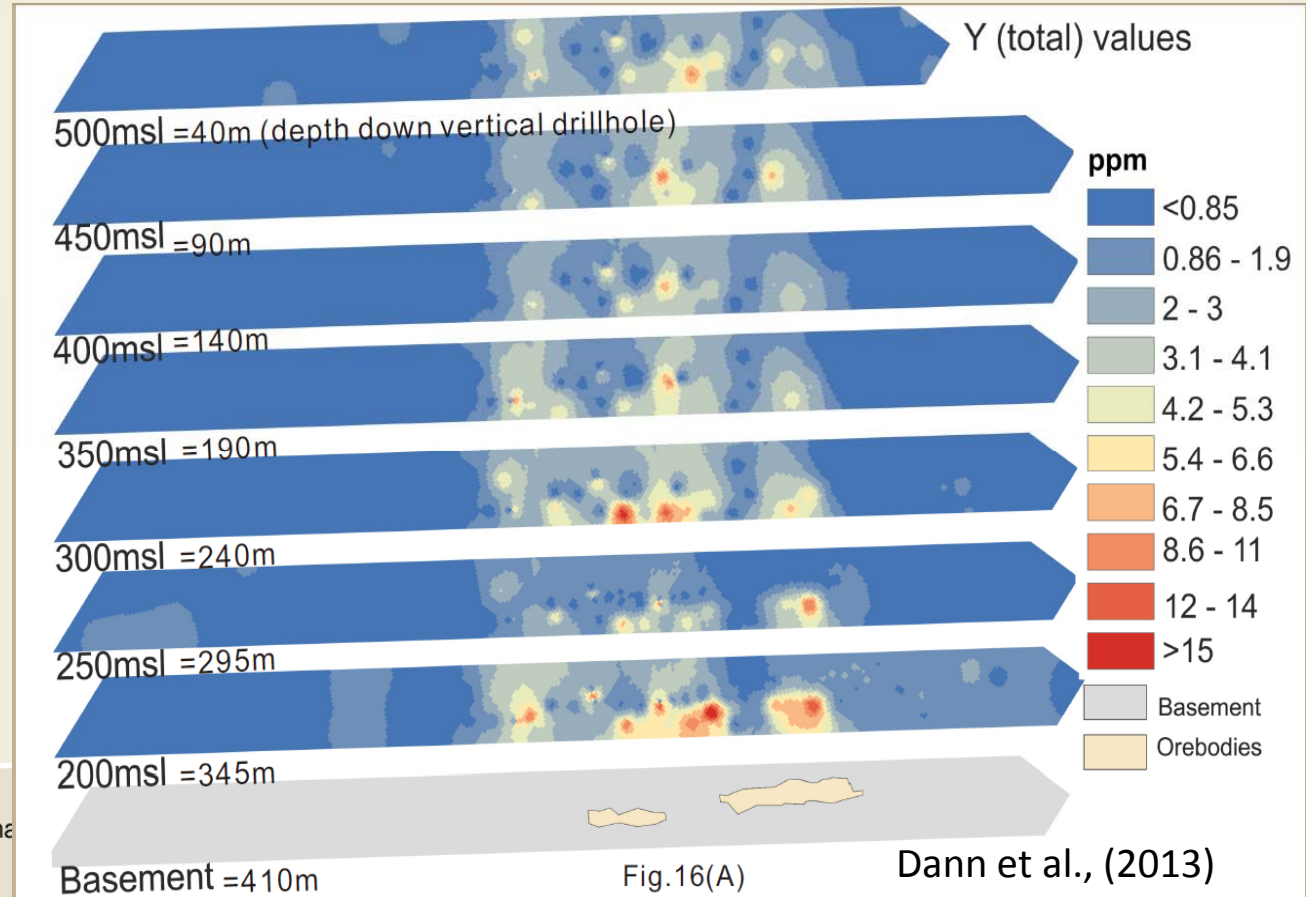


Fig.16(A)

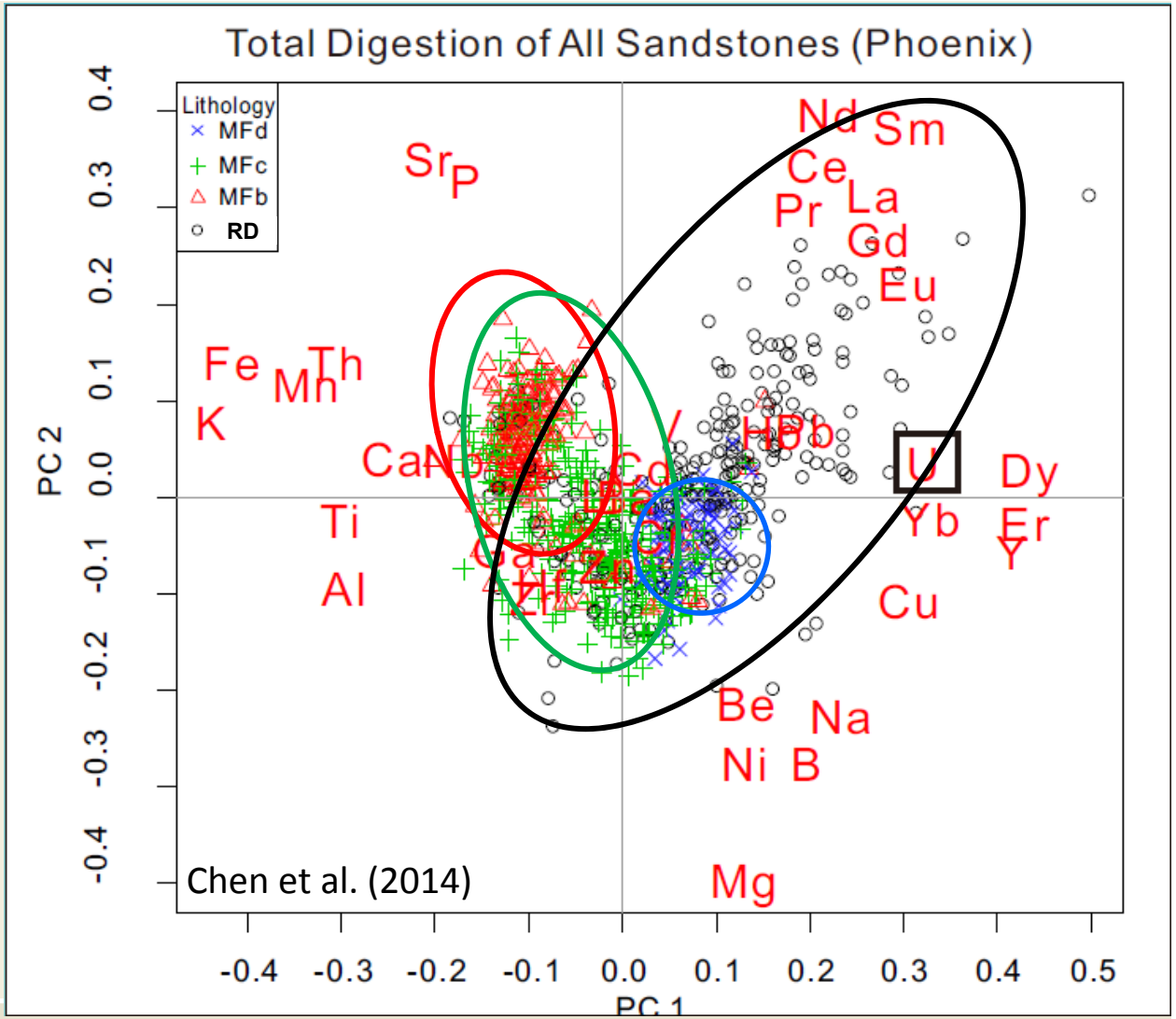
Dann et al., (2013)

