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GEOLOGICAL SURVEY OF CANADA
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Protracted Paleoproterozoic Gold History at the Archean BIF-Hosted Meliadine Gold District, Nunavut

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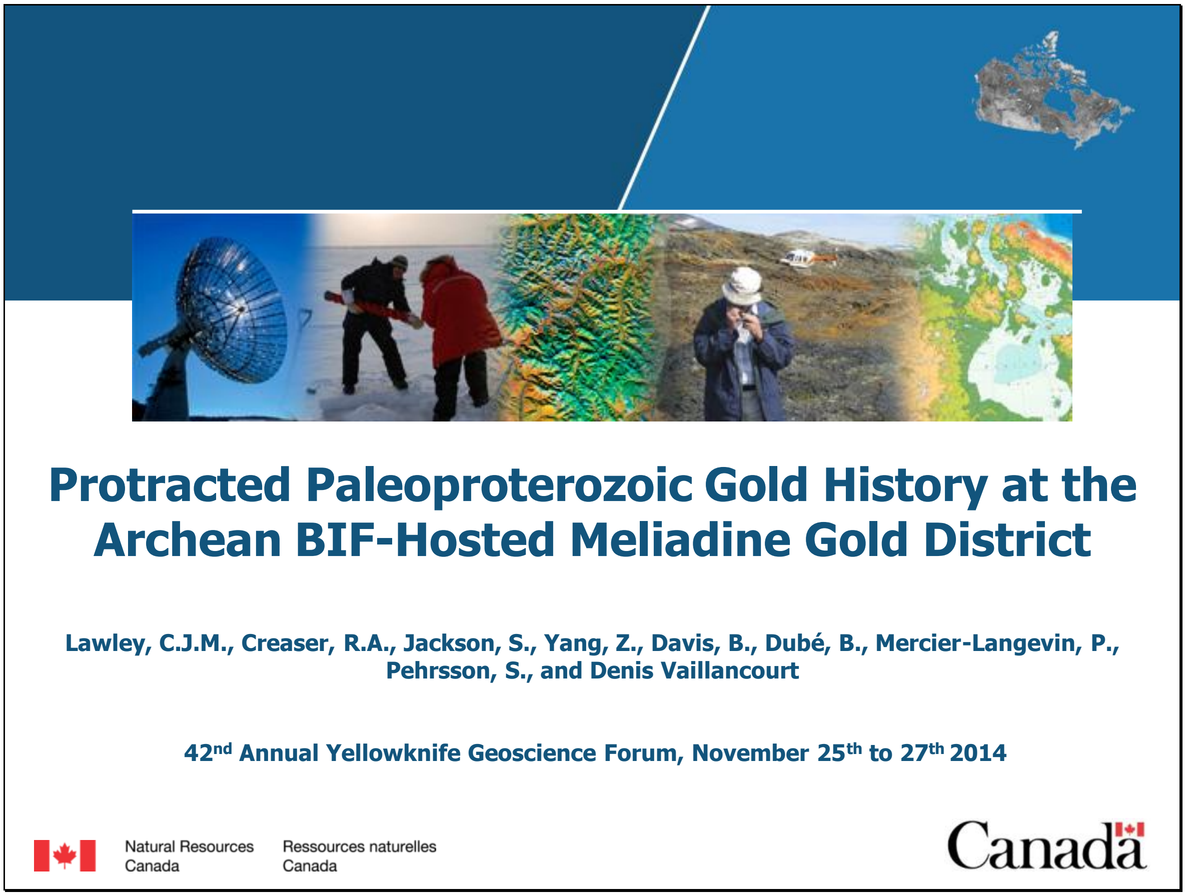
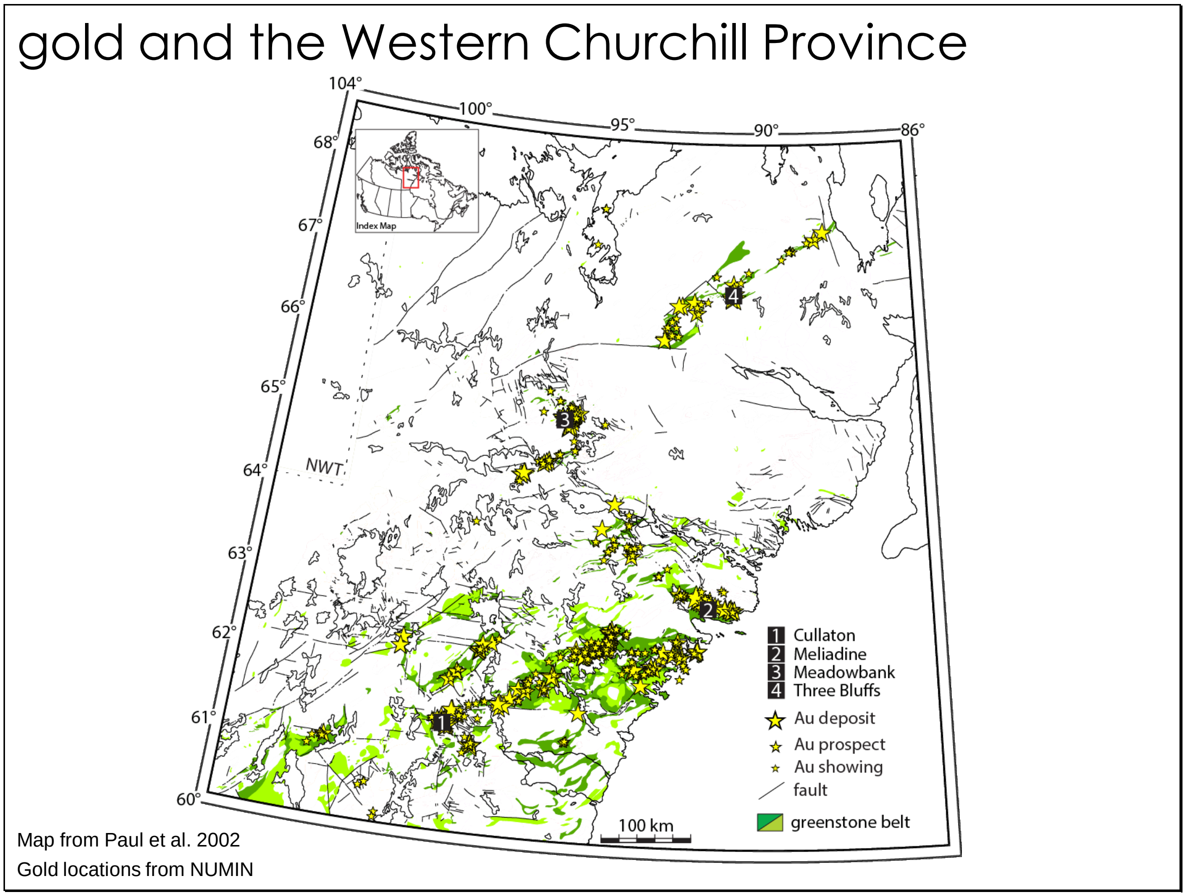
The Meliadine Gold District, Nunavut, represents one of Canada's largest emerging greenstone- and BIF-hosted gold districts (reserves of 2.8 Moz Au, plus indicated and inferred resources of 5.8 Moz Au). Most known gold deposits are co-spatial with the Pyke Break, which cuts Meso to Neoarchean (ca. 2.66 Ga) supracrustal and igneous rocks and represents an E-W trending fault associated with a NE-SW trending trans-cratonic fault network. The latter cuts the Western Churchill Province and records a complex and protracted reactivation history that spans at least four Paleoproterozoic orogenic episodes. Gold occurs as inclusions within idioblastic arsenopyrite crystals, at sulfide crystal boundaries and/or as sulfide fracture fills. Arsenopyrite crystal boundaries and domains adjacent to late fractures are variably recrystallized and relatively enriched in precious- and base-metals. In contrast, inclusion-free arsenopyrite crystals and overgrowths along with arsenopyrite domains devoid of fractures are relatively gold-poor. Clusters of gold and galena that correspond with recrystallized arsenopyrite domains and at contacts between disparate arsenopyrite generations suggest that sulfide recrystallization liberated gold and was remobilized, at least locally, into low-strain micro-textural sites along with precious- and base-metals during late fluid-assisted and deformation/metamorphic-driven remobilization. New U-Pb xenotime ages at ca. 1.86 Ga, coupled with previously reported U-Pb hydrothermal monazite ages, post-date arsenopyrite recrystallization, which suggests that gold remobilization was concomitant with the Trans-Hudson orogeny (1.9¬–1.8 Ga). New Re-Os arsenopyrite model ages range from 2.3–1.8 Ga and document a hitherto unrecognized and complex pre-1.86 Ga hydrothermal and sulfide history. The range of Re-Os model ages tends to support partial open-system behaviour and/or mixing of disparate arsenopyrite generations that are evident from micro-textures and in situ element mapping. Replicate analyses of the two most Re-rich and homogeneous arsenopyrite samples yield Re-Os model ages at ca. 2.27 and 1.90 Ga, which are broadly concurrent with the Arrowsmith (2.4–2.3 Ga) orogeny and the earliest phase of the Trans-Hudson orogeny (known locally as the Snowbird orogeny; ca. 1.9 Ga), respectively. These Re-rich samples also tend to be gold-poor and likely yield ages that pre-date gold remobilization and subsequent enrichment along arsenopyrite crystal boundaries and fractures at 1.86 Ga. We speculate that the bulk of the gold was initially introduced at 2.27 Ga and/or 1.90 Ga along with idioblastic arsenopyrite crystals and was subsequently re-mobilized, coupled with arsenopyrite recrystallization, during the Trans-Hudson orogeny.

