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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 7664

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

E.G. Potter

2015

Canada

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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

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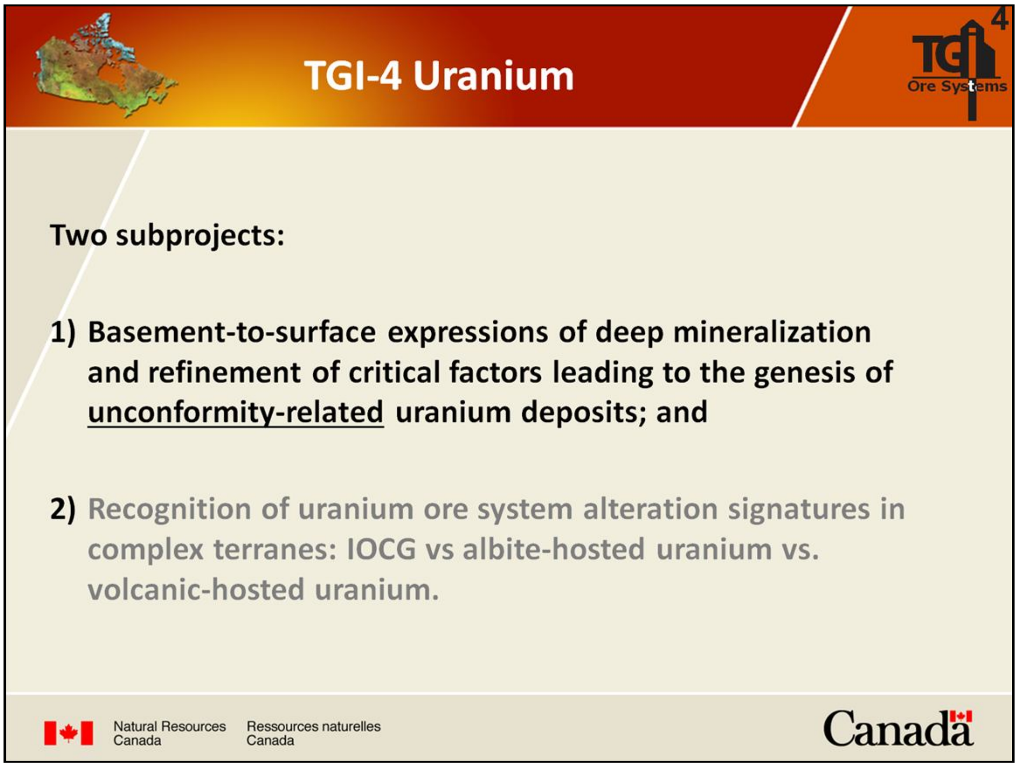
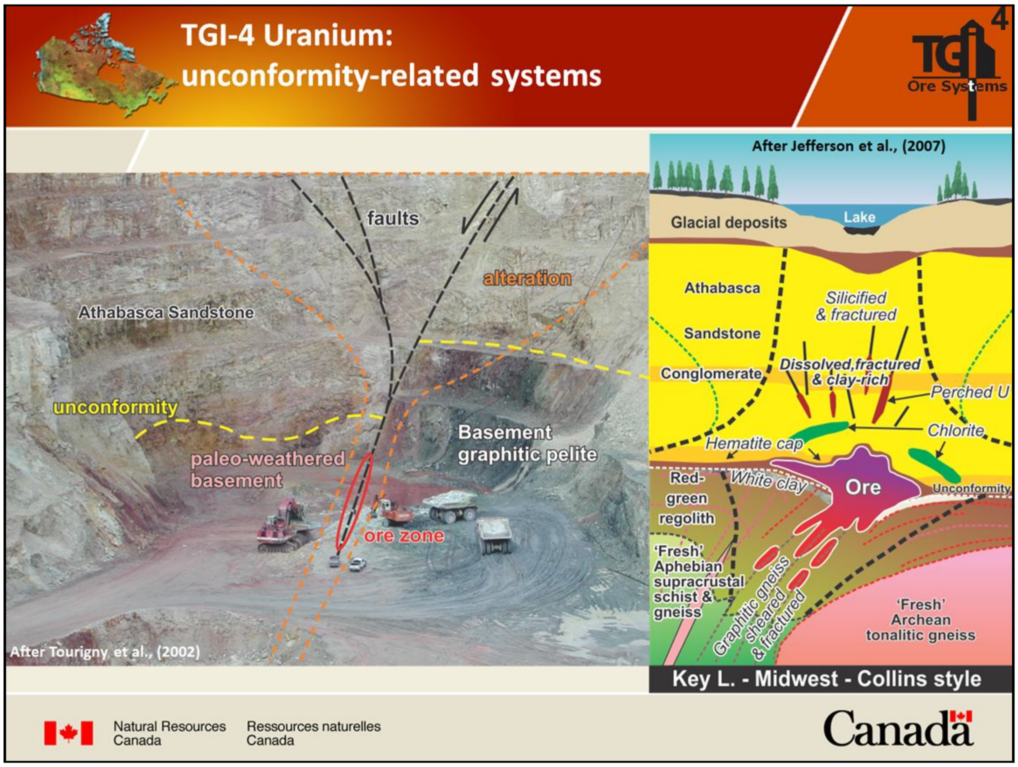
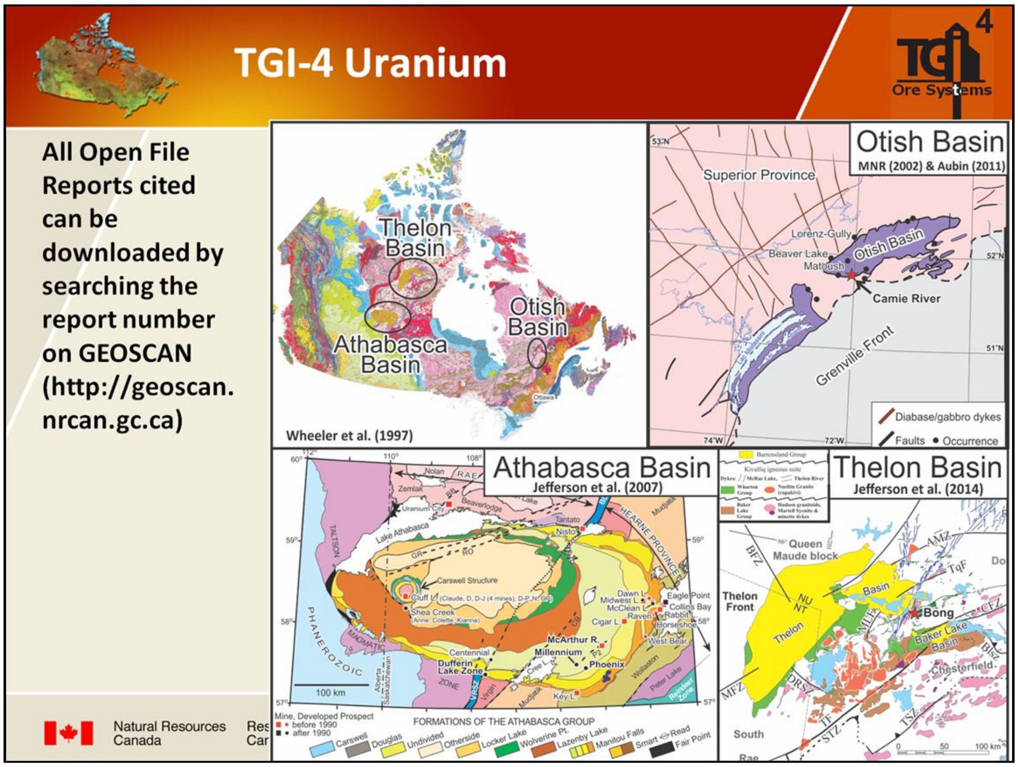


Due to time constraints, this presentation covers only the key activities in subproject #1: Basement to surface expressions of deep mineralization and refinement of critical factors leading to the genesis of unconformity-related uranium deposits



Taking a system-wide approach to basement to surface expressions of deep mineralization and refinement of critical factors leading to the genesis of unconformity-related uranium deposits.