Elemental assemblages in Athabasca Group sandstones, Phoenix Deposit

Chris Chen, Keiko Hattori, Eric Grunsky

- Elemental associations:
  - LREE
  - U, HREE
  - B, Na, Ni, Mg
  - Sr, P
  - K, Fe, Mn Th
- Each Member/ Formation has unique signature

GSC Open File Report 7578



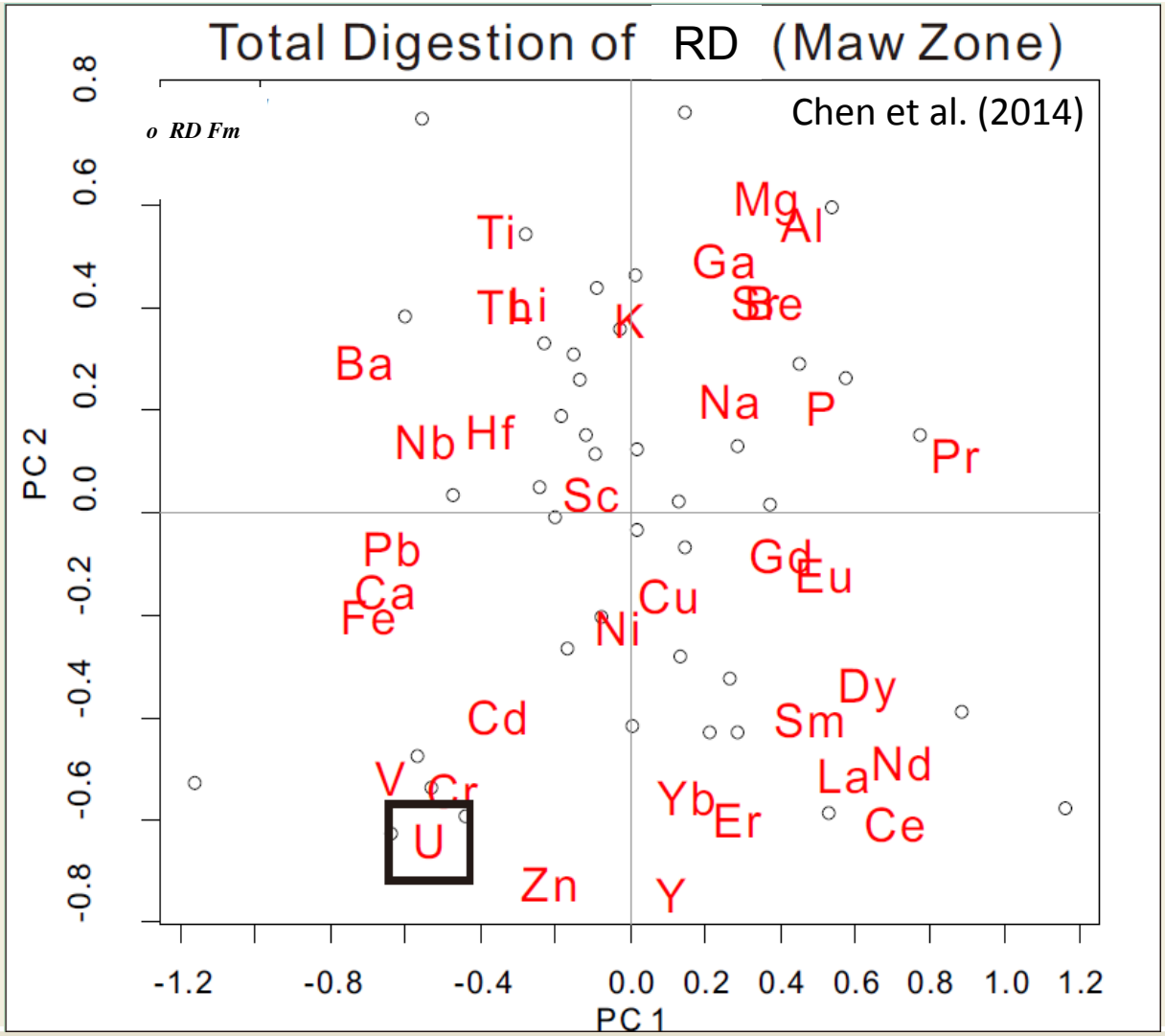
Elemental assemblages in Athabasca Group sandstones, Maw Zone

Maw Zone: REE-bearing breccia with no significant U, ca. 6 km SW of the Phoenix deposit.

Different element associations reflecting difference processes.

Correlation between U, Fe, V, Cr = oxidizing fluids were U-bearing, but no efficient reductants

GSC Open File Report *in press*



Distal Expressions of buried U systems

Donald Wright, Eric Potter

TGI 4 Ore Systems

Peridot Geoscience Ltd.