Slide 1



Herein we report Targeted Geoscience Initiative (TGI)-4 program results at the Meliadine Gold District, Nunavut, Canada.

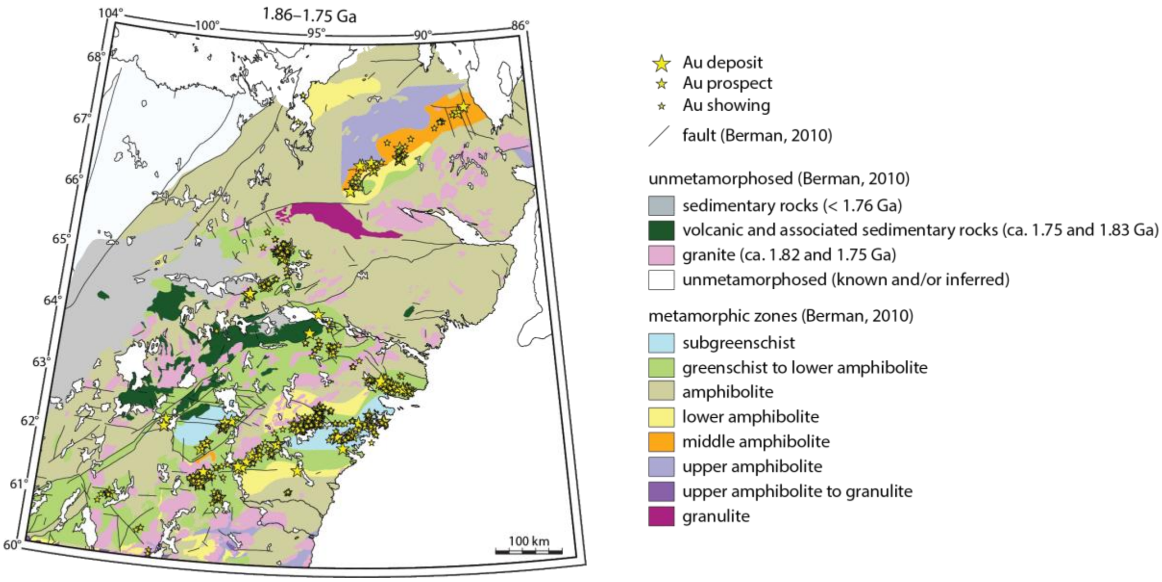
Slide 2



Regional geologic setting of the Western Churchill Province (WCP; after Paul et al., 2002). Archean greenstone belts are co-spatial with most gold occurrences despite significantly pre-dating gold. Gold occurrences are taken from NUMIN. Cullaton, Meliadine, Meadowbank, and Three Bluffs are shown for reference.