Project areas: 1) Athabasca Basin (Phoenix, Millennium, McArthur River deposits and the Dufferin Lake zone), 2) Thelon Basin (Bong deposit), and 3) Otish Basin (Camie River deposit).

TGI-4 Uranium

TGI 4 Ore Systems

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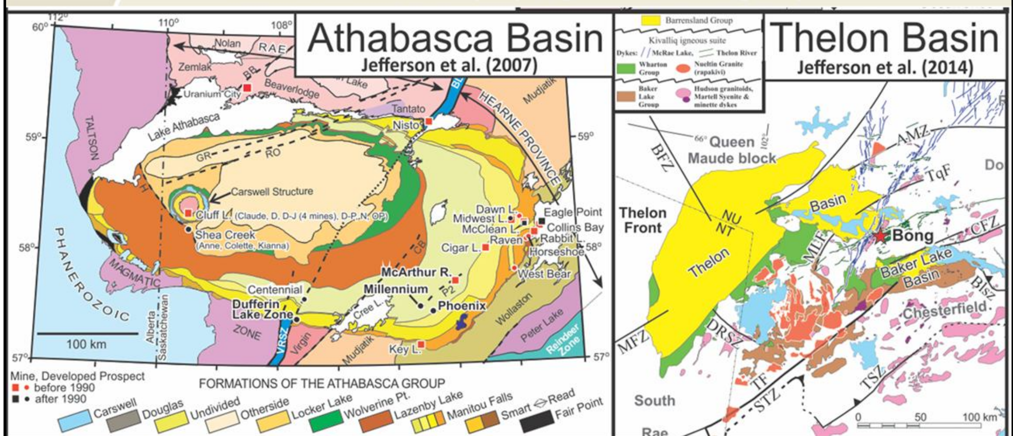
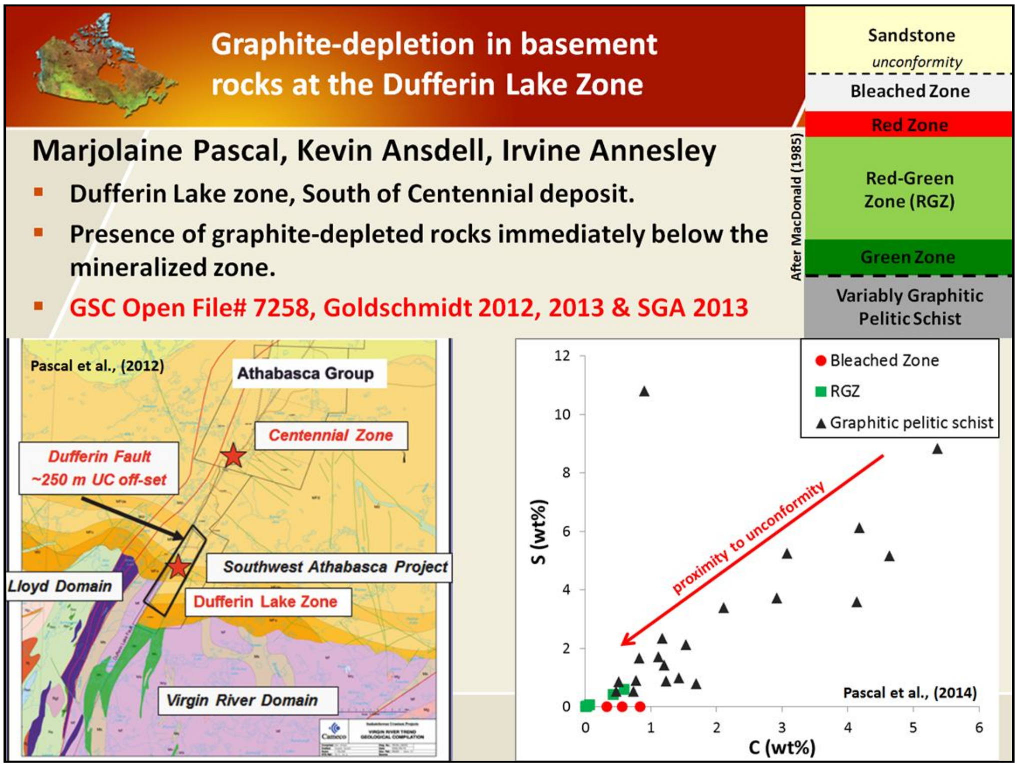
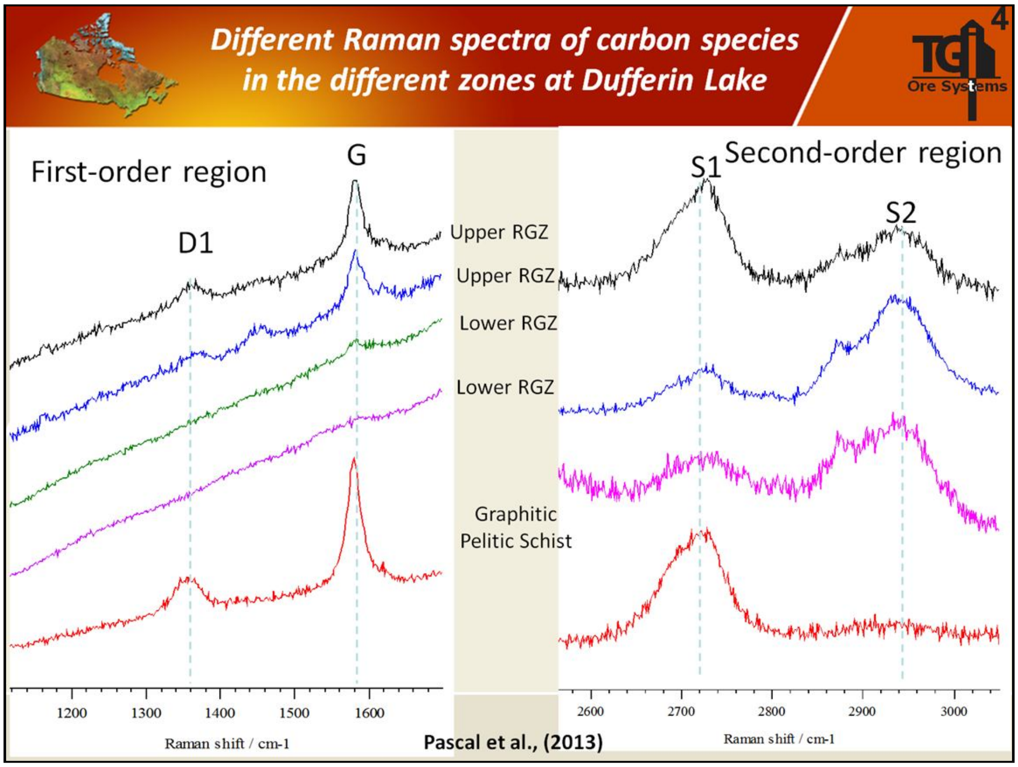


Athabasca sites: McArthur River, Phoenix, Millennium, Dufferin Lake.
Thelon: Bong