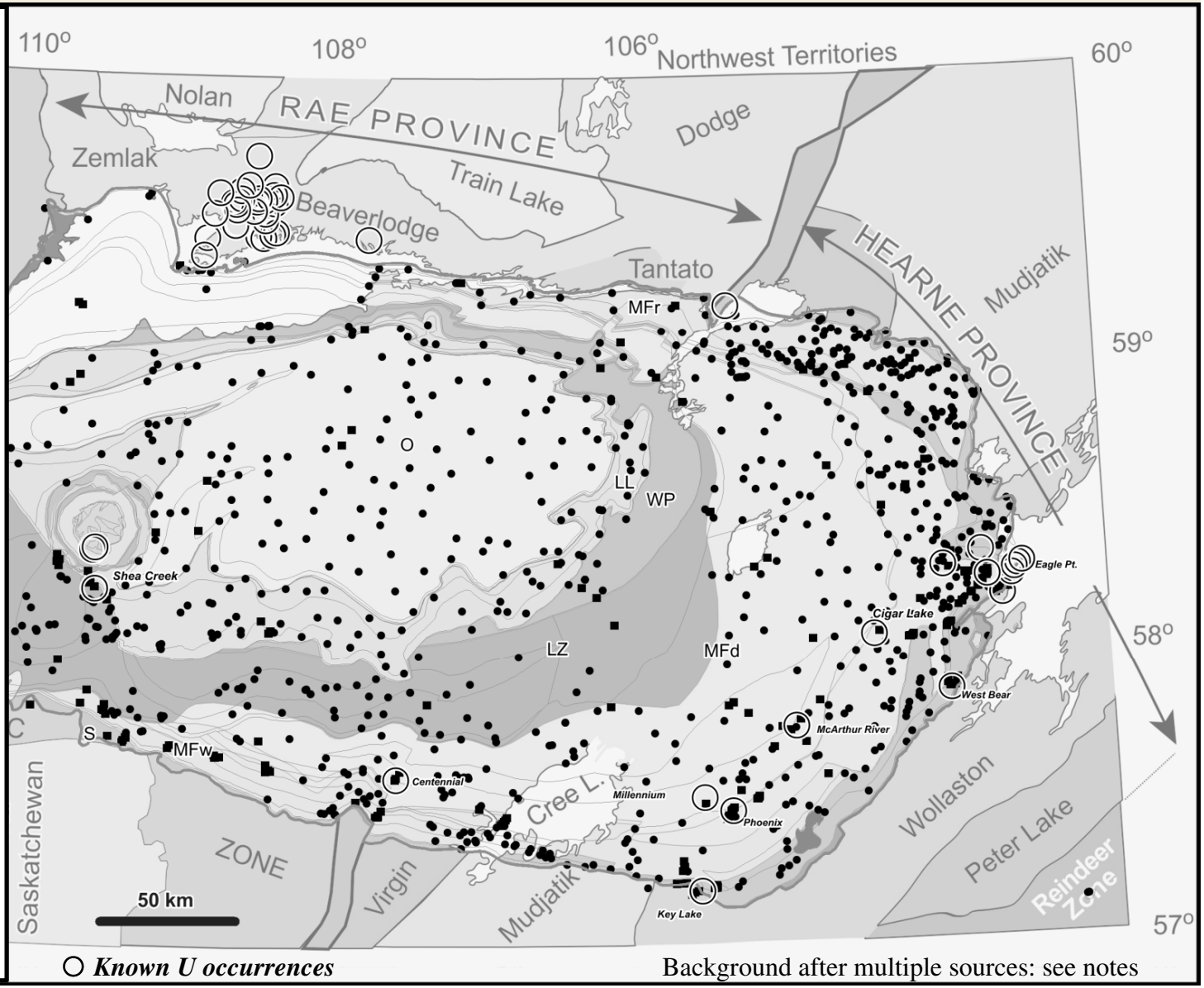
A compilation of geochemical sampling over the Athabasca Basin to encourage examination of regional signatures.

Sources:

- Saskatchewan Geological Survey Data File Publications
- Saskatchewan Mineral Assessment Database Files

Contents:

- 30,256 Samples
  - 50% Athabasca Group
    - 50% Basement
- **Digestions:**
  - Partial Digest
  - Total Digest
- **Analyses**
  - ~ 50% U + select elements
  - ~ 50% Multielement
- **Metadata include:**
  - Spatial Coordinates
    - Company
    - Laboratory
    - Sample Lithology



Regional Surface Rock Geochemistry, Athabasca Basin, Saskatchewan

GSC Open File Reports: 7495 & 7614

TGI 4 Ore Systems

Peridot Geoscience Ltd.

Key Observations

1. Important geochemical signatures are recorded by the uppermost units across the basin

2. Geochemical signatures highlight lineaments and lineament intersections are loci for uranium mineralization

3. A regional hydrothermal U signature is also expressed in the Wolverine Point Fm.

Geochemical Signatures in samples <50 m depth

- U Enrichment
- Hydrothermal
- Distal

Lineament Extensions

- D_3 - 070°
- D_3 - 110°

After Portella & Annesley (2000)

○ ***Known U occurrences***

110° 108° 106° Northwest Territories 60° 59° 58° 57°

Nolan RAE PROVINCE Dodge Zemlak Train Lake Beaverlodge FP Tantato MFr HEARNE PROVINCE Mudjatik O D C LL WP LZ MFd S MFw Shea Creek Eagle Pt. Cigar Lake West Bear McArthur River Centennial Millennium MFc MFb Phoenix Key Lake Wollaston Peter Lake Saskatchewan ZONE Virgin Mudjatik Ry 50 km

Background after multiple sources: see notes

Regional Surface Rock Geochemistry, Athabasca Basin, Saskatchewan

GSC Open File Reports: 7495 & 7614

TGI 4 Ore Systems

Peridot Geoscience Ltd.

Key Observations

1. Important geochemical signatures are recorded by the uppermost units across the basin
2. Geochemical signatures highlight lineaments and lineament intersections are loci for uranium mineralization
3. **A regional hydrothermal U signature is also expressed in the Wolverine Point Fm.**