Slide 3

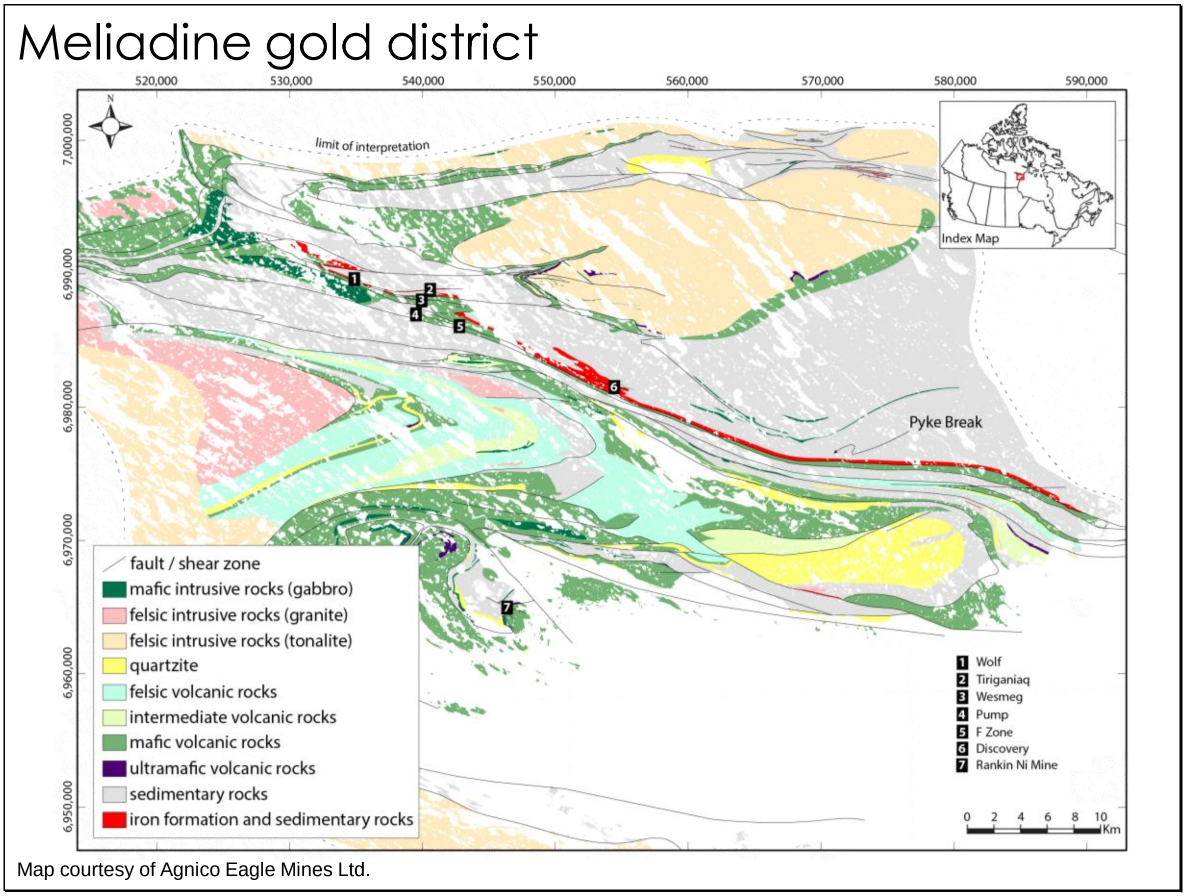
gold and the Trans-Hudson Orogeny



Map from Berman, 2010
Gold locations from NUMIN

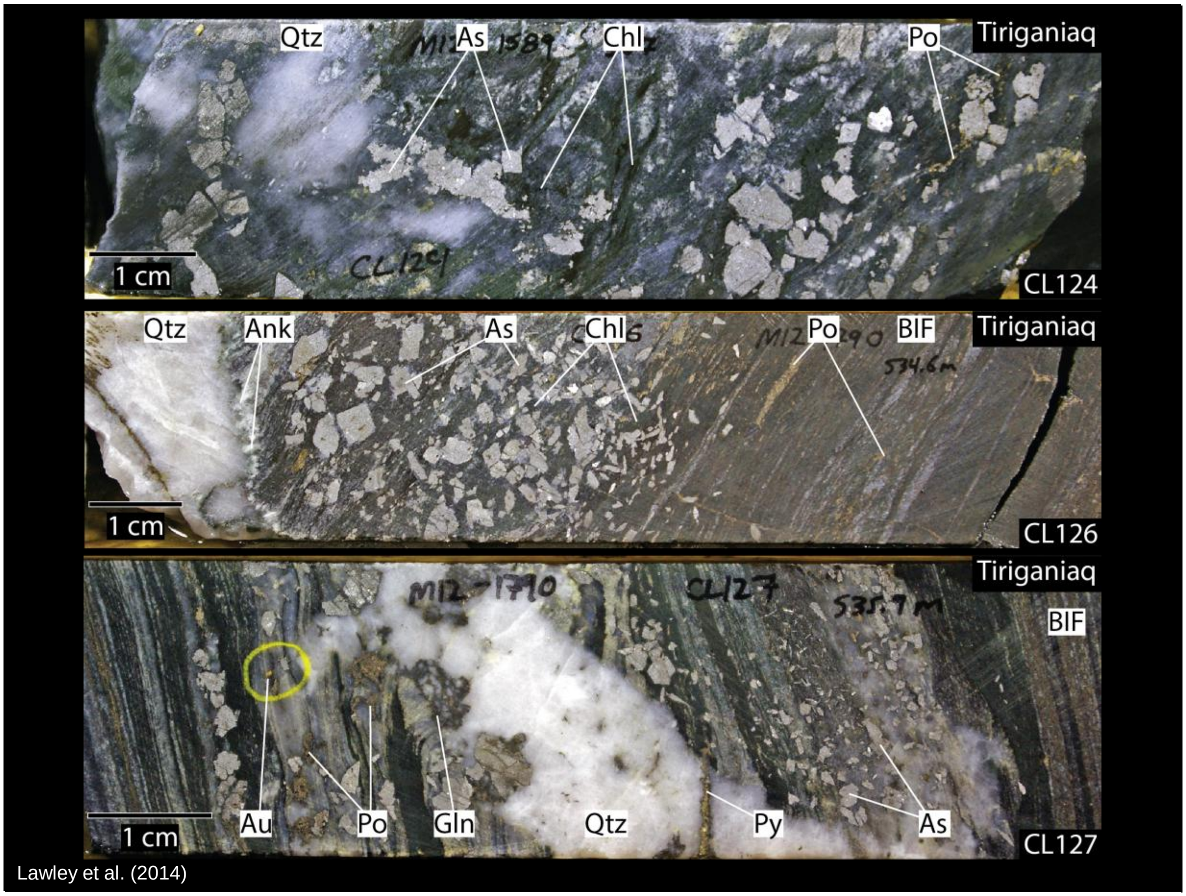
Western Churchill Province metamorphic map (simplified after Berman, 2010). Gold deposits, prospects and showings are shown for reference and are compiled from NUMIN (accessed 2014). Map shows the inferred spatial distribution of the main phase of the Tran-Hudson orogeny (1.86–1.75 Ga) along with unmetamorphosed sedimentary, volcanic and granitic rocks.

Slide 4



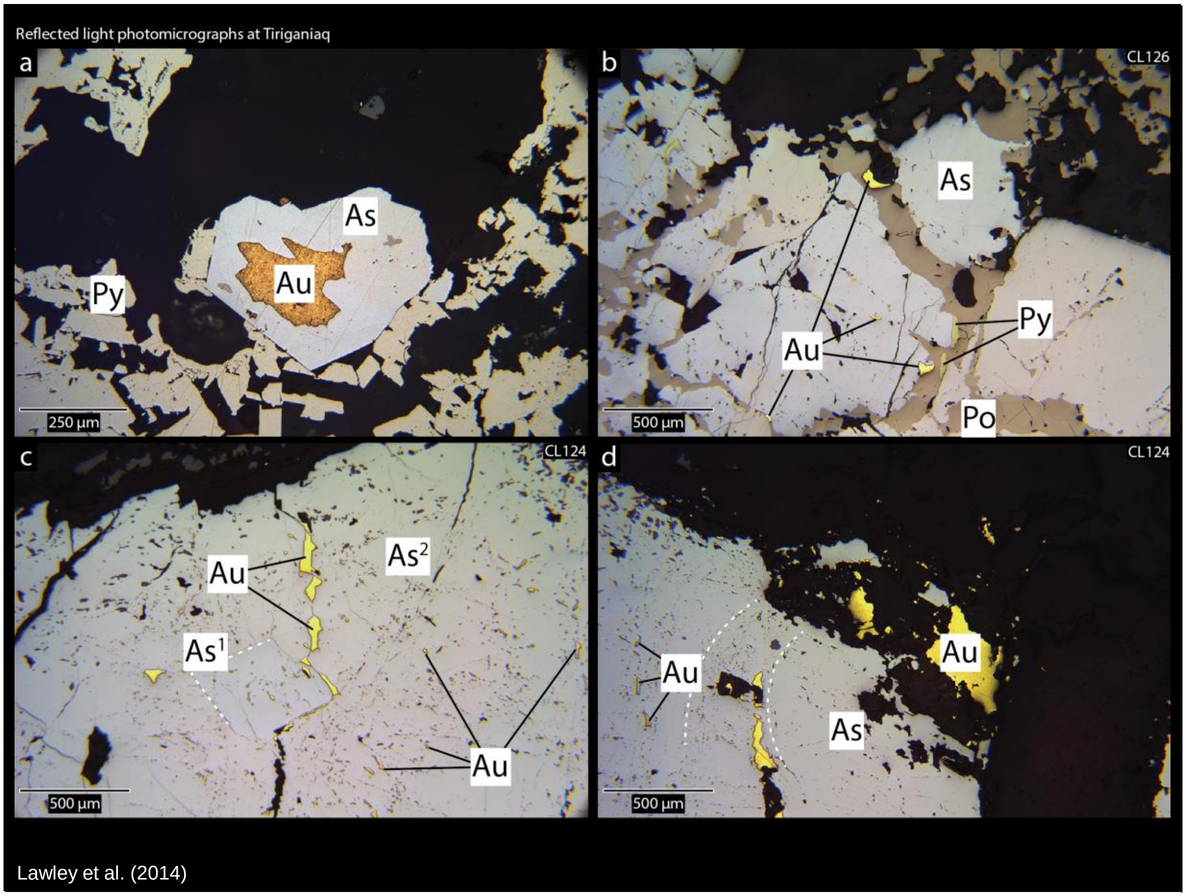
Local geological map of the Meliadine Gold District (map courtesy of Agnico Eagle Mines Ltd.). The largest of the known gold deposits occur along the Pyke Break (Wolf, Tiriganiaq, Wesmeg, Pump, F Zone, and Discovery). The former Rankin nickel mine is shown for reference.