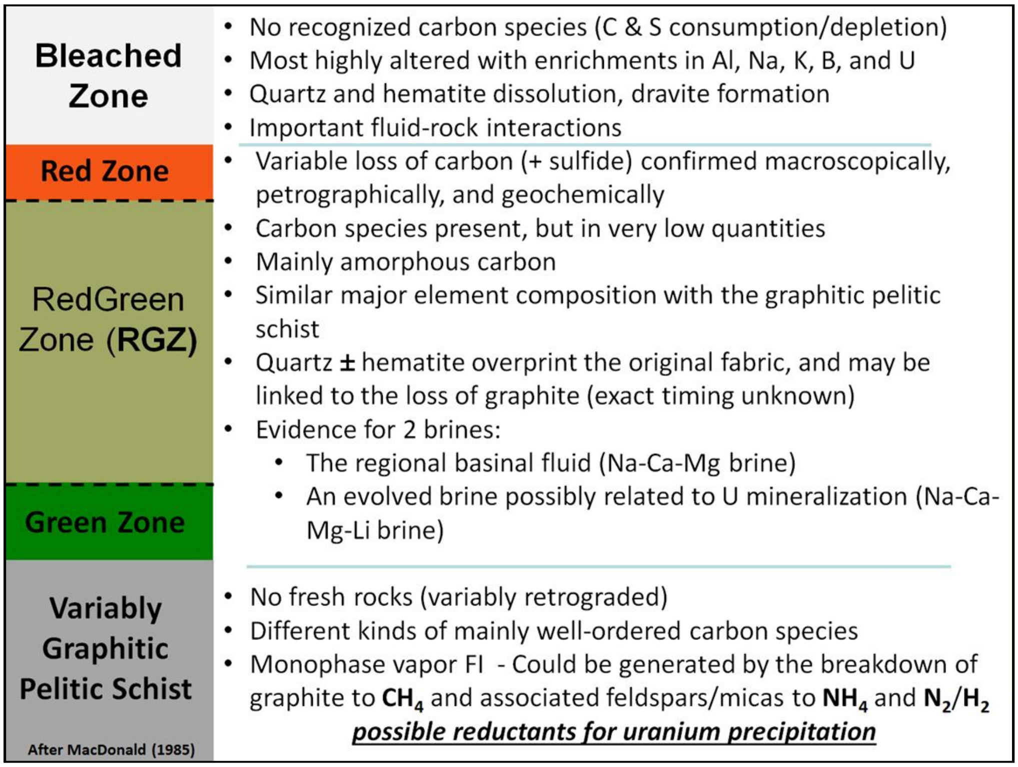
The Dufferin Lake zone in the south-central Athabasca Basin is underlain by highly deformed variably graphitic pelitic gneisses. Foliation and shear zones extend into a zone immediately below the unconformity in which graphite has been lost. The goal of this project was to provide possible constraints on the processes that might have been operating to consume the graphite.



Raman spectra were obtained from carbon species in shear zones and surrounding rocks in the basement, and of the rare carbon species in the RedGreen Zone (RGZ). No carbon species were recognized in the bleached zone above the RGZ. The distinct G peak, and obvious S1 peaks indicate well-crystallized graphite, whereas the presence of D1 and G, and S1 and S2 together indicate poorly-crystallized carbon, or carbonaceous matter.

In the basement: well-ordered carbon species (graphite) dominate

RGZ zone: where present, mostly amorphous carbon, but appears to be some more crystalline carbon species in the upper part of the RGZ



In summary, and working from the bottom up. The Variably Graphitic Pelitic Schist (VGPS) has been affected by retrograde metamorphism, and interaction with fluids of various ages along structures. Raman analyses indicate the dominance of well-crystalline carbon, and fluid inclusions in quartz veins contain N2 and CH4, which may have been generated by the breakdown of graphite, micas and feldspars. Similar fluids may have escaped upward and acted as reductants. Wilson et al., (2007), Ramaekers and Catuneanu (2013) and Chi et al., (2014) have proposed that CH4 may be related to post-ore alteration of hydrocarbons derived from the overlying Douglas Formation or Western Canada sedimentary basin rocks.

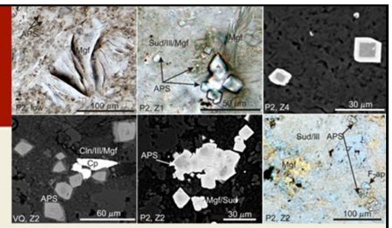
The RGZ is texturally similar to the VGPS, and has a similar major element composition. However has lost S and C, but amorphous carbon still exists. Aqueous inclusions are also seen in quartz veins, that suggest that both the regional basinal fluid, and an evolved brine linked to U mineralization in other deposits, has interacted with these rocks.

The thin bleached zone at the unconformity is the most highly altered, enriched in a variety of elements including U and B – dravite, completely depleted in C and S, and has likely been affected by fluids over a significant length of time.

Overall, there is textural, geochemical, Raman, and fluid inclusion evidence that the carbon species in the basement have been consumed, although this may be linked to multiple processes along the PT-t path followed by the rocks, such as retrograde metamorphism, weathering, and interaction with basinal fluids of various types. The timing of the generation of C- and N-bearing fluids/gases is not known, but may have occurred at the time of uranium mineralization.

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: sudoite ± illite, Mgf (magnesiofoitite), zoned APS
- Spatial association and similar chemistry along the P2 suggests that outer rims of APS plus Mgf were contemporaneous & formed by uraniferous oxidizing fluid – outer rims of 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, Goldschmidt 2013, SGA 2013, GAC-MAC 2014

Iron and Magnesium isotopic signatures related uranium precipitation processes

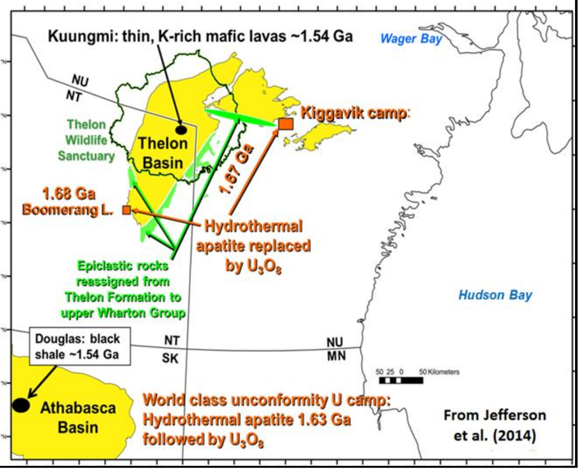
Two components:

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.

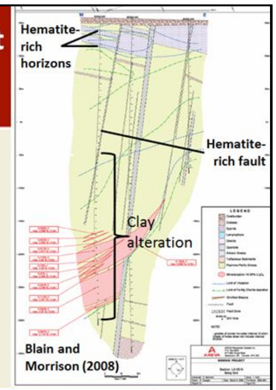
Outputs: Potter et al., GAC-MAC 2014; Sci. Presentation *in press*, Kyser et al., open file *in prep.*