Geochemical Signatures

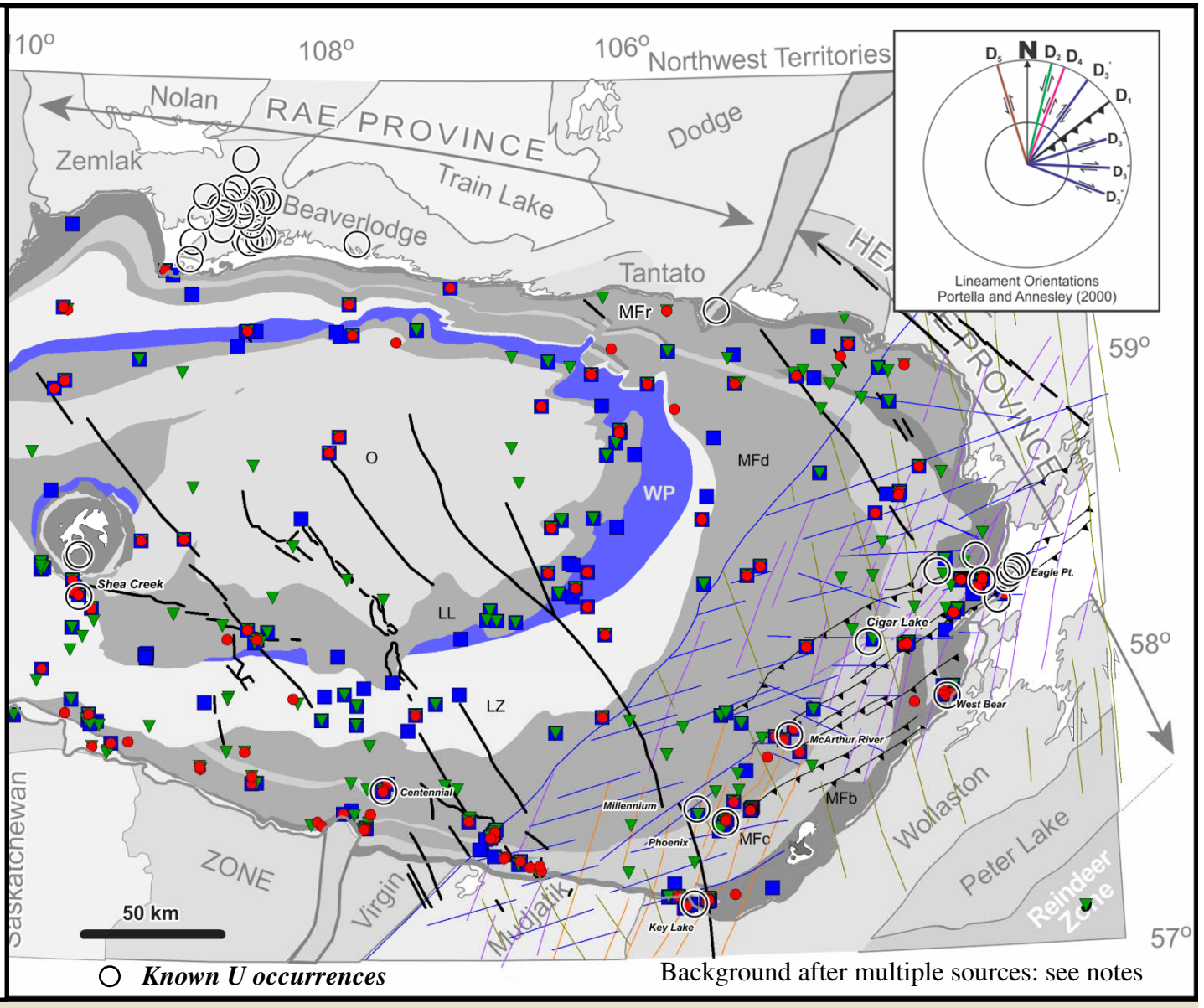
(Surface Samples (< 50 m)

- U Enrichment
- Hydrothermal
- Distal

Structural Features

After multiple references, see notes.

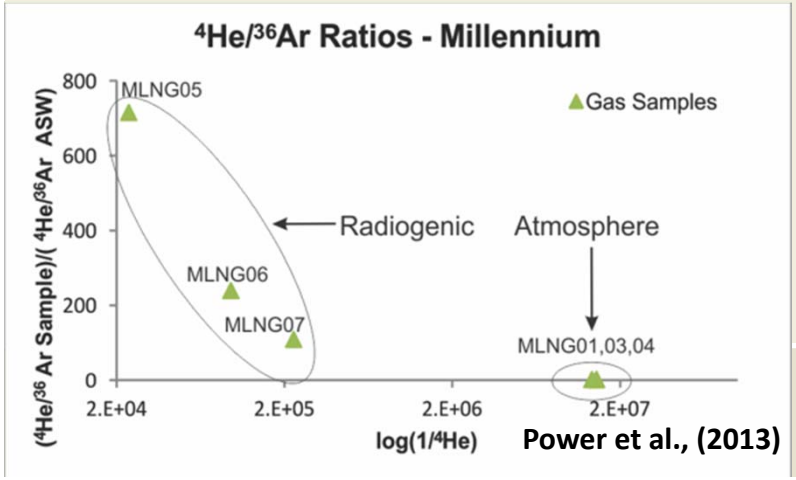
- Diabase dyke trace
- Lineaments



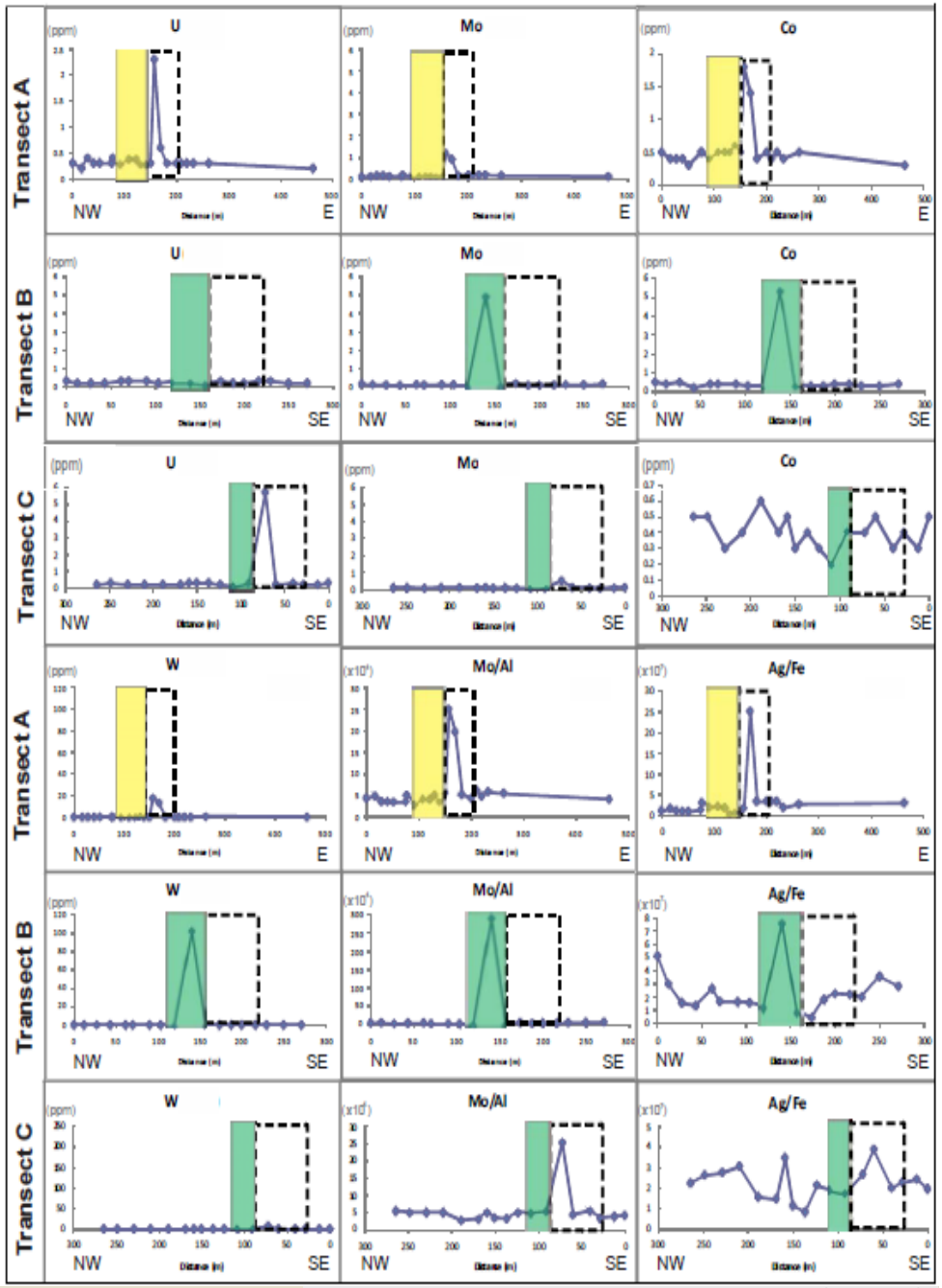
Surficial Geochemical Anomalies: Phoenix & Millennium Deposits