Slide 5



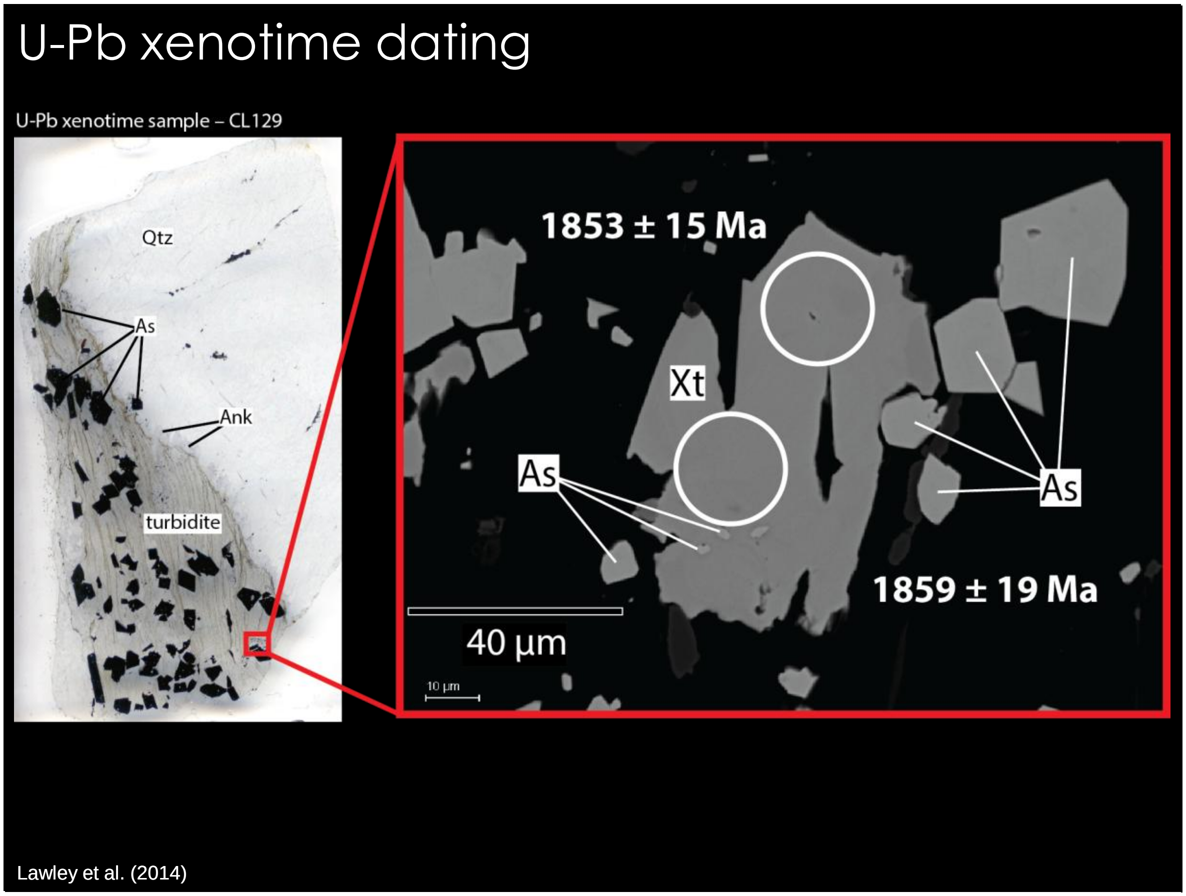
Re-Os geochronology samples showing veined and hydrothermally altered BIF. Auriferous quartz (± ankerite) veins cut BIF at the hand sample scale, but are in turn folded and transposed sub-parallel to the main deposit fabric. Locally, quartz veining is difficult to differentiate from recrystallized chert intervals. Coarse idioblastic arsenopyrite crystals are good indicators of gold-grade, but gold also occurs in the absence of arsenopyrite (abbreviations: Po = pyrrhotite; As = arsenopyrite; Qtz = quartz; Chl = chlorite; Py = pyrite; Ank = ankerite; Gln = galena).

Slide 6



Reflected light photomicrographs of gold at Tiriganiaq. Gold mostly occurs as inclusions within idioblastic arsenopyrite crystals and at crystal boundaries. Pyrrhotite and pyrite also fills idioblastic arsenopyrite fractures and likely post-date arsenopyrite. Clusters of gold are typical micro-textures at metamorphosed deposits, where gold is liberated from early sulphides during fluid-assisted recrystallization and later remobilized into low-strain micro-structural sites (abbreviations: Py = pyrite; As = arsenopyrite; Po = pyrrhotite).

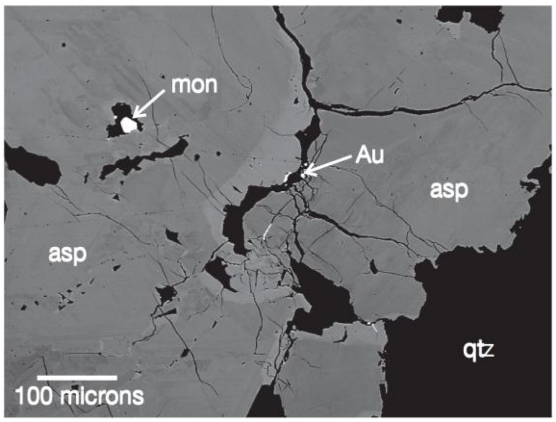
Slide 7

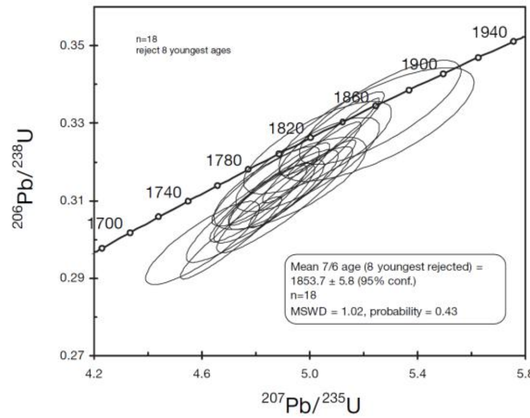


Photomicrographs of U-Pb xenotime sample from the 1000 lode (CL129) at Tiriganiaq. Xenotime is generally late and wraps early sulphide phases, but locally xenotime occurs as inclusions within arsenopyrite and pyrrhotite (not shown). Arsenopyrite mineral separates from this samples (CL129) were also dated by Re-Os geochronology. Analysis spots and $^{207}Pb/^{206}Pb$ ages, reported at 1σ, are shown for reference (abbreviations: As = arsenopyrite; Qtz = quartz; Ank = ankerite; Xt = xenotime).

