Differential gold endowment during the development of accretionary and dome-and-keel greenstone architectures: A case study from the eastern Archean Wabigoon subprovince, Canada

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Saskatchewan Geological Open House 2023

METAL EARTH

A new Canadian research initiative funded by Canada First Research Excellence Fund.

CANADA FIRST RESEARCH EXCELLENCE FUND

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MERC
Mineral Exploration Research Centre

What is Metal Earth?

- **METAL EARTH** is a collaborative research project focused on metal endowment in the Precambrian shield.

- It is led by the Mineral Exploration Research Centre (MERC) of Laurentian University.

- It involves many partners, including UQAC, Laval, U Ottawa, U Toronto, U Alberta, and geological surveys …

- **THE GOAL** is to improve the science for targeting and finding new orebodies.

- **MAIN QUESTION** addressed by Metal Earth is why are greenstone belts enriched in metals and others not. What are the processes or factors responsible for the preferential metal endowment of greenstone belts?

Metal Earth Strategy

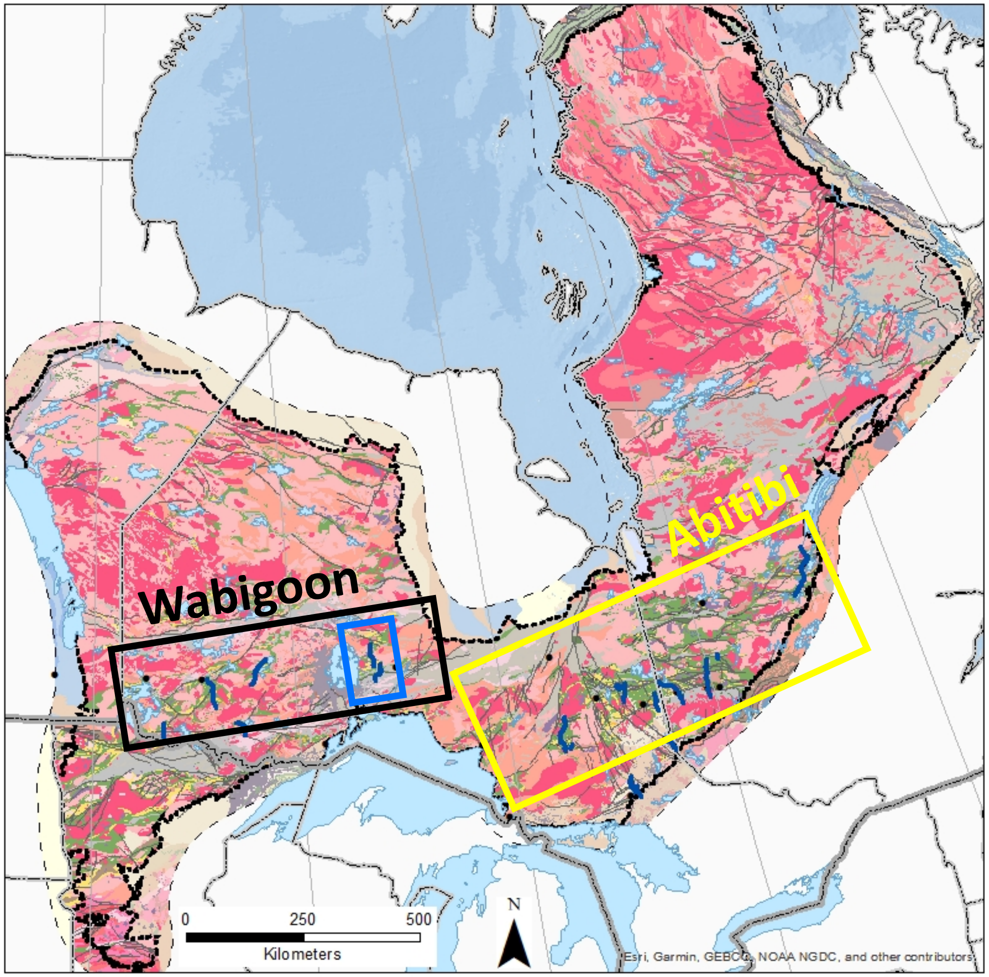
- Focus on Archean greenstone belts, which represent 60% of Earth history and almost 50% of Canada's metal wealth
- **Resolve ore system-scale controls at craton - greenstone belt - district - deposit scales**
- **Image ore and non-ore systems at full crust-mantle scale**
- **Focused on the Superior Craton as the level of framework geoscience is unprecedented, take this into other Precambrian terranes**