Michael Power, Keiko Hattori, Tom Kotzer, Eric Potter

- U, Mo, Co, Ag and W anomalies in humus and B-horizon soils
- Elevated He dissolved in ground-water above Millennium deposit
- **GSC Open File Reports: 7257, 7235, Abstracts: Goldschmidt 2013, SGA 2013, GAC-MAC 2012, 2013**



Power et al., (2013)



Power et al., (2012)

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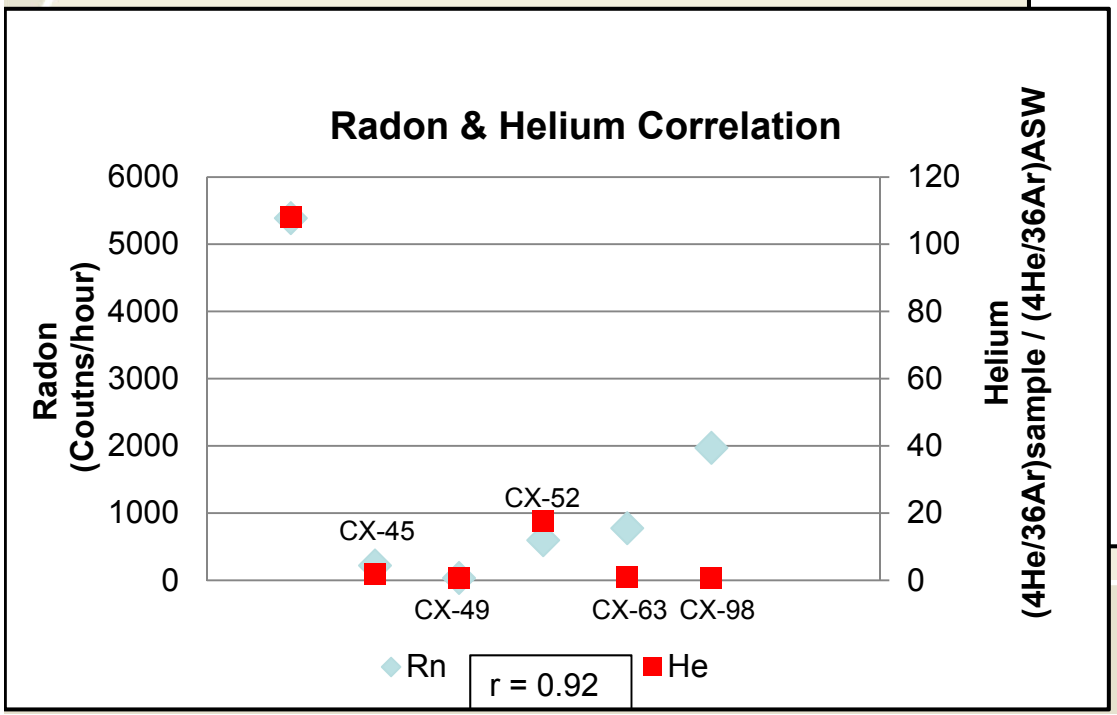
Phoenix deposit (surface projection)

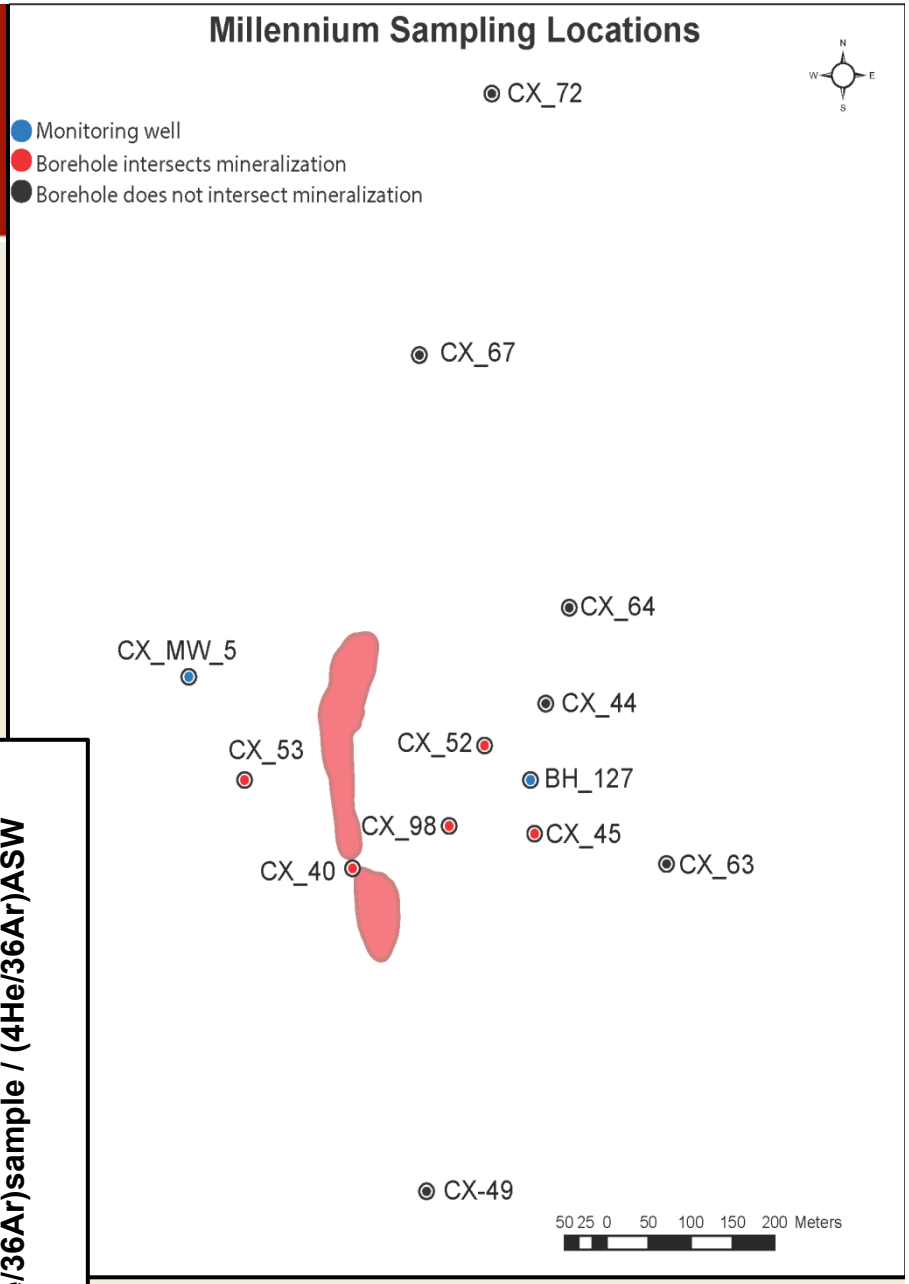
Surficial Geochemical Anomalies: Phoenix & Millennium Deposits