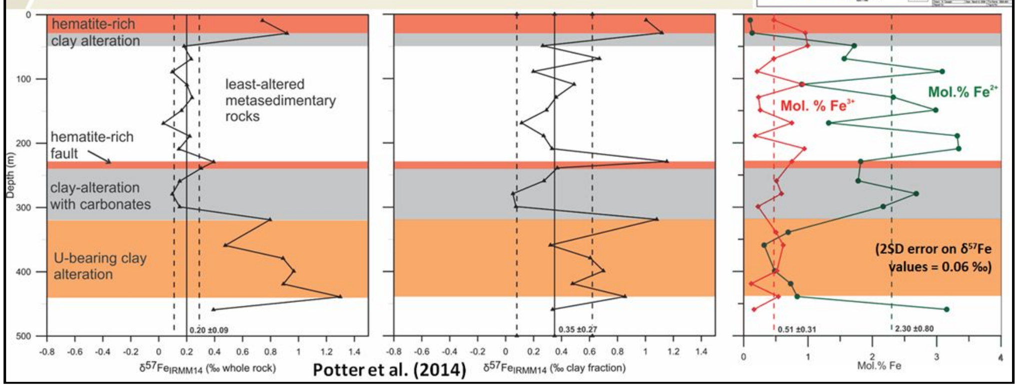


Whole-rock Fe & Mg isotopes: Bong deposit

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

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



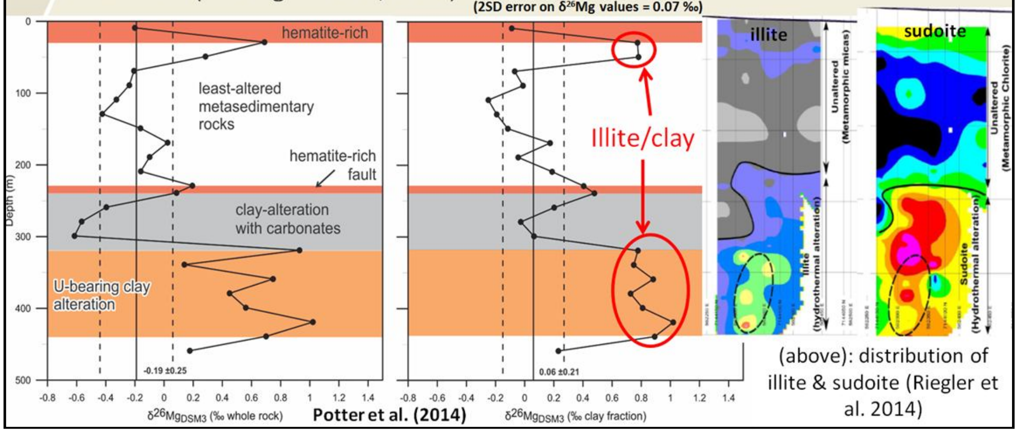


Potter et al. (2014)

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 et al., 2014)

(2SD error on $\delta^{26}Mg$ values = 0.07 ‰)

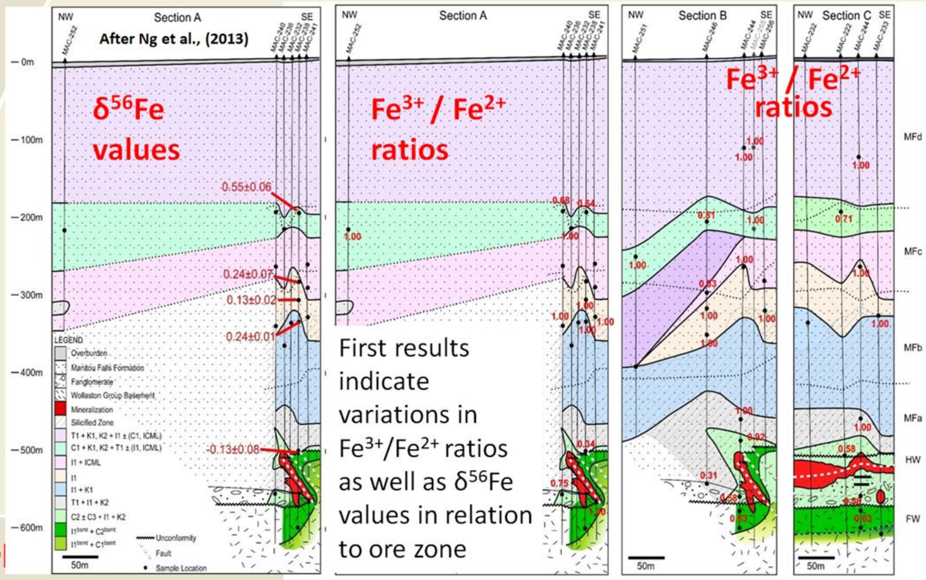


Potter et al. (2014)

(above): distribution of illite & sudoite (Riegler et al. 2014)

Fe and Mg isotopic composition of clay minerals from McArthur River

Kurt Kyser, Andrés Acevedo, Urmidola Raye, Don Chipley



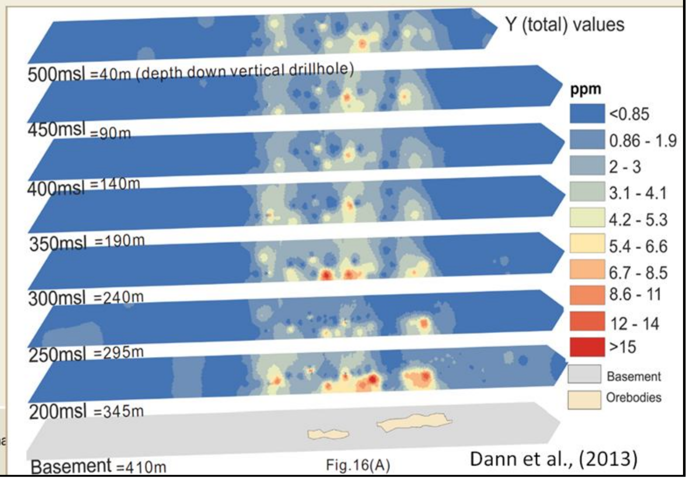
First results indicate variations in Fe^{3+}/Fe^{2+} ratios as well as $\delta^{56}Fe$ values in relation to ore zone

Geochemical Anomalies in host rocks: Phoenix Deposit

TGI 4 Ore Systems

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**



Dann et al., (2013)

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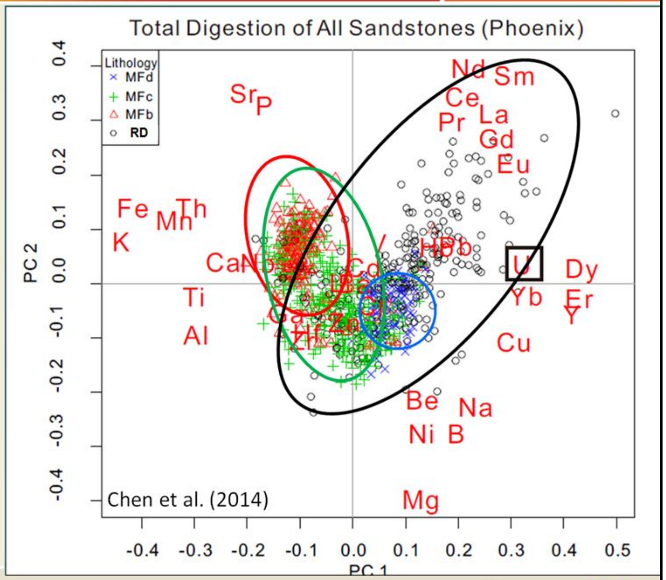
Elemental assemblages in Athabasca Group sandstones, Phoenix Deposit