Metal Earth Four Main Components

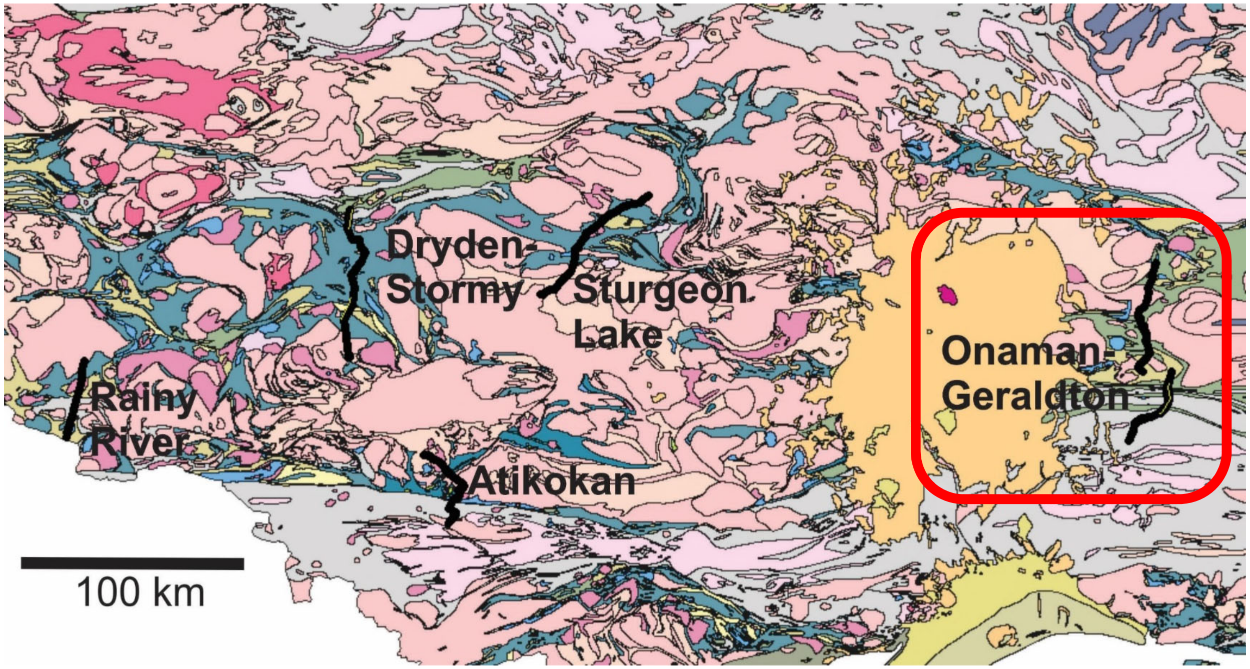
- **Craton Scale Research**: investigate the architecture of greenstone belts and their link with surrounding granitoids during craton assembly and mineral district formation
- **Data Analytics Research**: Develop data integration, analysis and interpretive tools to predict metal endowment and guide exploration
- **Thematic Research**: to address specific processes or questions on metal endowment
- **Transect Scale Research**: resolve the lithospheric-crustal architecture and fluid pathways, providing a geological and geophysical framework to resolve the differential endowment of terranes and structures

Transect research involves:

- Acquisition of new seismic and MT surveys;
- Their integration with existing gravity and magnetic data;
- Targeted geoscience to improve our understanding of the geology.



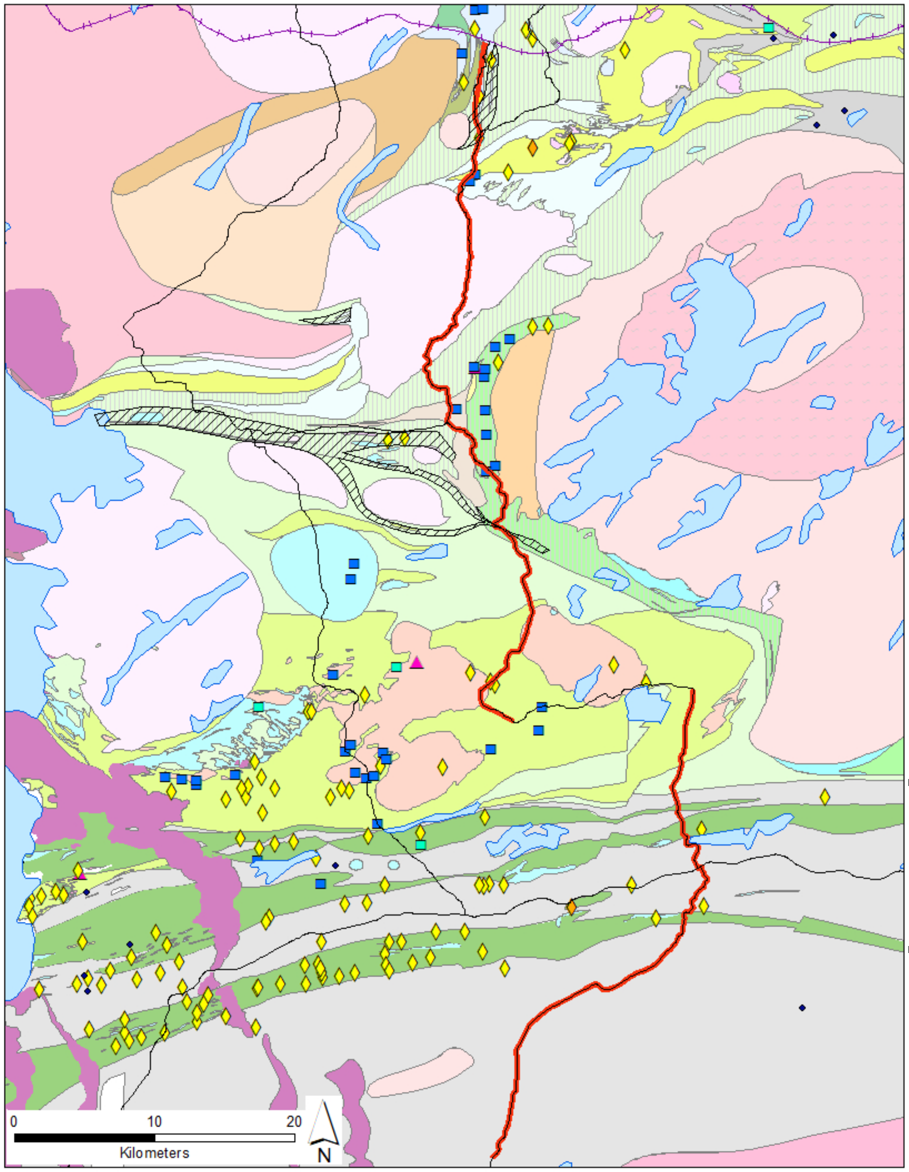
Wabigoon Transects



All of this to address the MAIN QUESTION of Metal Earth: Why are greenstone belts enriched in metals and others not. What are the processes or factors responsible for the preferential metal endowment of greenstone belts?

OUTLINE

- Overview of the geology of the two main greenstone belts in the eastern Wabigoon subprovince: Onaman-Tashota Belt and Beardmore-Geraldton Belt;
- Comparison of their structural history, including the relative and absolute timing of structures in the two belts;
- Comparison of the gold mineralization history of the two belts;
- Integration of these results with the new seismic and MT transect;
- Summarize the factors and processes responsible for the preferential gold endowment of the eastern Wabigoon subprovince.