Austin Krahenbil, Keiko Hattori, Tom Kotzer

Anomalous Rn and He dissolved in groundwater above Millennium deposit

- **GSC Open File Report 7611**
  Mary Devine (unpubl., Rn data)



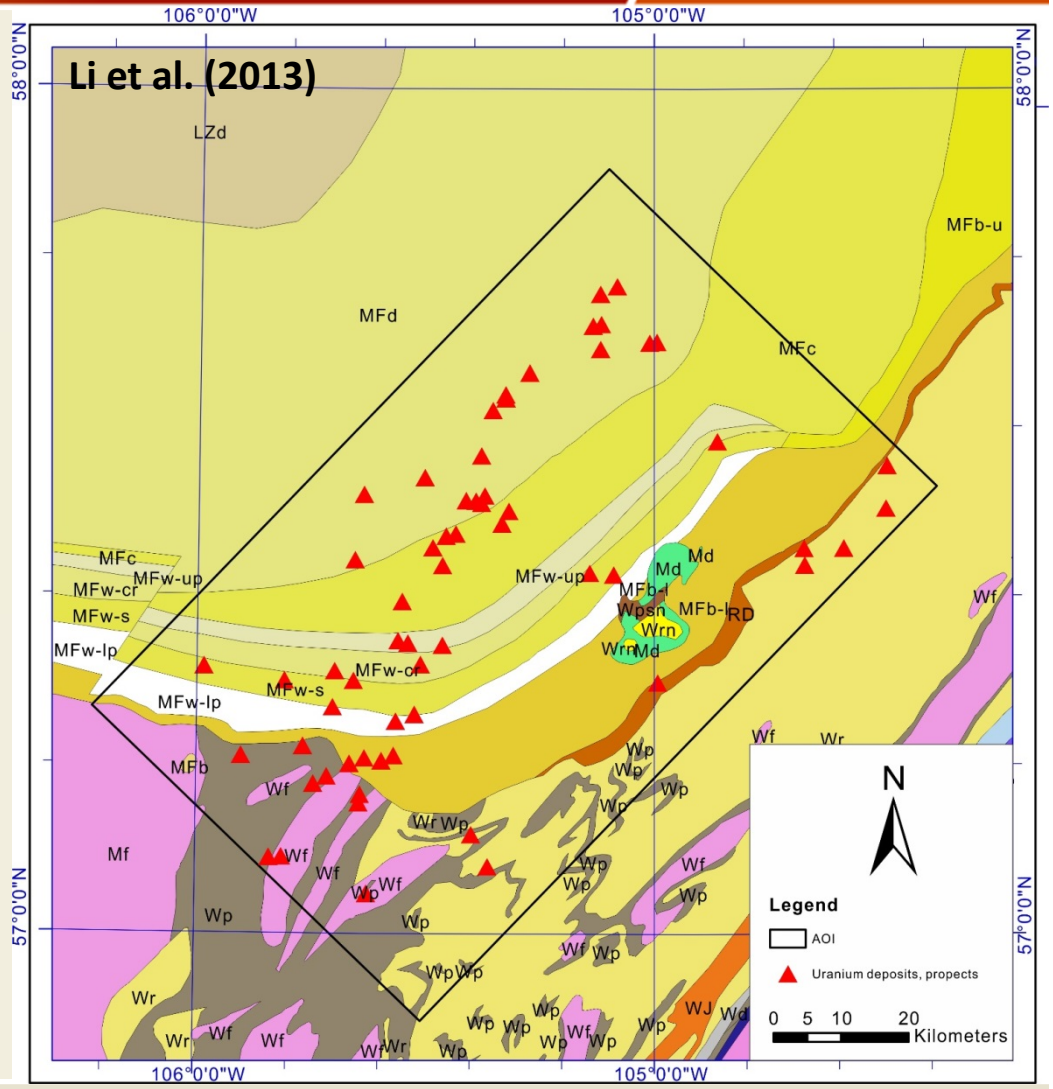


Canada

Fluid-structural relationships and 3D modelling, SE Athabasca Basin

Zenghua Li, Kathryn Bethune, Guoxiang Chi, Sean Bosman, Colin Card

Evaluating the spatial configuration of basement structures, the unconformity surface and younger fault sets, as well as clay alteration patterns in relation to lithology and structure, to model where, when and how U-bearing fluids travelled