TGI 4 Ore Systems

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

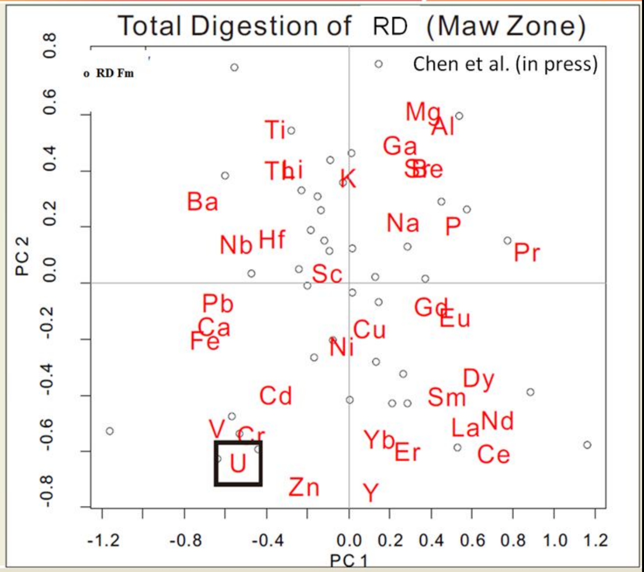
Chris Chen, Keiko Hattori, Eric Grunsky

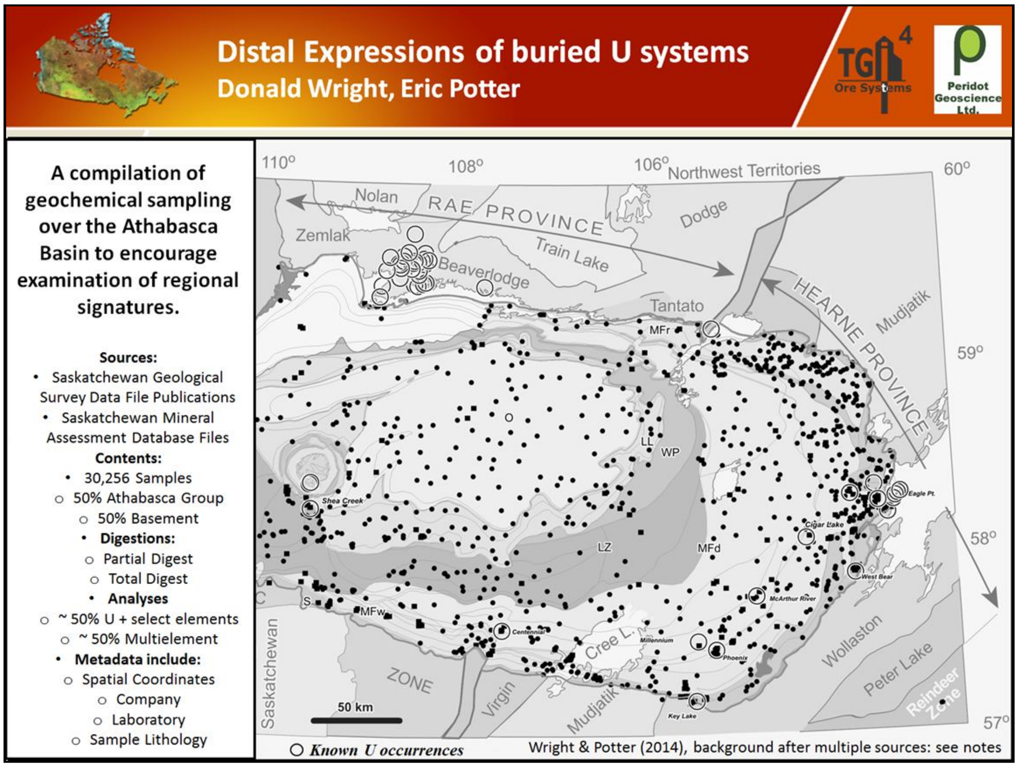
Maw Zone: REE-bearing breccia with no significant U, ca. 6 km SW of the Phoenix deposit.

Different element associations reflecting difference processes.

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

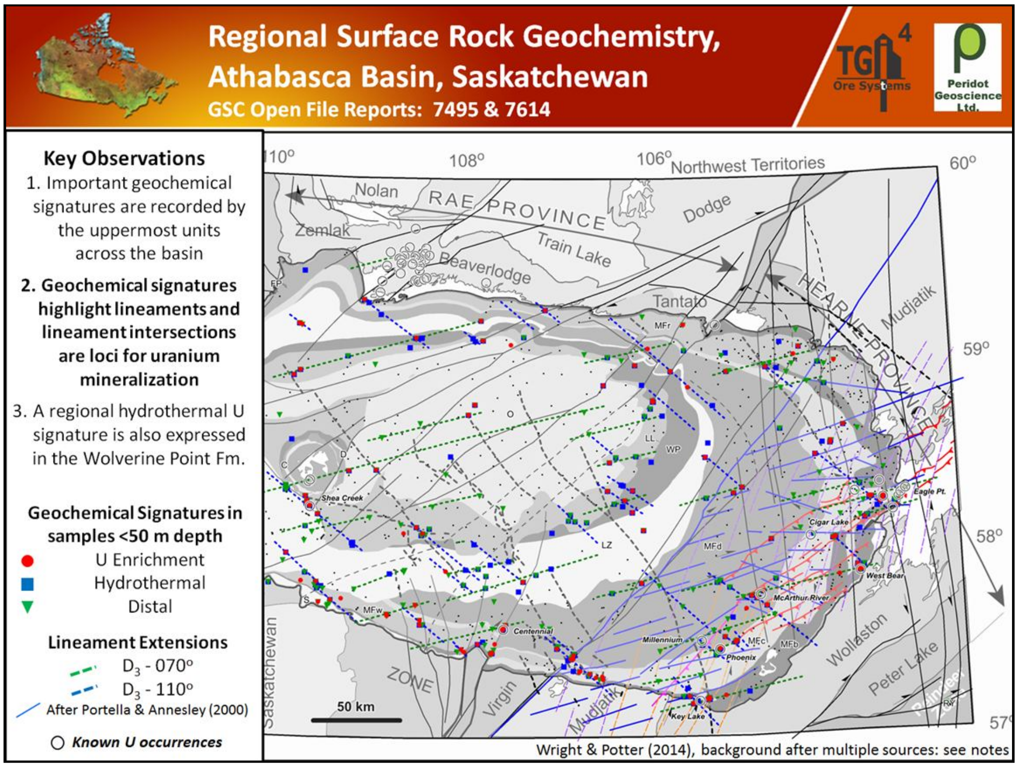
GSC Open File Report in press





Map compiled from several sources, including:

- Base lithological map and major structures: Jefferson *et al.* (2007); Ramaekers *et al.* (2007); Bosman and Schwab (2009); Bosman *et al.* (2012); Saskatchewan Geological Atlas.
- Structures in the East Athabasca: Portella and Annesley (2000)



Regional examination and integration of geochemical data with other components of the uranium exploration model can influence mineral exploration.

Key Observations:

1. Geochemical signatures of hydrothermal alteration (Y^2/Th, P_2O_5/TiO_2, MgO/Li, Li), distal alteration (Cu^2/Co, U^2/Th) and focused uranium mineralization (U^2/Th) are present in the upper exposed and near-surface units of the Athabasca Basin;