Overview of the geology of the two greenstone belts in the eastern Wabigoon terrane

Onaman-Tashota Belt (eastern Wabigoon terrane)

(< 100,000 ounces gold)

Mineral occurrences:

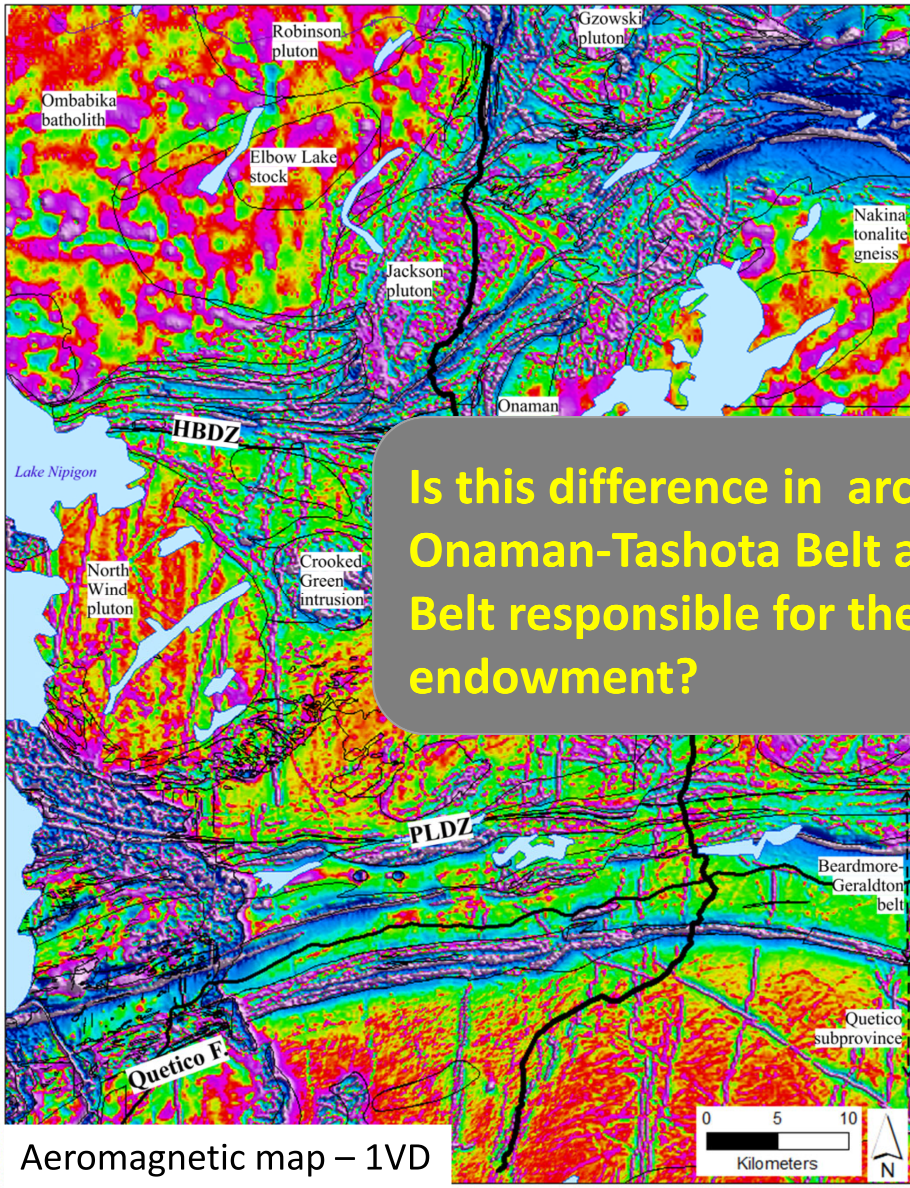
- ◆ • Au; Au-Zn; Au-Cu; Au-Sb
- ◆ • Ag
- ■ • Base metals: Cu; Zn; Zn-Pb; Cu-Zn-Ni; Cu-Zn; Cu-Zn-Pb; Cu-Ni; Cu-Au-Ag; Cu-Au;
- ▲ • Mo
- □ • Ni

Beardmore-Geraldton Belt (eastern Wabigoon Terrane)

(> 4 million ounces gold)

Quetico subprovince

Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005



Aeromagnetic map – 1VD

Different Architectures…

Onaman-Tashota Belt
(eastern Wabigoon terrane)

Dome-and-keel architecture

nfolded volcanic units in
ween granitic domes

00,000 ounces gold)

Is this difference in architecture between the Onaman-Tashota Belt and Beardmore-Geraldton Belt responsible for their differential gold endowment?

Beardmore-Geraldton Belt
(eastern Wabigoon Terrane)