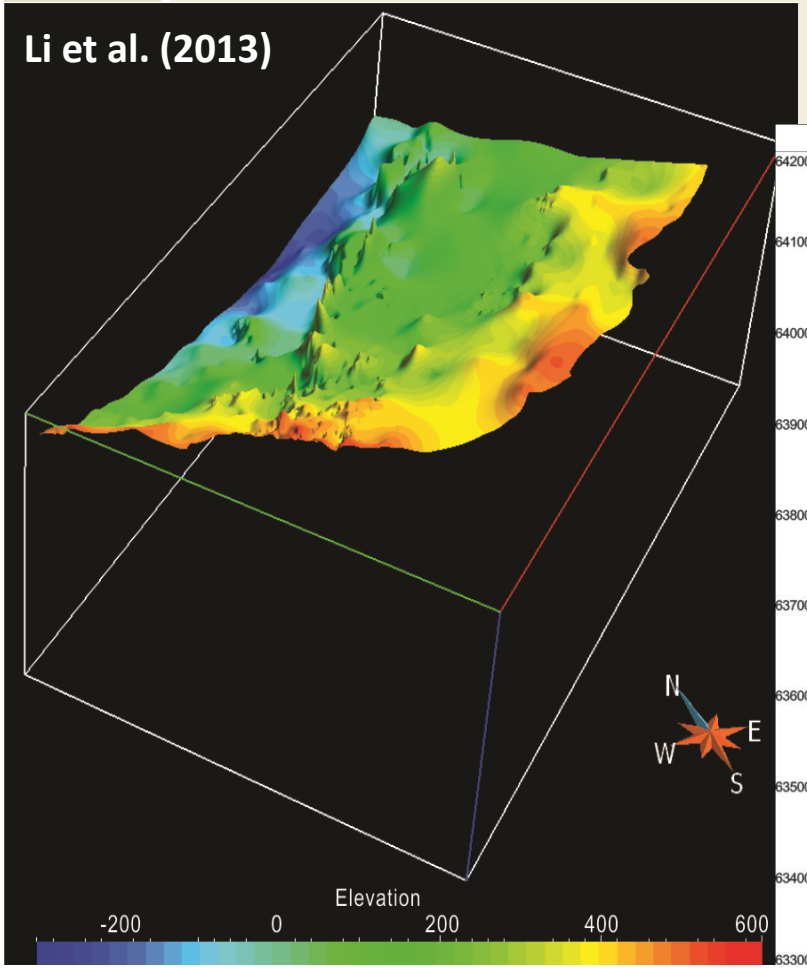
GSC Open File # 7436, GAC-MAC 2013 & 2014

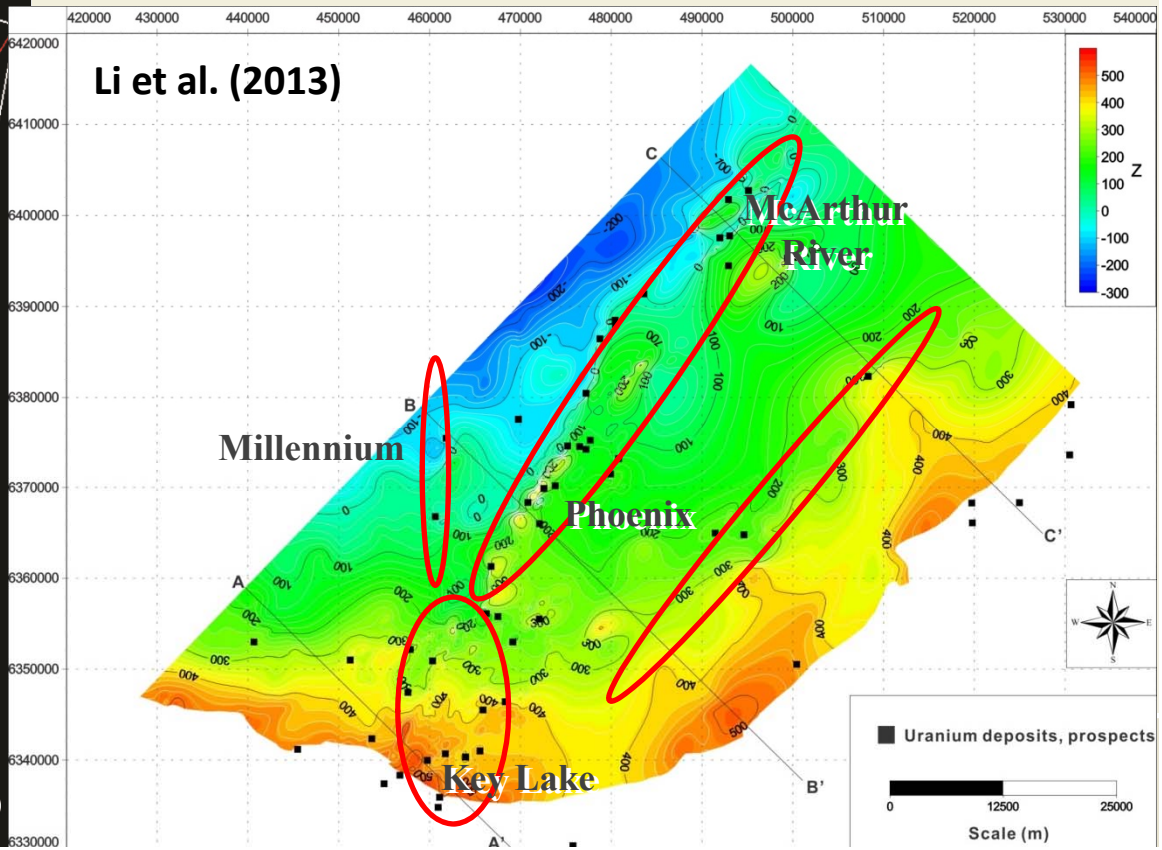
Fluid-structural relationships and 3D modelling, SE Athabasca Basin

Nearly all the deposits & prospects are associated with topographic features visible on the unconformity surface. The features are a function of three principal factors:

1) pre-Athabasca group ductile faulting; 2) differential weathering/erosion;

3) post-Athabasca fault reactivation, localized in pre-existing, graphite-rich ductile shear zones.