Slide 8

ca. 1.85 Ga U-Pb hydrothermal monazite age

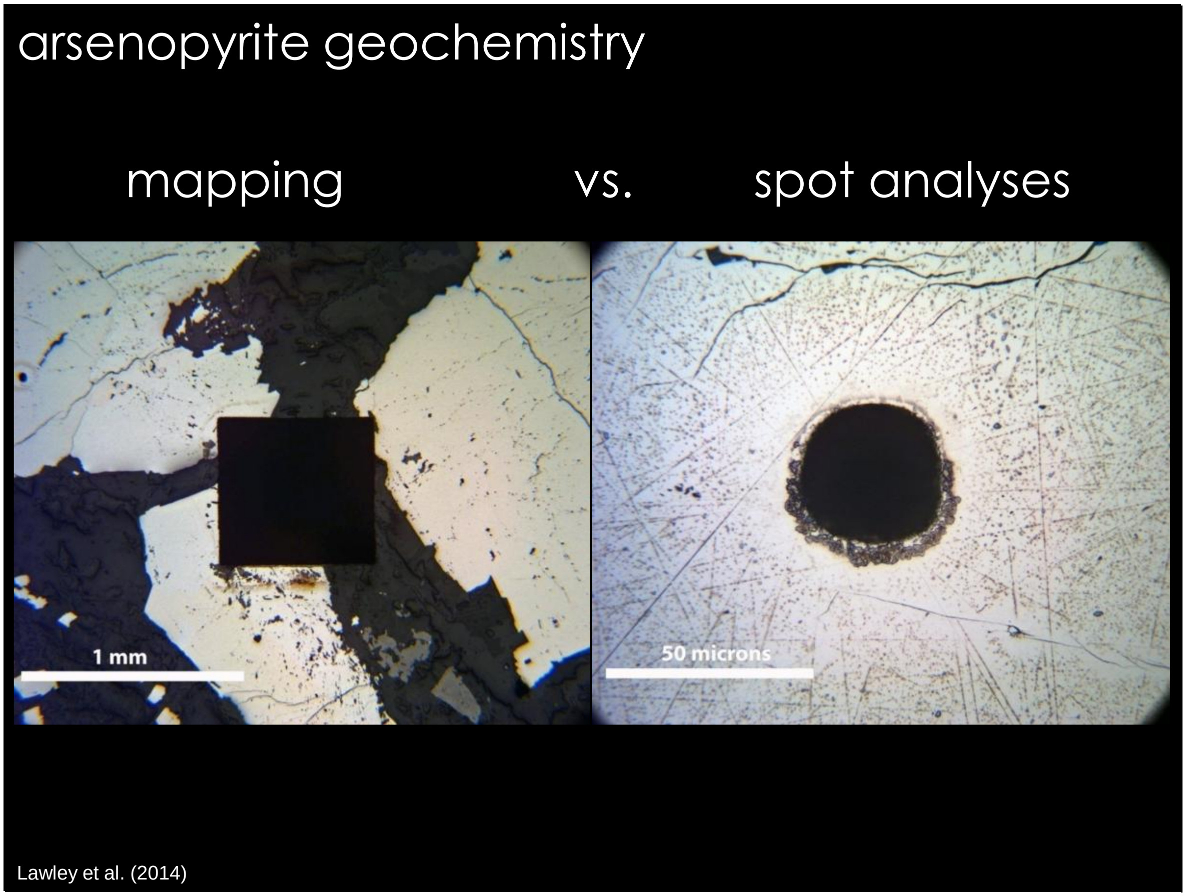




Carpenter et al. 2005

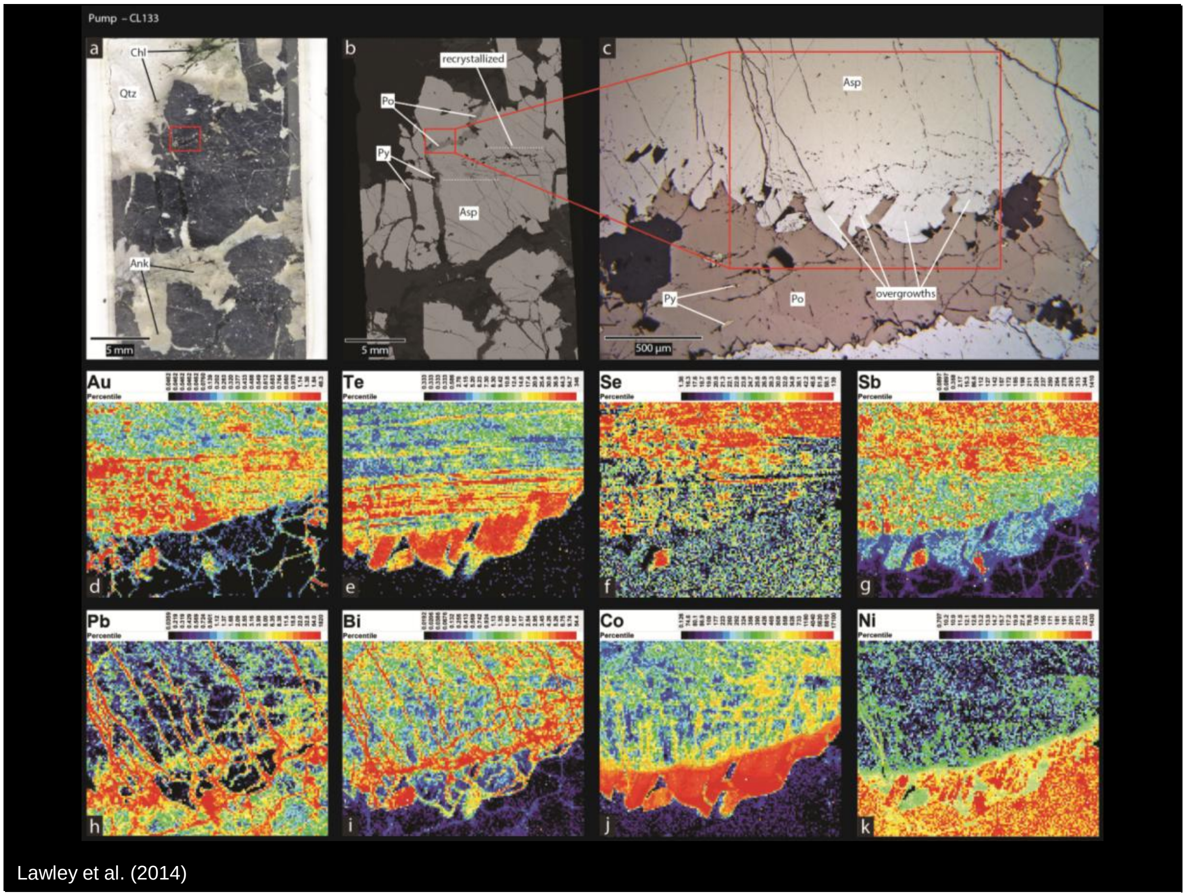
Our U-Pb xenotime ages are in good agreement with a previously reported U-Pb monazite ages (ca. 1.85 Ga) for the same deposit (Carpenter et al., 2005). Hydrothermal phosphate minerals (monazite and xenotime) occur with gold in low-strain micro-textural sites and likely date the timing of remobilization (abbreviations: mon = monazite; asp = arsenopyrite; qtz = quartz).

Slide 9



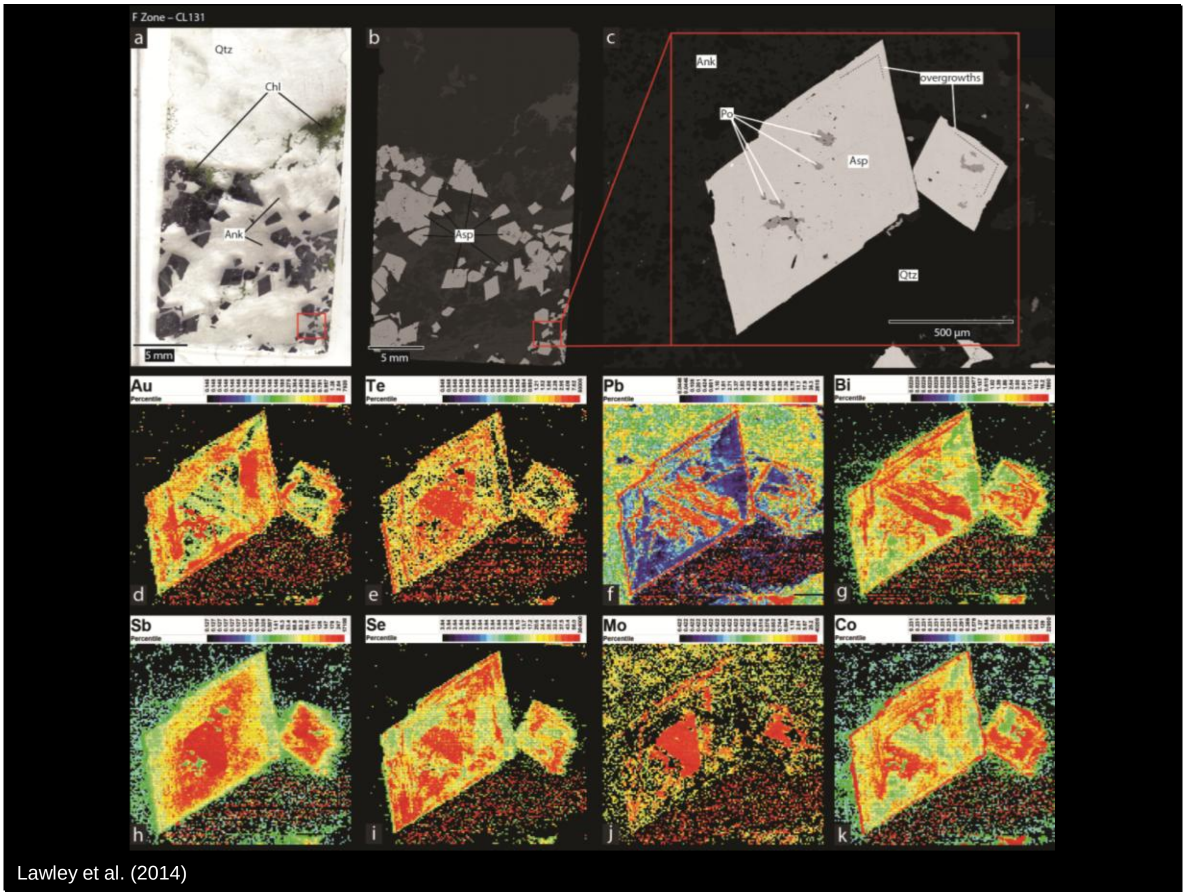
We adopted two different approaches for LA-ICP-MS arsenopyrite geochemistry: (1) spot analyses (right) and (2) mapping (left). Spot analyse yield more precise results and greater sensitivity for elements close to the detection limit (e.g., Re) due, in part, to the larger sampling volume and longer analysis time. Whereas, element mapping was performed using a grid sampling pattern comprising thousands of individual 10 µm spot analyses. These maps provide an opportunity to map the trace element concentration of specific micro-textural features.