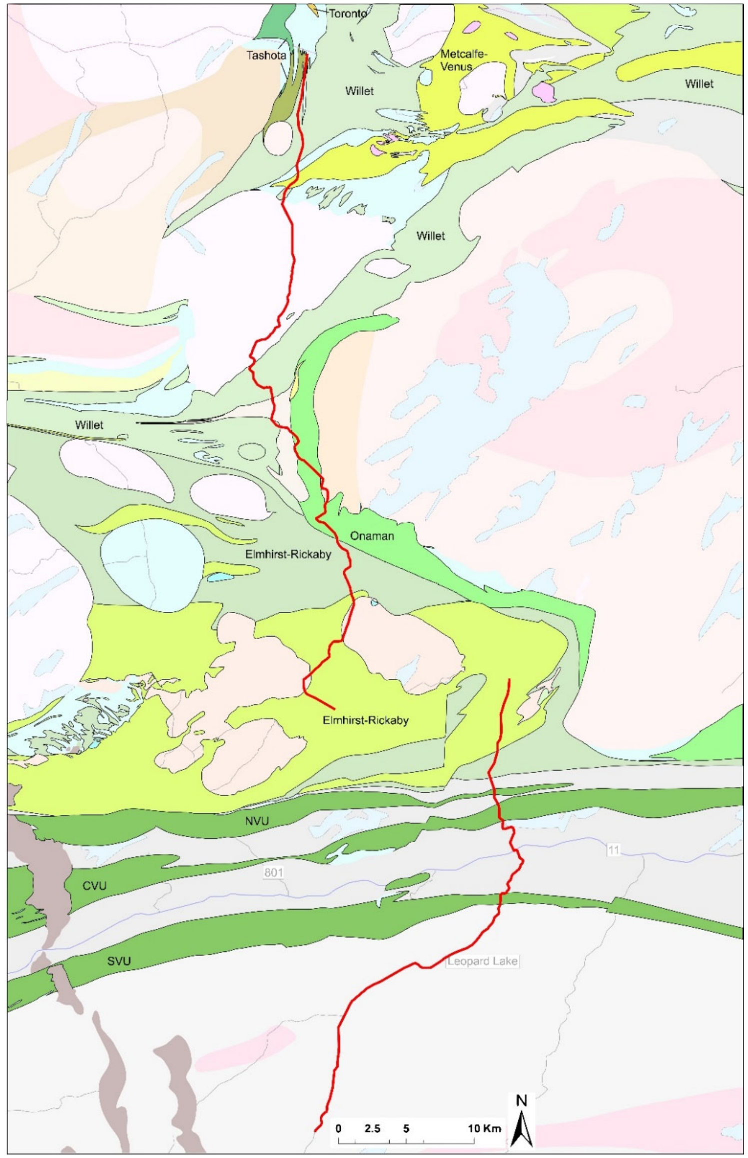
Linear accretionary architecture

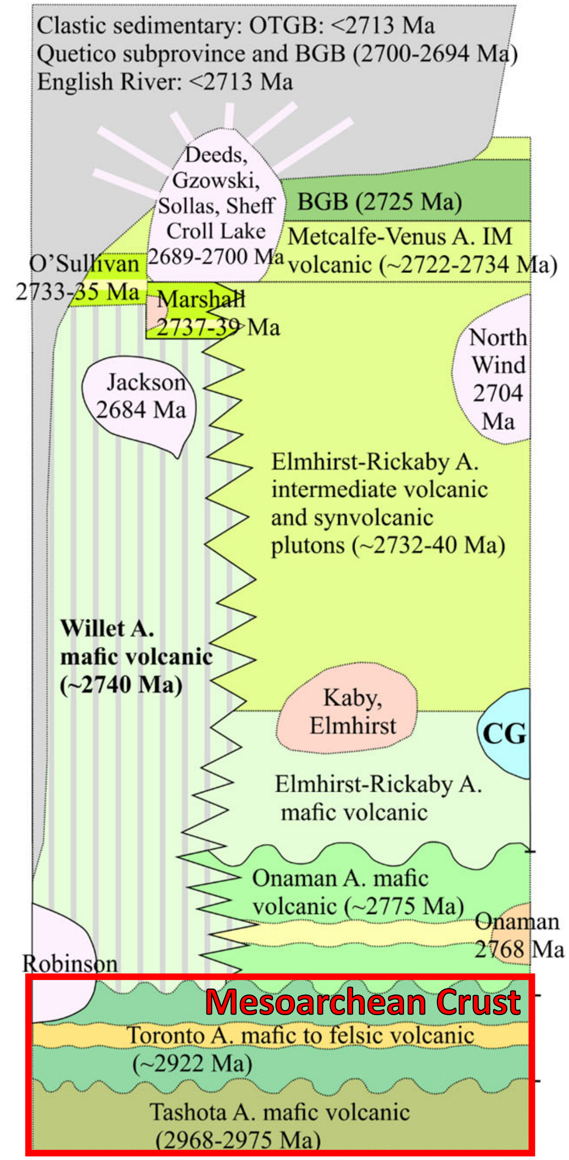
Interleaved panels of volcanic and sedimentary units

(> 4 million ounces gold)