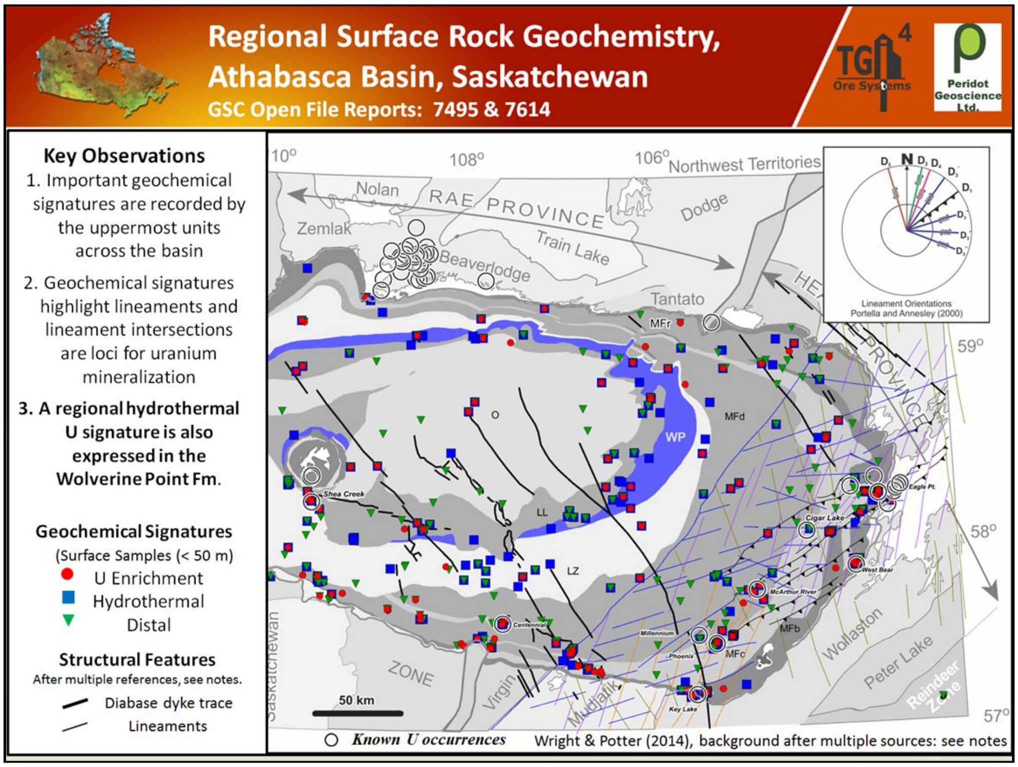
2. Geochemical signatures correspond with lineaments and highlight lineament intersections are loci for uranium mineralization; and

3. A distinct but locally stratabound hydrothermal signature that is possibly temporally and genetically related to focused uranium deposition elsewhere in the Athabasca Basin is also expressed in the Wolverine Point Formation (U^2/Th, Y^2/Th, P_2O_5/TiO_2).

Map compiled from several sources, including:

• Base lithological map and major structures: Jefferson *et al.* (2007); Ramaekers *et al.* (2007); Bosman and Schwab (2009); Bosman *et al.* (2012); Saskatchewan Geological Atlas.

• Structures in the East Athabasca: Portella and Annesley (2000)



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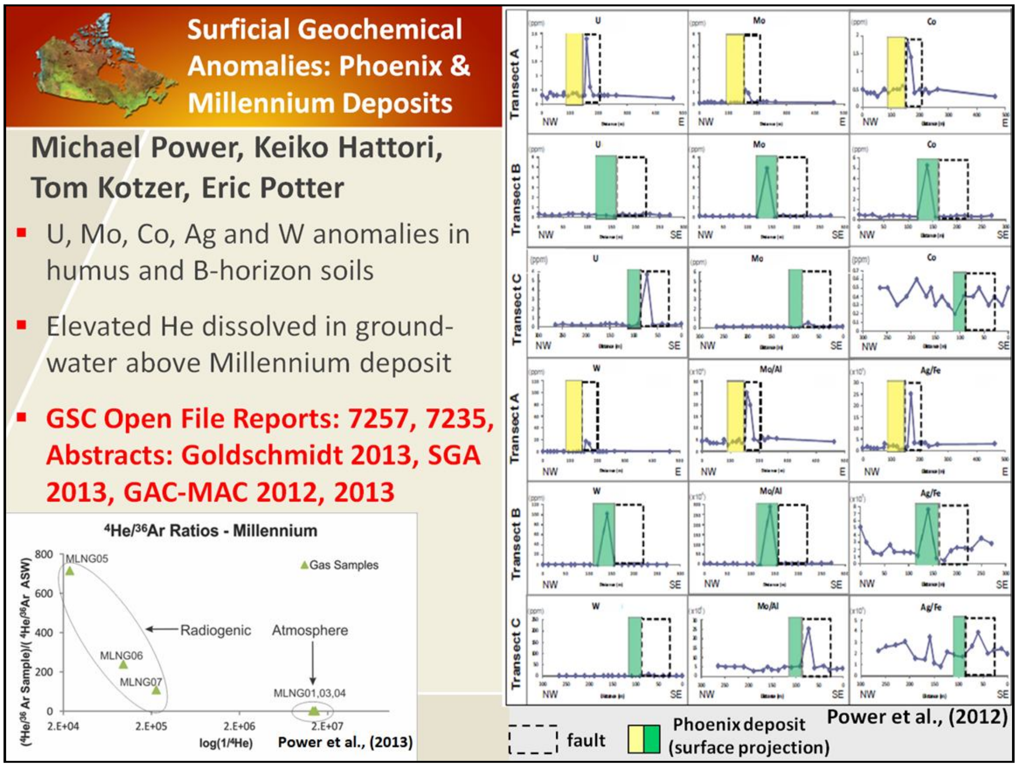


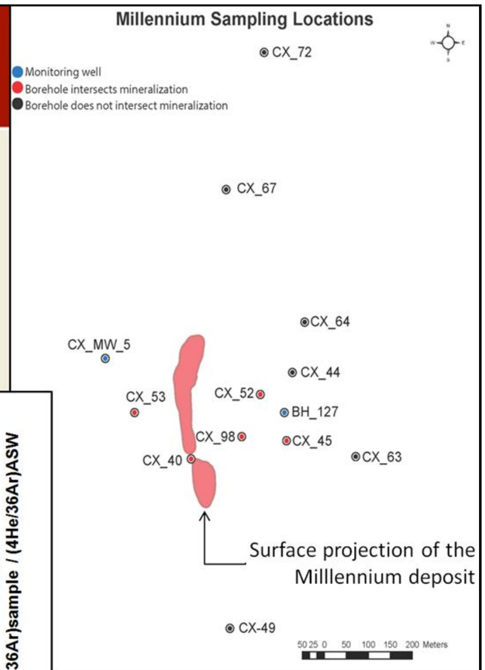
Overlying the surface projection of the ore body and ore-hosting fault, contents of uranium (5.7 ppm U), molybdenum (4.8 ppm Mo), cobalt (5.2 ppm Co), silver (0.98 ppm Ag) and tungsten (100 ppm W) are elevated relative to background values. Likewise, in B-horizon soil, uranium (with maximum concentration of 573 ppb U), silver (11 ppb Ag) and tungsten (16 ppb W) are elevated relative to background values.