Slide 10



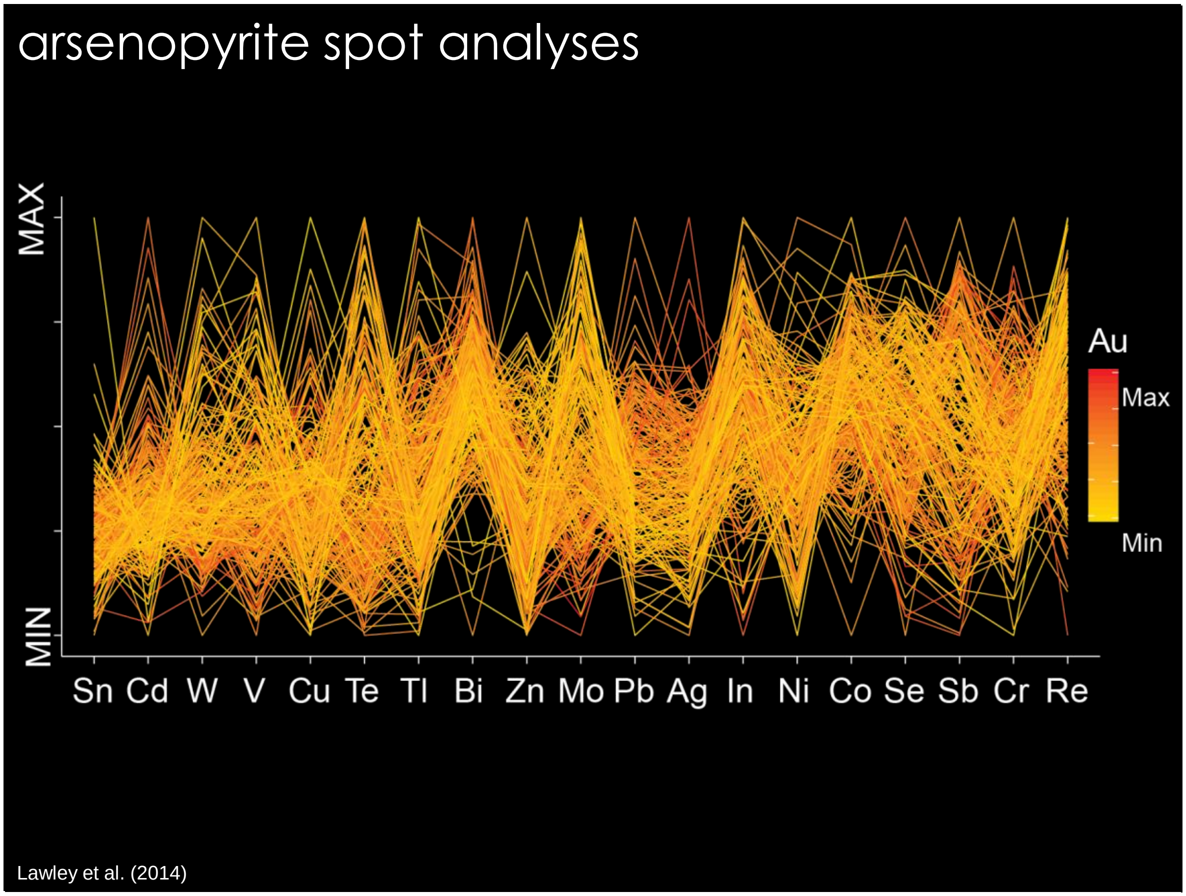
LA-ICP-MS element maps targeting arsenopyrite overgrowths (CL133): (a) thin section scan showing auriferous quartz-ankerite vein and mapped region; (b) thin-section scale SEM backscatter photomicrograph showing the mapped region and a band of recrystallized arsenopyrite; (c) zoomed in reflected light photomicrograph showing arsenopyrite overgrowths and late pyrite-pyrrhotite filling arsenopyrite fractures; (d–k) element maps plotted at percentile scale and reported in ppm. Maps clearly delineate multiple fracture sets that cut coarse-grained idioblastic arsenopyrite and geochemically distinct arsenopyrite overgrowths. The latter are relatively Au (± Se ± Sb)-poor and Te (±Co ± Ni)-rich. Gold- and Te-rich fractures cut arsenopyrite and are in turn cut by base-metal (Pb ± Bi ± Ni) rich fractures. The latest fracture set also cuts late pyrrhotite (abbreviations: Chl = chlorite; Qtz = quartz; Ank = ankerite; Po = pyrrhotite; Py = pyrite; Asp = arsenopyrite).

Slide 11



LA-ICP-MS maps targeting arsenopyrite overgrowths (CL131): (a) thin section scan showing auriferous quartz-ankerite vein and mapped region; (b) thin-section scale SEM backscatter photomicrograph showing mapped region; (c) zoomed-in SEM back-scatter photomicrograph of mapped arsenopyrite. Arsenopyrite overgrowths are delineated by mineral inclusion trails. Pyrrhotite inclusions point to a cryptic pre-arsenopyrite sulfide history; (d–k) element maps plotted with percentile concentration scales (all scales in ppm). Oscillatory-zoning is preserved by Sb (± Te ± Se); whereas the remaining elements record pos-crystallization processes. Gold is concentrated peripheral to the Sb-rich arsenopyrite core and along the arsenopyrite crystal boundaries. Base-metals (Pb-Bi) are concentrated along late recrystallized arsenopyrite bands and at arsenopyrite crystal boundaries (abbreviations: Qtz = quartz; Chl = chlorite; Ank = ankerite; Asp = arsenopyrite; Po = pyrrhotite).