Quetico subprovince

Volcanic stratigraphy
Onaman-Tashota Belt
Beardmore-Geraldton Belt





Neoarchean sedimentary assemblages

Onaman-Tashota Belt

Humboldt assemblage
<2713 Ma

Albert-Gledhill assemblage <2710
Ma

Conglomerate assemblage
<2707 Ma

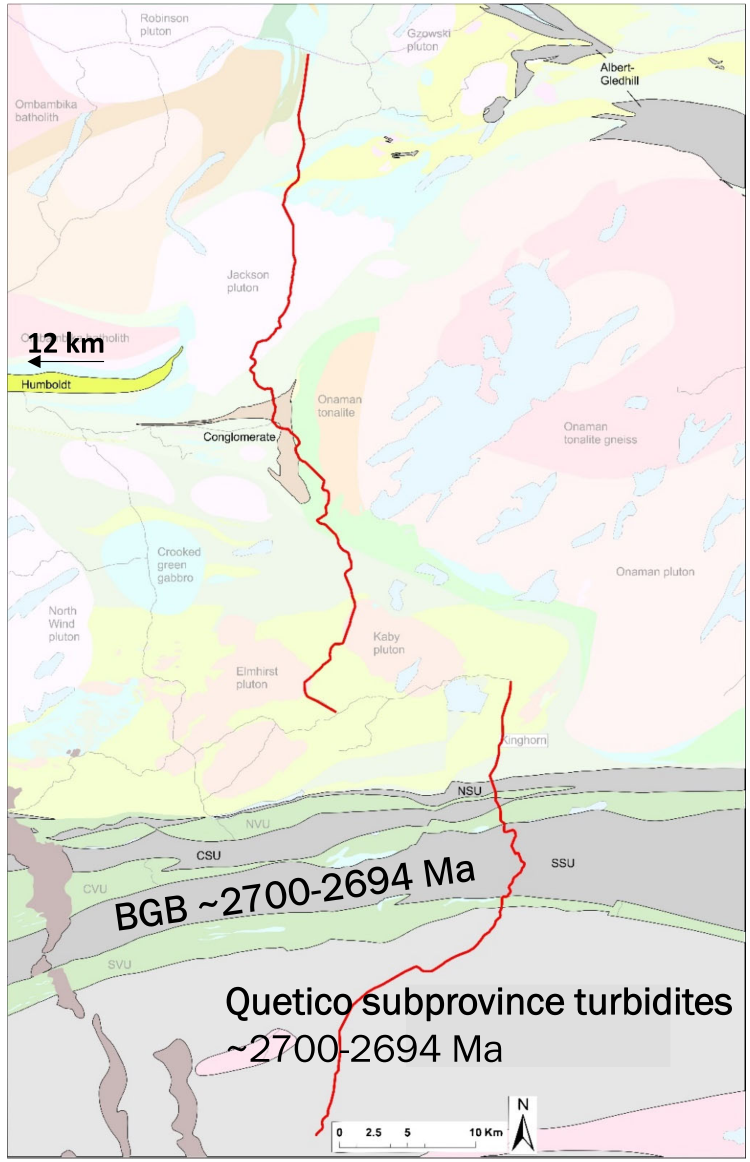
Humboldt-Nipigon conglomerate
<2671 Ma

Beardmore-Geraldton Belt

BGB metasedimentary rocks
~2700-2694 Ma

Quetico Subprovince

Turbidites ~2700-2694 Ma



Quetico subprovince
- Fine clastic sedimentary rocks

Beardmore-Geraldton belt
- Fine to coarse clastic sedimentary rocks
- Mafic to intermediate with lesser felsic volcanic rocks

Conglomerate assemblage (<2707 Ma)
- Coarse clastic sedimentary rocks

Albert-Gledhill assemblage (<2710 Ma)
- Coarse clastic sedimentary rocks
- Wacke

Humboldt assemblage (<2713 Ma)
- Intermediate to felsic tuff

Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; Tóth 2018

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Onaman pluton and tonalite gneiss – composite massive and gneissic granitoid intrusion with amphibolite 2923 – 2672 Ma

*Esnagami batholith (2921 Ma)

Syn-volcanic plutons: 2780-2720 Ma

- **Onaman tonalite** 2768 Ma
- **Kaby pluton** 2734 Ma
- **Elmhirst pluton** 2731-2738 Ma
- **Crooked Green intrusion** 2732-2735 Ma
- **Elbow Lake** pluton 2722 Ma

Syn- to late-tectonic plutons 2700-2680 Ma

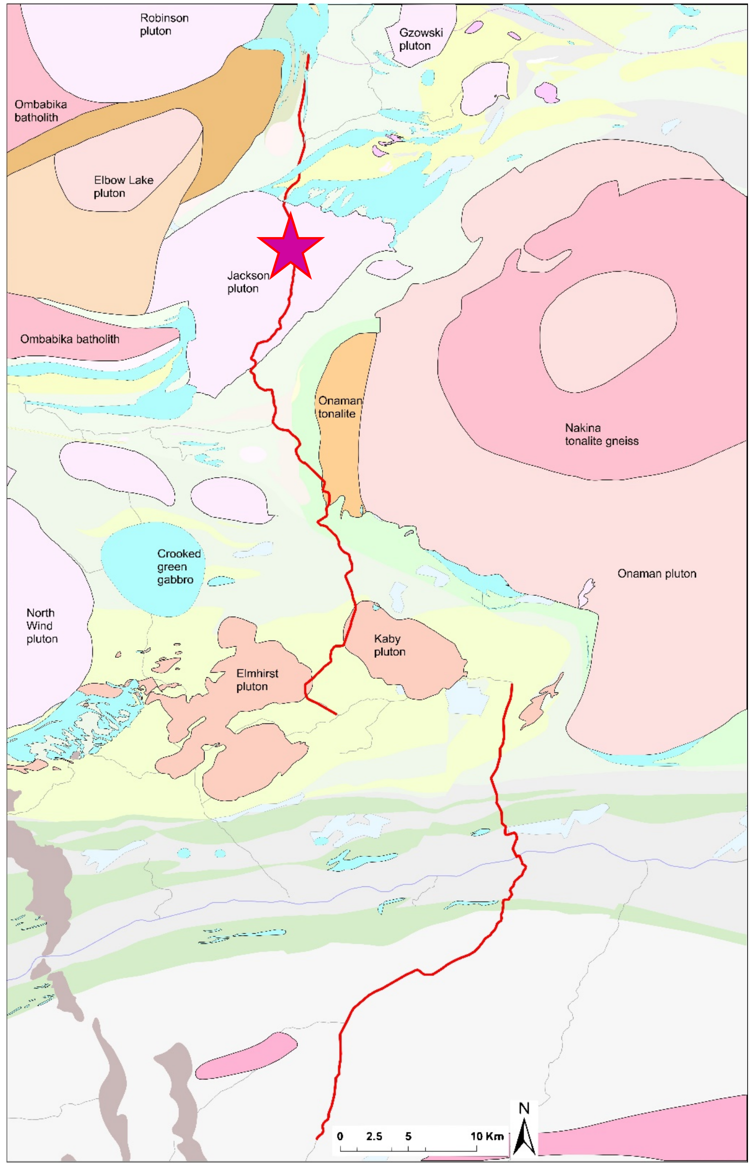
Gzowski pluton 2698 Ma

*Sheff pluton 2698 Ma

*Deeds pluton 2694 Ma

*Sollas pluton 2692 Ma

Jackson pluton 2684±3 Ma
(Hamilton, 2019-2020; pers. comm.) ★



Mesoarchean to Neoarchean intrusive rocks in the Onaman-Tashota Belt

ARCHEAN
- Diorite to quartz diorite
- Tonalite to granodiorite
- Granodiorite to tonalite
- Tonalite to granodiorite

NEOARCHEAN
- Granit to granodiorite
- Granodiorite, monzogranite, monzonite
- Gabbro

Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; Bjorkman 2017

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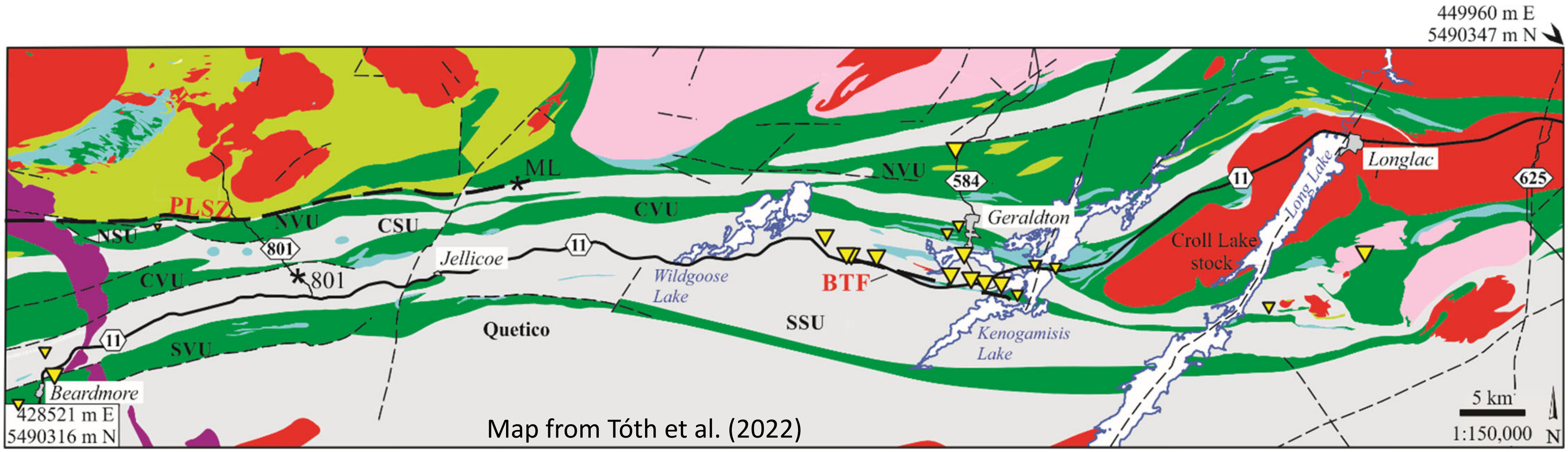
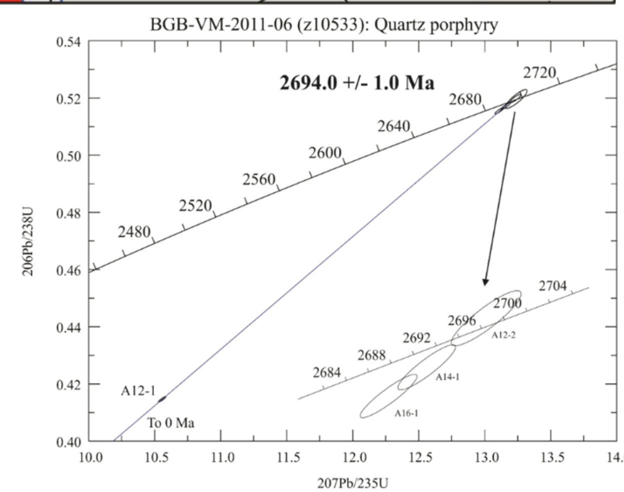
Neoarchean intrusive rocks in the Beardmore-Geraldton Belt



Map from Tóth et al. (2022)

Croll Lake stock 2690±1 Ma (Corfu, 2000)

Quartz-feldspar porphyry 2694±1 Ma (Tóth et al., 2022)



Overview of geology of the Onaman-Tashota Belt and Beardmore-Geraldton Belt

	Onaman-Tashota belt	*Beardmore-Geraldton belt*
Volcanism	Neoarchean volcanism (2722- 2780 Ma) Mesoarchean volcanism (2922 Ma -2975 Ma)	Neoarchean volcanism (ca. 2725 Ma)
Sedimentation	Turbidites and polymictic conglomerates (2713 Ma - 2692 Ma)	Turbidites and polymictic conglomerates (2700 Ma - 2692 Ma)
Plutonism	Neoarchean plutonism Syn-volcanic pluton (2780 Ma – 2720 Ma) Late syn-tectonic plutons (2700 Ma – 2680 Ma) Mesoarchean plutonism (2922 Ma)	Neoarchean plutonism Late syn-tectonic plutons (2694- 2790 Ma)

Structural Geology of the Onaman-Tashota Belt and the Beardmore-Geraldton Belt

What are the important structures?