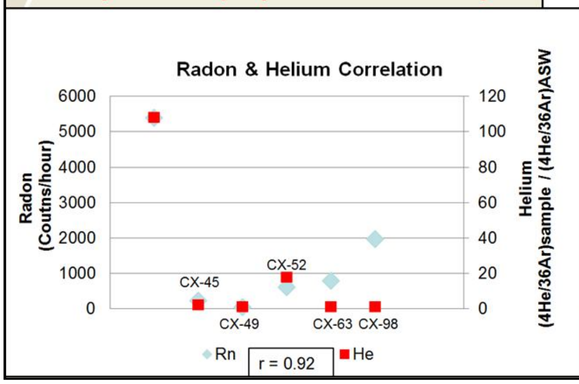
Surficial Geochemical Anomalies: Phoenix & Millennium Deposits

Austin Krahenbil, Keiko Hattori, Michael Power, Tom Kotzer

Anomalous Rn and He dissolved in groundwater above Millennium deposit

- **GSC Open File Report 7611 and Mary Devine (unpubl. Radon data)**





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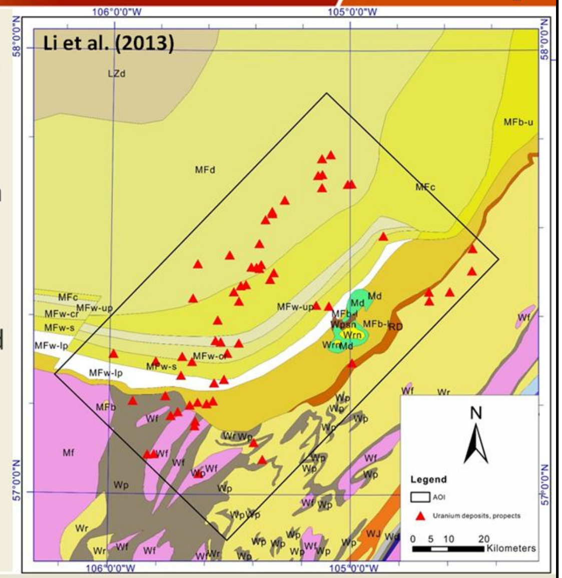
Fluid-structural relationships and 3D modelling, SE Athabasca Basin

TGI 4 Ore Systems

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



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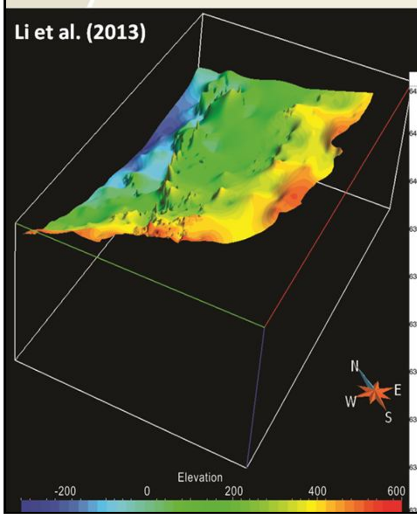
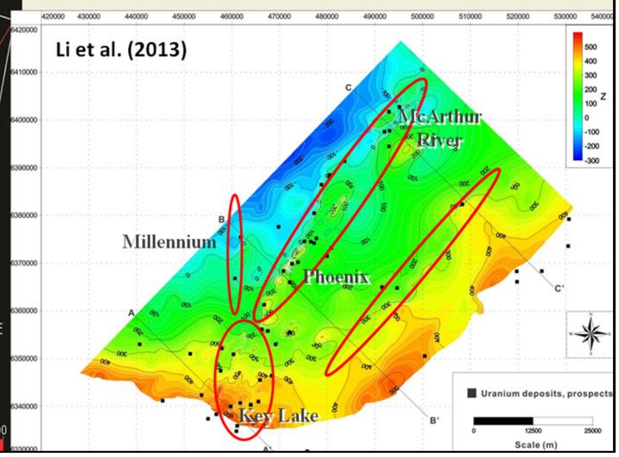
Fluid-structural relationships and 3D modelling, SE Athabasca Basin

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, Athabasca Basin

TGI 4 Ore Systems

Guoxiang Chi, Zenghua Li, Kathryn Bethune

- If 5 km of eroded sediment above the preserved Athabasca strata are assumed to be composed of 50:50 mix of shale and sand with moderate permeability, the fluid overpressures developed within this layer are so small that the fluid pressures are essentially hydrostatic (base model).
- Despite this, the fluid overpressure gradient was sufficient to drive oil generated in the Douglas Formation downward, although gas migrates upward.
- In contrast, if the permeabilities are taken to be one order of magnitude lower than the base model, fluid overpressures generated in the eroded strata are significantly higher, and both oil plus gas generated in the Douglas Formation are driven downward.
- Therefore, this study (Chi et al., 2013) confirms that it is hydrodynamically possible that some hydrocarbons found in the unconformity-related uranium deposits were derived from the Douglas Formation, as suggested by Wilson et al. (2007)

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Summary & Significance

TGI 4 Ore Systems

Critical Factors:

Reinforcement of historical models and research using modern techniques

- Graphite and sulfide depletion, alteration of feldspars/micas and evidence of two brines occur in the immediate basement rocks underlying U mineralization (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 ore preservation with 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.)

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Summary & Significance

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.)

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Acknowledgments

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

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References (1/4)

Adlakha, E.E., Hattori, K., Potter, E.G. and Sopuck, V., 2013. The paragenesis and chemistry of alteration associated with the P2 fault in the basement rocks of the Athabasca Basin; Geological Survey of Canada, Open File 7365, 1 poster.

Adlakha, E.E., Hattori, K., Zaluksi, G., Kotzer, T. and Potter, E.G., 2013. Alteration within the basement rocks associated with the P2 fault and the McArthur River uranium deposit, Athabasca Basin; Geological Survey of Canada, Open File Report 7462, 35 p.

Adlakha, E.E. Hattori, K., Zaluski, G., Kotzer, T., Potter, E.G., 2014. Ore fluids recorded in the compositions of magnesiofoitite and alumino-phosphatesulfate (APS) minerals in the basement along the P2 structure and the McArthur River deposit, Athabasca Basin; Joint annual meeting of GAC-MAC 2014, Abstracts v. 37, p. 4–5.

Aubin, A., 2011. The Camie-Beaver and Otish South projects and uranium potential of the Otish sedimentary basin; Symposium Mines Baie-James, May 31, Chibougamau, Quebec.

Blain, M. and Morrison, D., 2008. Kiggavik Project, Annual Report, 2010, volume 1; AREVA Resources Canada Inc., Internal Report, 31 p.

Chen, S., Hattori, K. and Grunsky, E.C., 2014. Principal Component Analysis of the Compositions of Sandstones Overlying Phoenix Uranium deposits; Geological Survey of Canada, Open File Report, 7578, 1 poster.

Chen, S., Hattori, K., Grunsky, E.C. and Lui, Y., in press. Elemental Assemblages in Sandstones Overlying the Phoenix U Deposits and REE-rich Maw Zone, Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File Report, 1 poster.

Chi , G., Li, Z. and Bethune, K.M., 2013. Numerical modeling of hydrocarbon generation in the Douglas formation of the Athabasca basin (Canada) and implications for unconformity-related uranium mineralization; Journal of Geochemical Exploration, doi:10.1016/j.gexplo.2013.10.015

Craddock, P. R. and Dauphas, N., 2011. Iron isotopic compositions of geological reference materials and chondrites; Geostandards and Geoanalytical Research, v. 35, p. 101–123.

References (2/4)

Dann, J., Hattori, K., Potter, E.G., Sorba, C., 2013. Alteration assemblages and geochemical signatures associated with the Phoenix unconformity-related uranium deposit, Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File 7366, 1 poster.

Dann, J., Hattori, K., Potter, E.G. and Sorba, C., 2013. Discrimination of elemental assemblages in the alteration halo of the Phoenix deposit, Saskatchewan, through applied GIS; Geological Survey of Canada, Open File 7463,

Dideriksen, K., Christiansen, B. C., Frandsen, C., Balic-Zunic, T., Mørup, S. and Stipp, S. L. S., 2010. Paleo-redox boundaries in fractured granite; Geochimica et Cosmochimica Acta, v. 74, p. 2866–2880.

Hill, P. S., Schauble, E. A. and Young, E. D., 2010. Effects of changing solution chemistry on Fe3+/Fe2+ isotope fractionation in aqueous Fe–Cl solutions; Geochimica et Cosmochimica Acta, v. 74, p. 6669–6689.