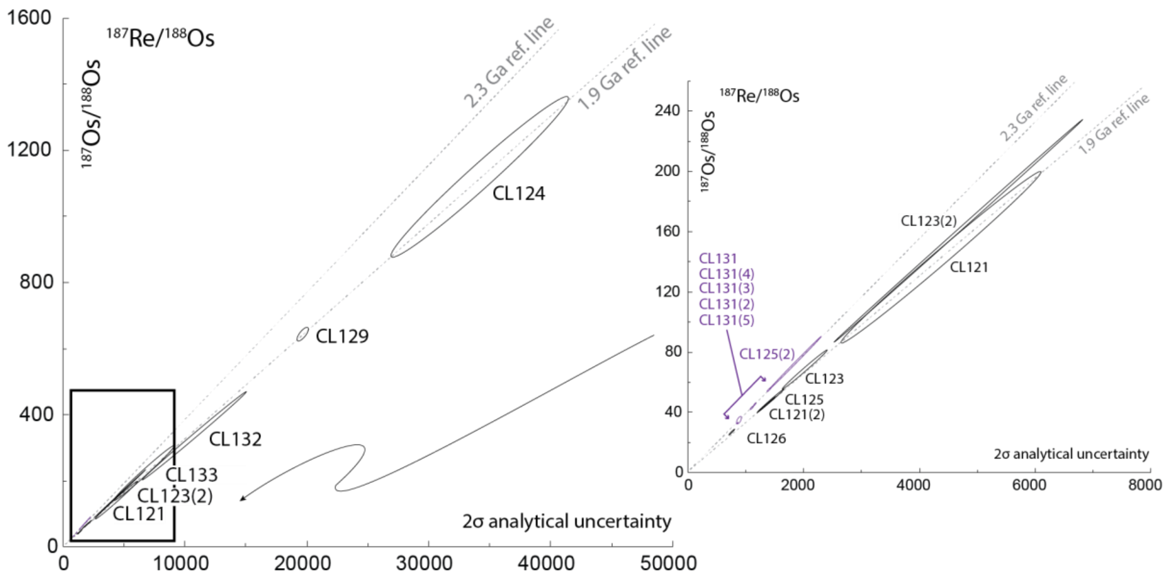
Slide 12



Parallel coordinate plot, or spider plot, for spot analyses scaled to 0–1 based on the maximum and minimum values for each center log ratio (clr)-transformed element concentration and colour coded to gold. Elements (x axis) are organized according to skewness, which increases left to right. Gold-rich analyses (red) are relatively elevated in Cd-Bi-Pb-Ag-Sb-Cr (from left to right), but yield relatively depleted concentrations of W-V-Te-Mo-Se-Sb-Re (from left to right). Critically, for Re-Os analysis, the most Re-rich samples also tend to be gold-poor and suggest that ages from Re-rich samples may pre-date late gold enrichment.

Slide 13

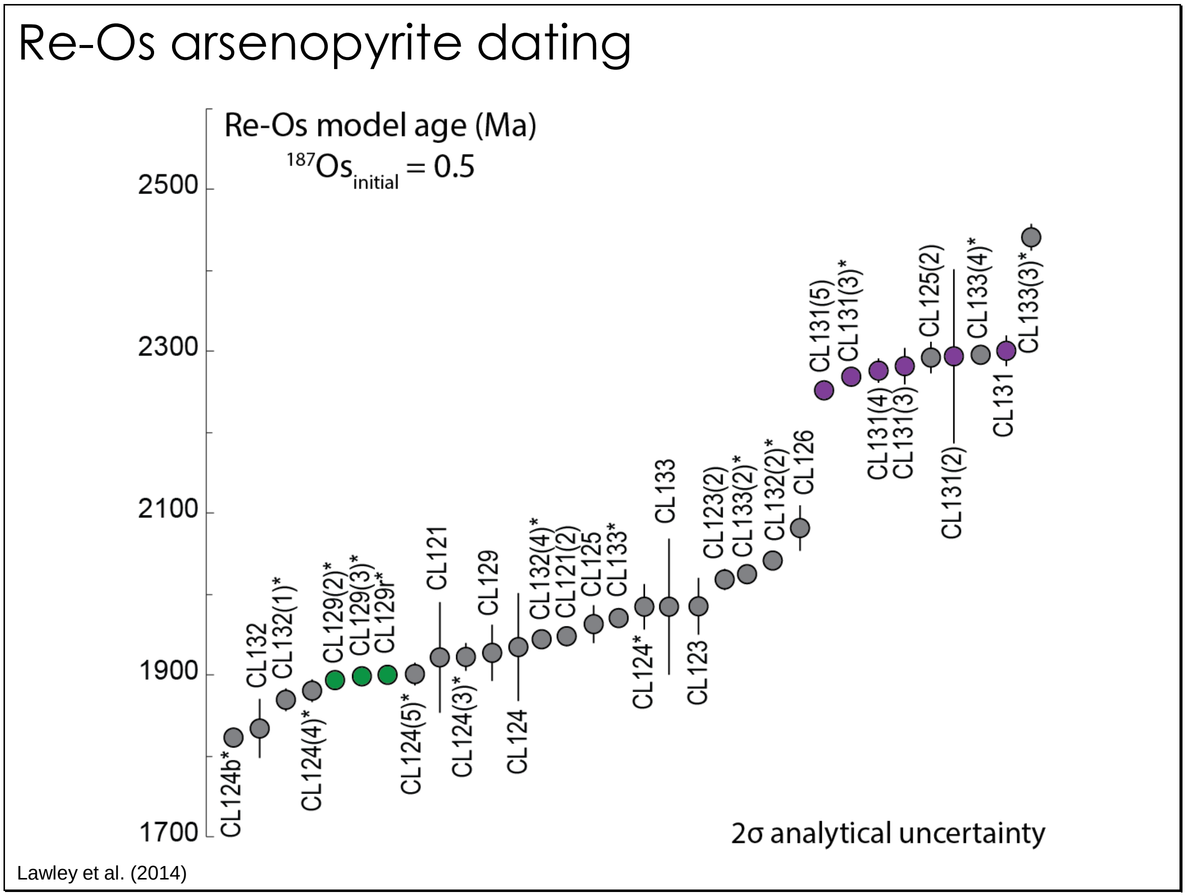
Re-Os arsenopyrite dating



Lawley et al. (2014)

Conventional Re-Os isochron diagram that is best-suited for plotting samples with measurable common Os that were analyzed with the $^{185}Re + ^{190}Os$ spike. Samples are generally co-linear with the 2.3 and 1.9 Ga reference lines, but possess large and correlated analytical uncertainties due to the highly-radiogenic isotopic composition of the analyzed arsenopyrite.

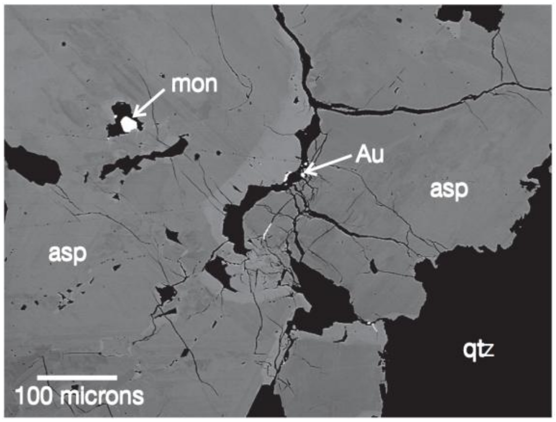
Slide 14

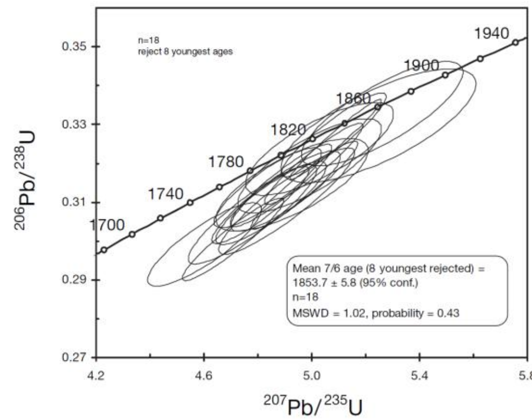


Re-Os arsenopyrite model ages for all analyses. Arsenopyrite aliquots devoid of common Os were analyzed with a mixed double spike. These analyses yield model ages that are analogous to molybdenite model ages and are highlighted by an asterisk next to the analysis name. Samples with common Os, and measured using ^{185}Re + ^{190}Os spike, are also shown for reference. The data yield a range of Re-Os model ages from 2.3–1.85 Ga that are clearly outside of analytical uncertainty at 2σ. These data are difficult to interpret within the context of a single and co-genetic arsenopyrite sample suite. Part of this complexity is explained by the relatively low Re-concentration of the analyzed samples. The two most Re-rich and reproducible samples, CL129 (green) and CL131 (purple), yield ages at 1.9 and 2.3 Ga, respectively. We suggest that gold was introduced at 2.3 Ga and/or 1.9 Ga along with arsenopyrite and was remobilized along with hydrothermal phosphate mineralization at 1.85 to 1.86 Ga.