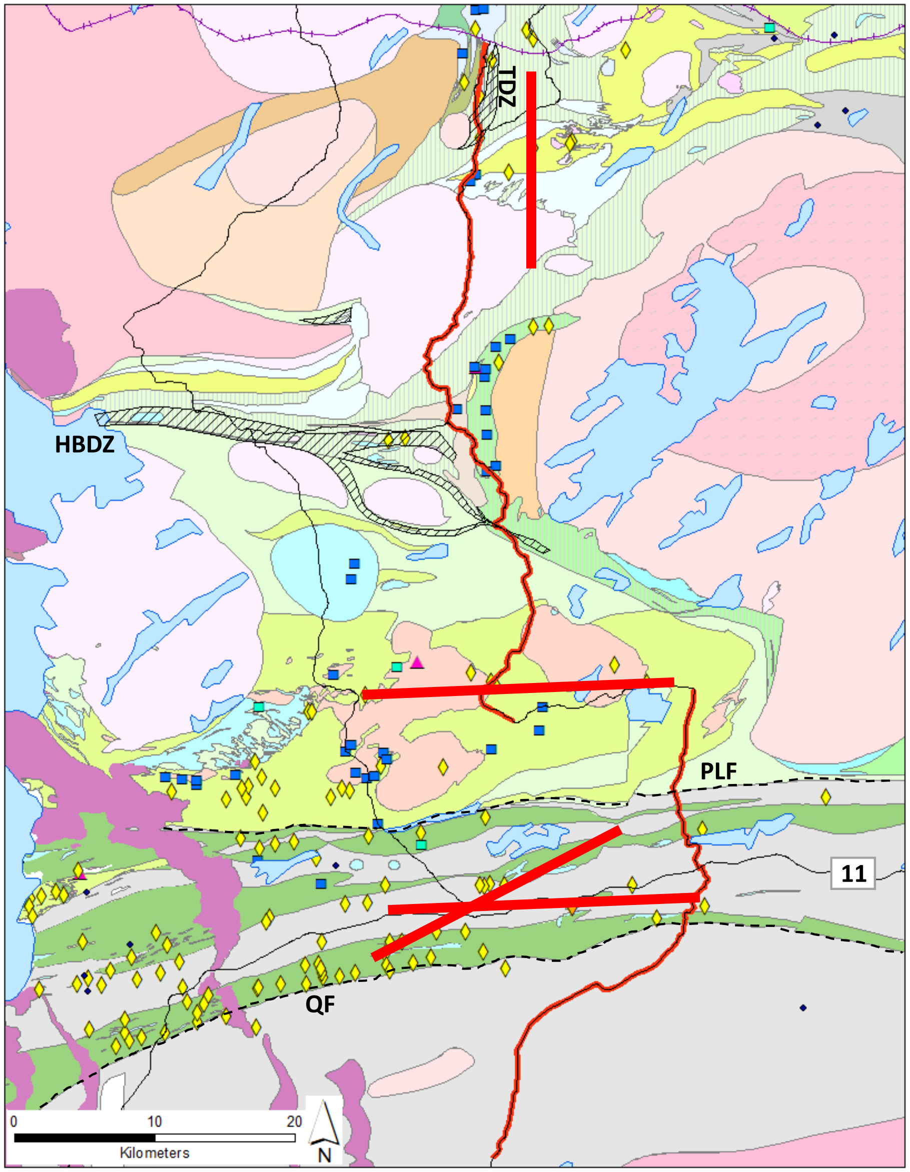
Regional foliations

Prominent N-S striking S1 foliation in the central part of the Onaman-Tashota Belt

Prominent E-W striking S2 foliation in the northern and southern part of the Onaman-Tashota Belt, and Beardmore-Geraldton Belt

Prominent NE-SW striking S3 foliation in the Beardmore-Geraldton Belt

Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; OGS MDI July, 2018



Structural Geology of the Onaman-Tashota Belt and the Beardmore-Geraldton Belt

What are the important structures?

Deformation Zones

D1 Tashota deformation zone (TDZ)

- N-striking deformation along batholith-volcanic contact

D2 & D3 Humboldt Bay deformation zone (HBZD)

- E-striking deformation corridor <u>within</u> the OTB

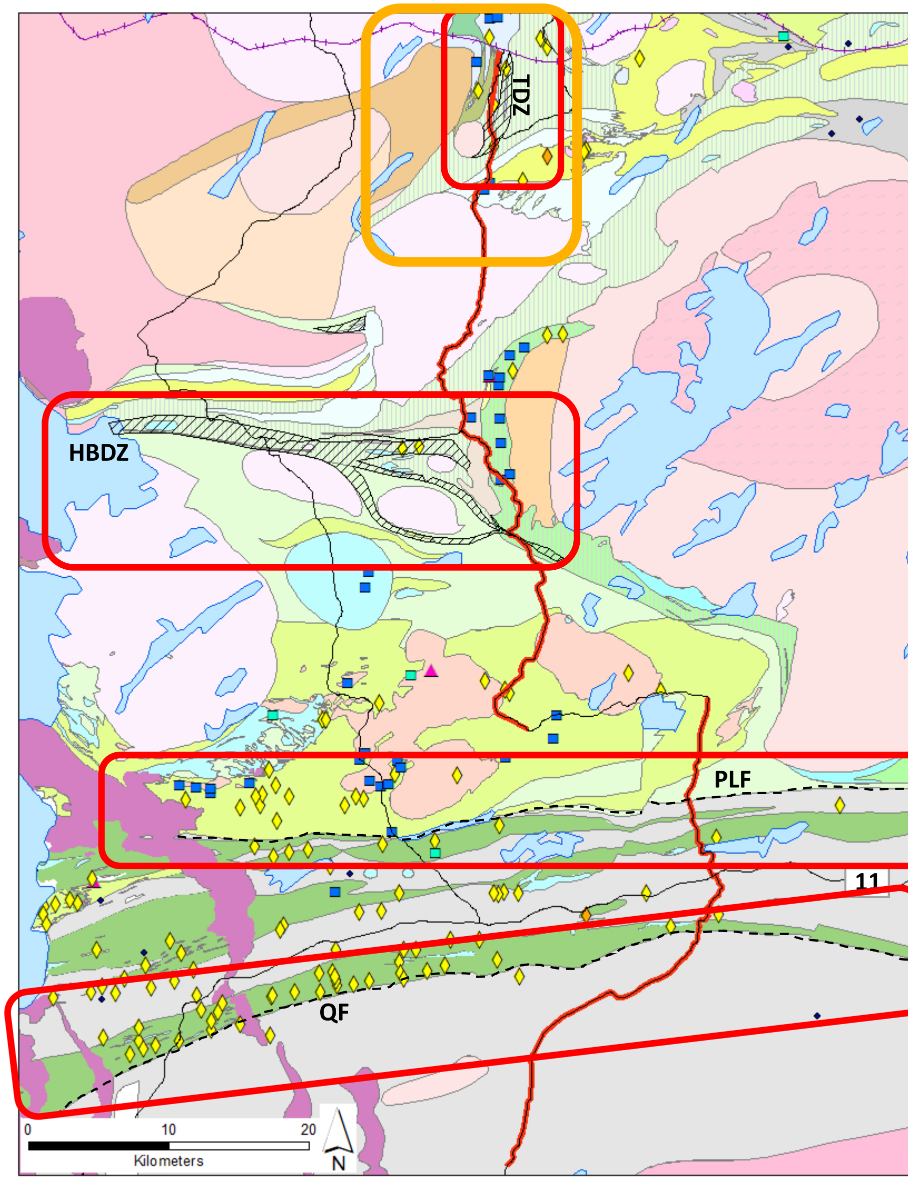
D2 & D3 Paint Lake Fault (PLF)