Jefferson, C.W., Thomas, D.J., Gandhi, S.S., Ramaekers, P., Delaney, G., Brisbin, D., Cutts, C., Portella, P. and Olson, R.A., 2007a. Unconformity-associated uranium deposits of the Athabasca basin, Saskatchewan and Alberta; in EXTECH IV: Geology and Uranium EXploration TECHnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta, C.W. Jefferson and G. Delaney (eds.); Geological Survey of Canada Bulletin 588, p. 23-67.

Jefferson, C. W., Thomas, D., Quirt, D., Mwenifumbo, C. J. and Brisbin, D., 2007b. Empirical models for Canadian unconformity-associated uranium deposits, in Proceedings of Exploration 07, B. Milkereit (ed.); Fifth Decennial International Conference on Mineral Exploration, p. 741-769.

Jefferson, C.W., Pehrsson, S., Peterson, T., Tschirhart, V., Anand, A., Wollenberg, P., Riegler, T., Bethune, K., Chorlton, L.B., McEwan, B., LeCheminant, A.N., Tschirhart, P., Scott, J.M.J., Davis, W., McNicoll, V., Riemer, W., White, J.C., Patterson, J., Morris, W.A., Keating, P. and Stieber, C., 2014. Bedrock geology of the western Marjorie-Tehek supracrustal belt and Aberdeen Sub-basin margin in parts of NTS 66A and 66B, Nunavut — context of the Kiggavik uranium camp; Geological Survey of Canada, Open File 7241.

Krahenbil, A., Hattori, K., Power, M., and Kotzer, T., 2014. Surficial Geochemistry associated with the deeply buried Millennium and Phoenix Uranium Deposits, Athabasca Basin, Northern SaskatchewanGeological Survey of Canada, Open File Report 7611, 1 poster.

References (3/4)

Li, Z., Bethune, K.M., Chi, G., Bosman, S.A. and Card, C.D., 2013. Preliminary 3D Modelling and Structural Interpretation of Southeastern Athabasca Basin; Geological Survey of Canada, Open File 7426, 21 p.

Liu, S. A., Teng, F. Z., He, Y., Ke, S. and Li, S., 2010. Investigation of magnesium isotope fractionation during granite differentiation: implication for Mg isotopic composition of the continental crust; Earth and Planetary Science Letters, v. 297, p. 646–654.

MacDonald, C. 1985.Mineralogy and geochemistry of the sub-Athabasca regolith near Wollaston Lake. Geology of Uranium Deposits; Canadian Institute of Mining and Metallurgy Special, v. 32, p. 155-158.

MRN, 2002. Geological map of Québec, Edition 2002; Ministère des Ressources Naturelles, DV 2002-07, scale 1:2 000 000.

Pascal, M., Ansdell, K., Annesley, I.R., Jiricka, D., Witt, G., and Brown, A., 2012. Graphite-bearing and graphite-depleted basement rocks in the Dufferin Lake Zone, south-central Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File 7258, 1 poster.

Ng, R., Alexandre, P. and Kyser, T.K., 2013. Mineralogical and Geochemical Evolution of the Unconformity-Related McArthur River Zone 4 Orebody in the Athabasca Basin, Canada: Implications of a Silicified Zone; Economic Geology, v. 108, p. 1657-1689.

Pascal, M., Ansdell, K., Annesley, I.R., Jiricka, D., Witt, G., and Brown, A., 2012. Graphite-bearing and graphite-depleted basement rocks in the Dufferin Lake Zone, south-central Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File 7258, 1 poster.

Pascal, M., Ansdell, K., Annesley, I.R., Boiron, M-C., Kotzer, T., Jiricka, D. and Cuney, M., 2013. Microthermometric and Raman analysis of fluids that interacted with variably graphitic pelitic schist in the Dufferin Lake zone, south-central Athabasca Basin: Implications for graphite loss and uranium deposition; Goldschmidt 2013 Conference Abstracts, p.1930.

Pascal, M., 2014. Graphite-bearing and graphite-depleted basement rocks in the Dufferin Lake Zone, south-central Athabasca Basin, Saskatchewan; Unpublished MSc. Thesis, University of Saskatchewan, Saskatoon.

Pogge von Strandmann P. A. E., Burton K. W., James R. H., van Calsteren P., Gislason S. R. and Sigfússon B., 2008. The influence of weathering processes on riverine magnesium isotopes in a basaltic terrain; Earth and Planetary Science Letters, v. 276, p. 187–197.

Potter, E.G., Sharpe, R., Girard, I., Fayek, M., Gammon, P., Quirt, D. and Robbins, J., in press. Preliminary coupled Fe and Mg isotope and Fe speciation investigations at the Bong uranium deposit, Thelon Basin, Canada; Geological Survey of Canada, Open File Report 7662.

References (4/4)

Power, M.J., Hattori, K., Sorba, C., and Potter, E.G., 2012. Geochemical anomalies in surface media and uppermost sandstones overlying the concealed Phoenix uranium deposit, Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File 7235.

Power, M.J., Hattori, K., Sorba, C., and Potter, E.G., 2012. Geochemical anomalies in the soil and uppermost siliciclastic units overlying the Phoenix uranium deposit, Athabasca Basin, Saskatchewan, Canada; Geological Survey of Canada, Open File 7257, 35 p.

Ramaekers, P., and Catuneanu, O., 2013. Rifting and the generation and modification of Athabasca uranium deposits, Open House 2013, Abstract Volume, Saskatchewan Geological Survey, p. 4.

Riegler, T., Lescuyer, J-L., Wollenberg, P., Quirt, D. and Beaufort, D., 2014. Alteration related to uranium deposits in the Kiggavik-Andrew Lake structural trend, Nunavut Canada: new insights from petrography and clay mineralogy; The Canadian Mineralogist, v. 52, p. 27–45.

Sharpe, R., 2013. The geochemistry and geochronology of the Bong uranium deposit, Thelon basin, Nunavut, Canada; unpublished M.Sc. thesis, University of Manitoba, 213 p.

Teng, F. Z., Li, W. Y., Rudnick, R. L. and Gardner, L. R., 2010. Contrasting lithium and magnesium isotope fractionation during continental weathering; Earth and Planetary Science Letters, v. 300, p. 63–71.

Tourigny, G., Wilson, G., Breton, G., and Portella, P., 2002. Geology of the Sue C uranium deposit, McClean Lake area, northern Saskatchewan; in Trip A1: The eastern Athabasca Basin and its Uranium Deposits, N. Andrade, G. Breton, C.W. Jefferson, D.J. Thomas, G. Tourigny, S. Wilson, G.M. Yeo (eds.); Geological Association of Canada-Mineralogical Association of Canada Field Trip Guidebook, p. 35-51.

Wilson, N.S.F., Stasiuk, L.D., and Fowler, M.D., 2007. Origin of organic matter in the Proterozoic Athabasca Basin of Saskatchewan and Alberta, and significance to unconformity uranium deposits; in EXTECH IV: Geology and Uranium EXploration TEChnology of the Proterozoic Athabasca Basin, Saskatchewan and Alberta, C.W. Jefferson and G. Delaney (eds.); Geological Survey of Canada Bulletin 588, p. 325-339.

Wimpenny, J., Colla, C. A., Yin, Q. Z., Rustad, J. R. and Casey, W. H., 2014. Investigating the behaviour of Mg isotopes during the formation of clay minerals; Geochimica et Cosmochimica Acta, v. 128, p. 178–194.

Wright, D.M., and Potter, E.G., 2014. Regional Surface Rock Geochemistry, Athabasca Basin, Saskatchewan; Geological Survey of Canada, Open File 7614, 32 p.

Wright, D.M., Potter, E.G. and Comeau, J-S., 2014. Athabasca Basin Uranium Geochemistry Database; Geological Survey of Canada, Open File 7495, 11 p. plus database.