Slide 15

ca. 1.85 Ga U-Pb hydrothermal monazite age





Carpenter et al. 2005

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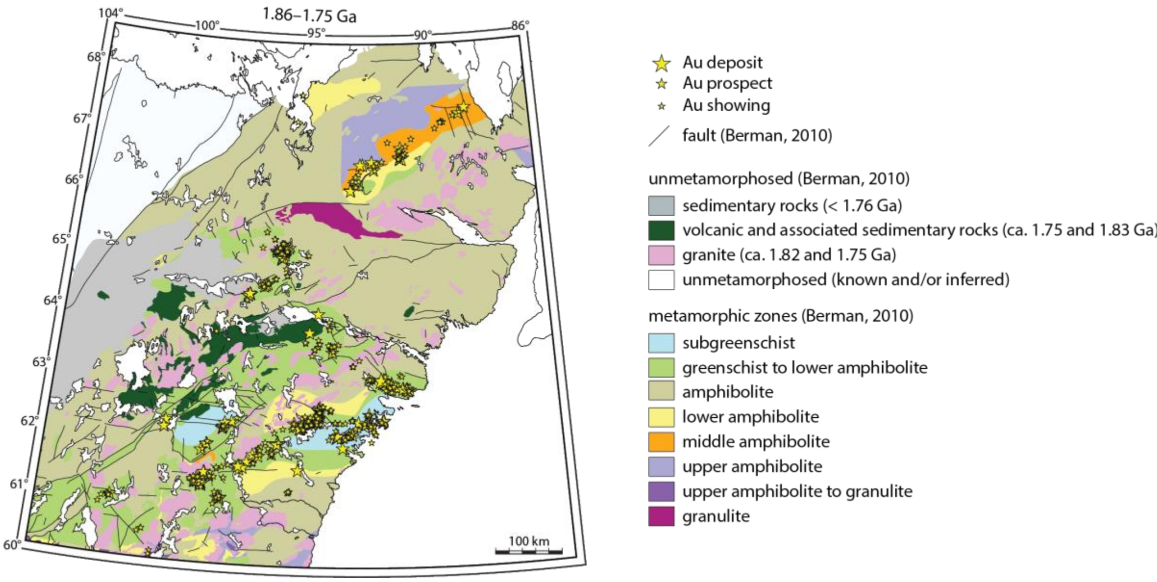
Slide 16

gold and the Trans-Hudson Orogeny



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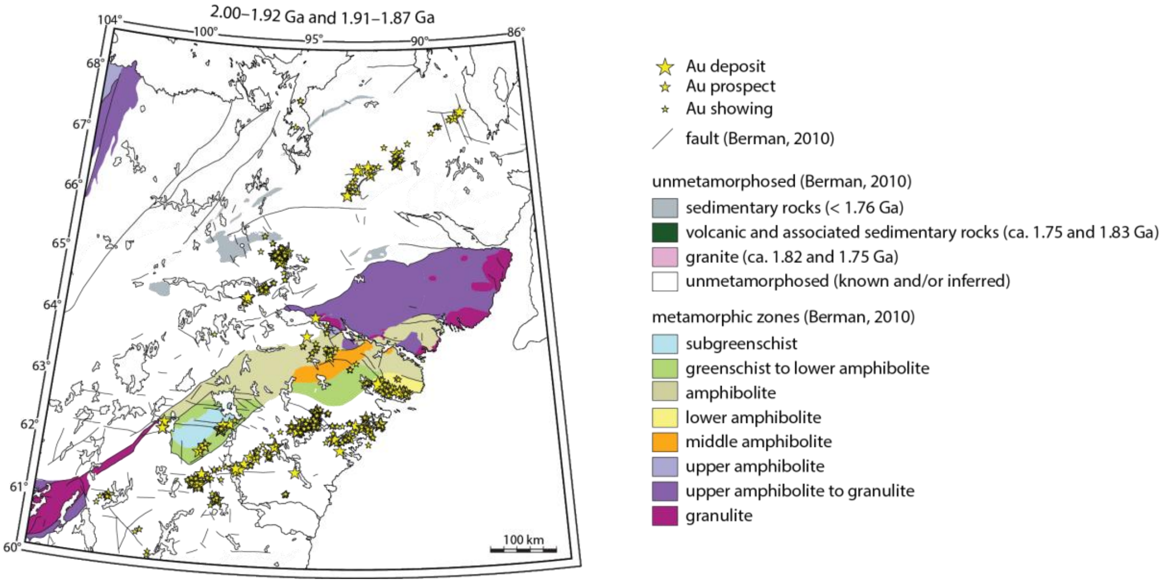
Slide 17

seeing through the Trans-Hudson Orogeny

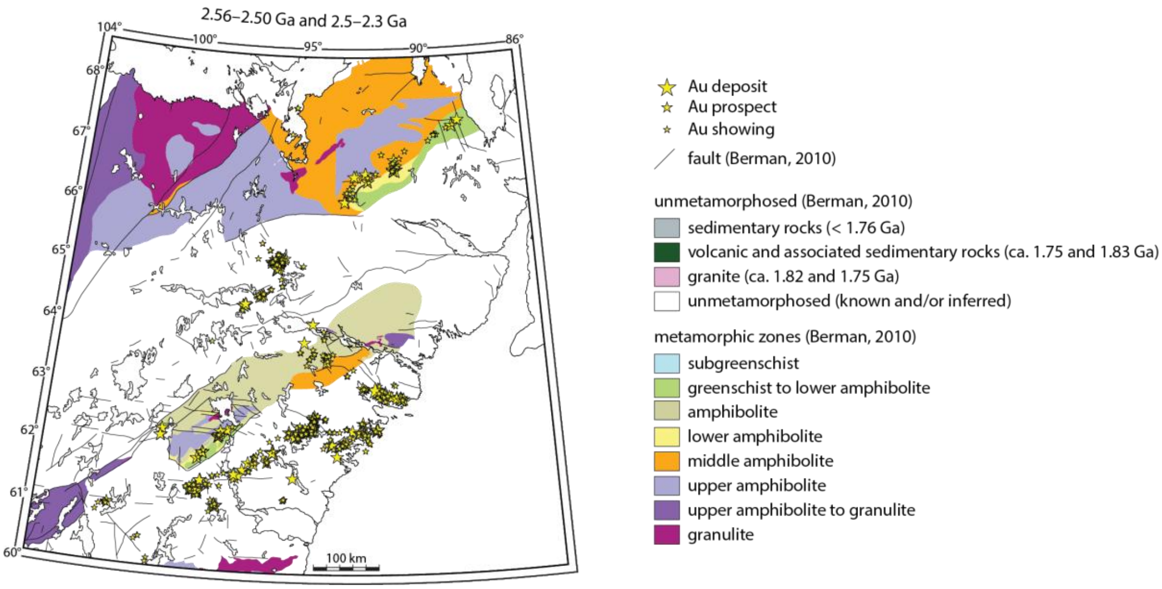


Map from Berman, 2010
Gold locations from NUMIN

Western Churchill Province metamorphic map (simplified after Berman, 2010). Gold deposits, prospects and showings are shown for reference and are compiled from NUMIN (accessed 2014). Map shows the inferred spatial distribution Thelon-Taltson (2.0–1.92 Ga) and Snowbird (1.91–1.87 Ga) orogenies along with unmetamorphosed granite

Slide 18

seeing through the Trans-Hudson Orogeny



Map from Berman, 2010

Gold locations from NUMIN

Western Churchill Province metamorphic map (simplified after Berman, 2010). Gold deposits, prospects and showings are shown for reference and are compiled from NUMIN (accessed 2014). Map shows the inferred distribution of the MacQuoid (2.56–2.50 Ga) and Arrowsmith (2.5–2.3 Ga) orogenies.

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conclusions

(1) Hitherto unrecognized pre-1.86 Ga sulphide history

(2) Gold remobilization and re-working at 1.86 Ga

(3) Importance of ca. 2.3 Ga (Arrowsmith) gold elsewhere in the Western Churchill Province?

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acknowledgements

AGNICO EAGLE

TGI 4 Ore Systems

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