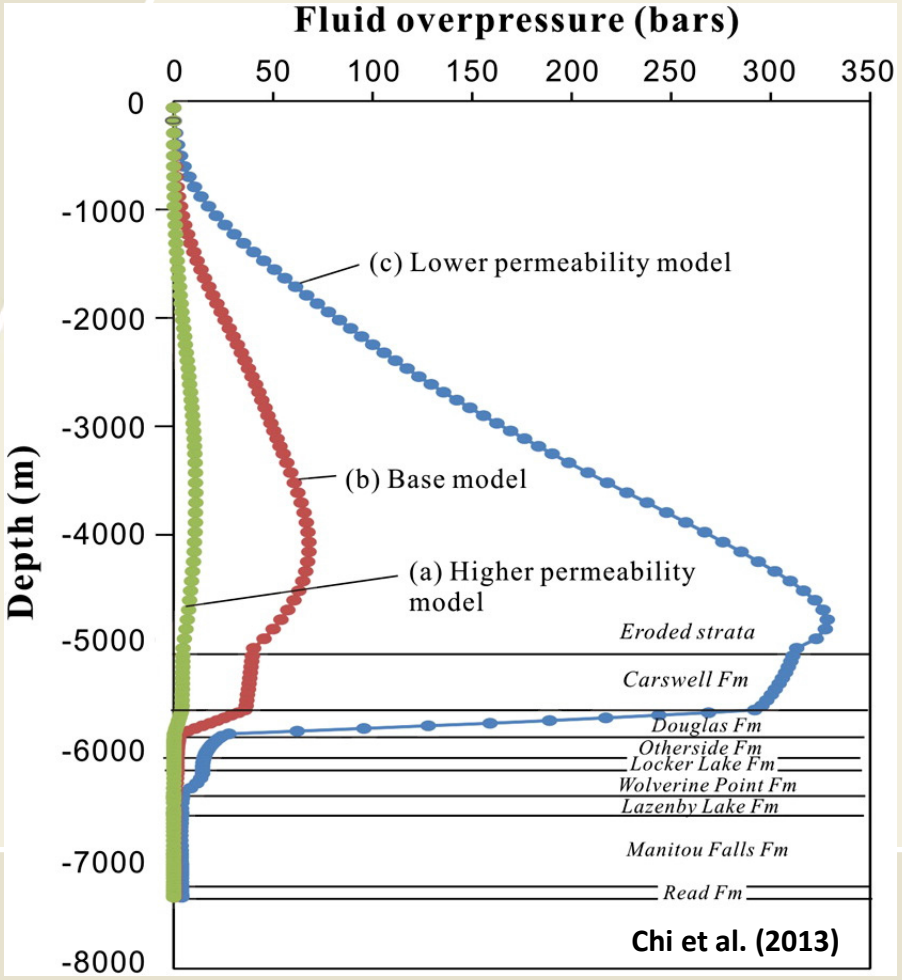


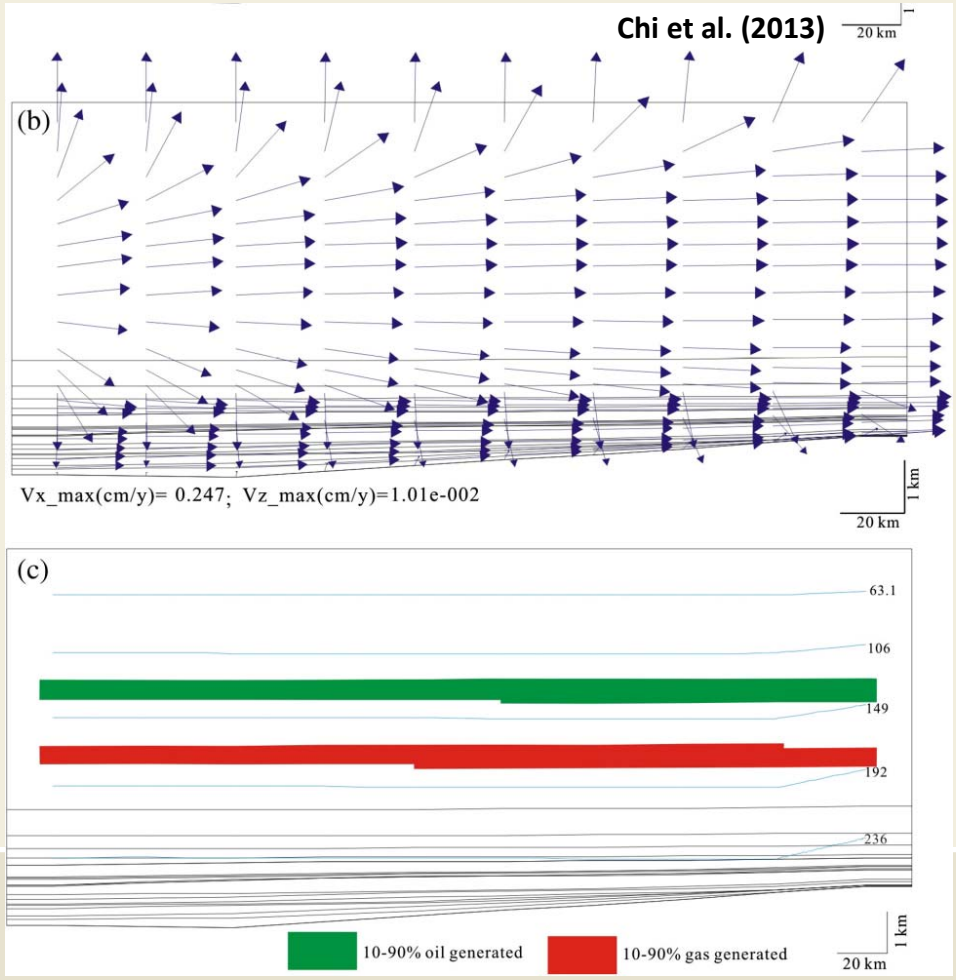


Fluid-structural relationships and 3D modelling, SE Athabasca Basin

Chi et al., (2013)
J. Geochem. Explor.
(doi:10.1016/j.gexplo.2013.10.015)

Using moderate permeabilities (base model), fluid overpressures may have caused oil generated from the Douglas Fm at the top of the Athabasca Group to migrate downwards to the sites of U precipitation, as suggested by biomarkers studies.





Summary & Significance

Critical Factors:

Reinforcement of historical models and research using modern techniques

- Graphite depletion in immediate basement may have released gases (NH_4, CH_4, N_2/H_2) for reduction of U (Pascal et al.)
- Mg and Fe isotopic compositions record clay formation (Mg) and redox reactions (Fe; Potter et al., Kyser et al.)
  - *Likely more than one process leading to highly efficient U reduction and potential applications for exploration*
- Evidence for U-bearing fluid movement along the P2 fault – localization of ore related to presence of an efficient reductant (Adlakha et al.)
- Topography of the unconformity likely focused fluid flow along the base of the sandstone column, as illustrated on the SE corridor of the Athabasca Basin (Li et al.)

Summary & Significance

TGI 4 Ore Systems

Expressions of deeply-buried mineralization:

- Geochemical signatures related to the deposits can extend 400m vertically from the deposit to the top of the sandstones (Dann et al.)
- Geochemical anomalies in soils and dissolved gases in groundwater overlie deeply buried (ca. 750 m) deposits (Power et al.)
- Geochemical signatures related to hydrothermal alteration and U enrichment processes are visible on the basin-wide scale (Wright & Potter)
- 3D modelling of basin architectures –coupled with fluid-flow modelling can be used to focus future exploration (Chi et al.)

Acknowledgments

TGI 4 Ore Systems

- TGI-4 management & academic researchers
- Industry collaborators and mentors
- Saskatchewan Geological Survey staff

All Open File Reports cited can be downloaded by searching the report number on (http://geoscan.nrcan.gc.ca)

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