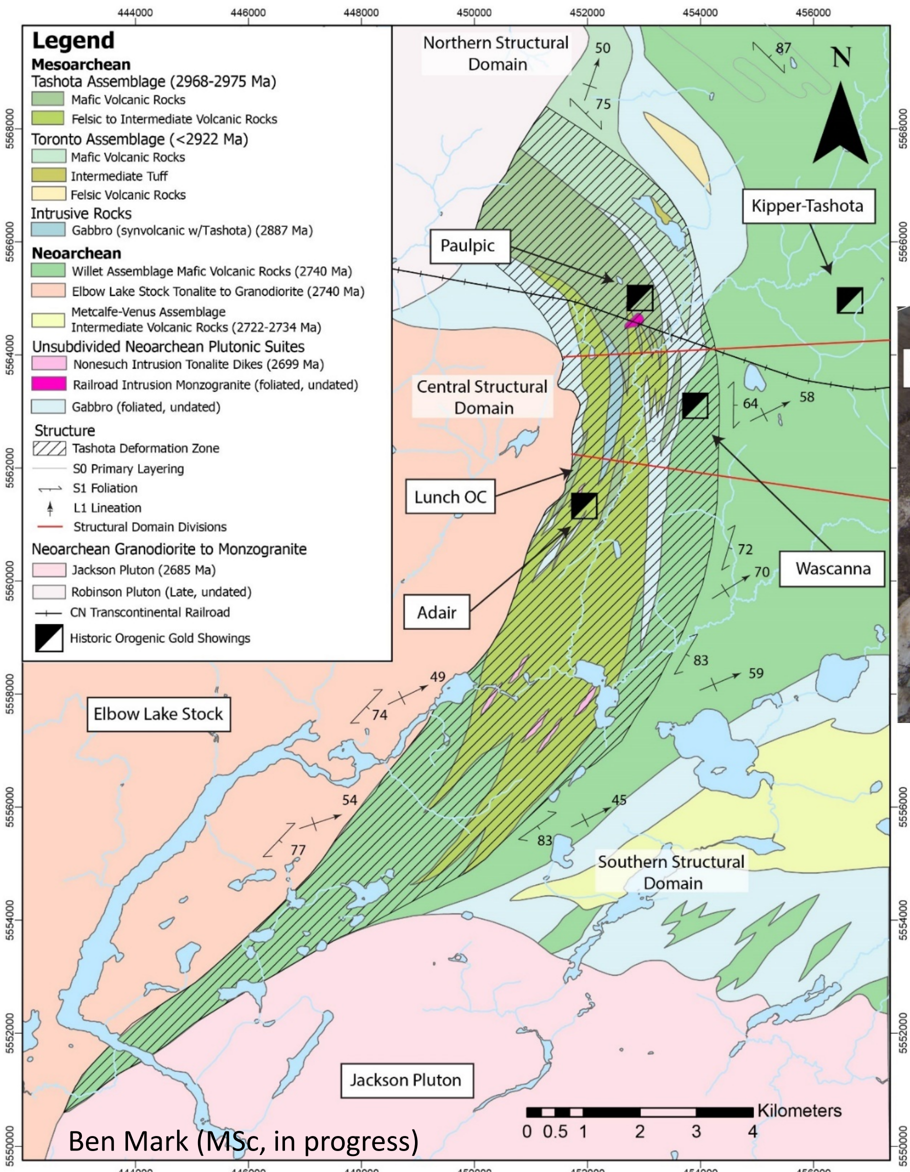
- E-striking deformation zone separating the BGB from the OTB

D2 & D3 Quetico Fault (QF)

- E-striking deformation zone separating the BGB from the Quetico

Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; OGS MDI July, 2018

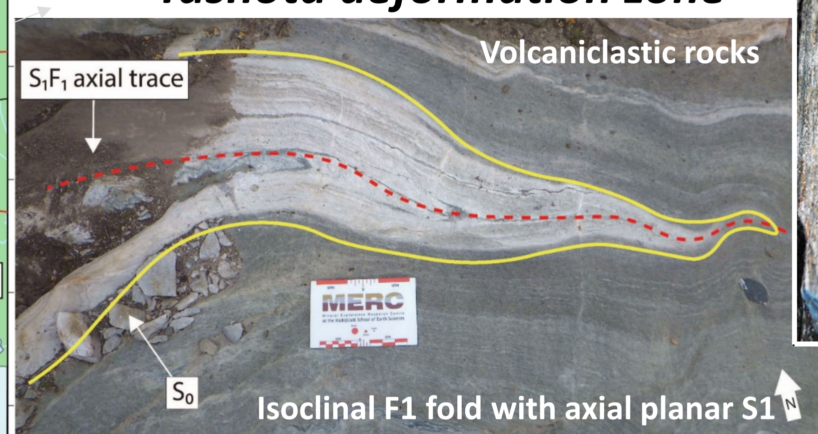




Structural Geology of the Onaman-Tashota Belt

D1 deformation event

Tashota deformation zone



Lunch outcrop

Ben Mark (MSc, in progress)

S_1 foliation

- Dominant foliation in the central part of the OTB, where it wraps around older Mesoarchean and Neoarchean syn-volcanic intrusions

L_1 lineation

- Steep mineral and stretching lineation along S_1 and defined by mineral streaks or elongate clasts

D_1 deformation event – Age constraints

Quartz-feldspar porphyry and tonalite dikes *contain S_1 foliation* in the Humboldt Bay deformation zone and Tashota deformation zone, respectively

Crystallization age of dikes:

HBDZ: 2699.1±1.7 Ma   TDZ: 2699.5±1.6 Ma

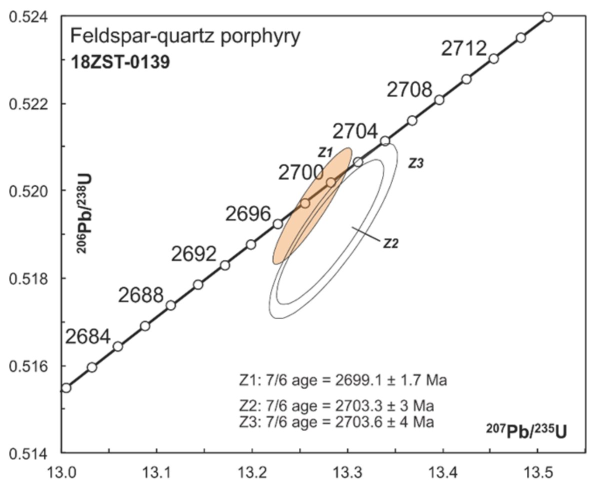
Maximum age of D_1 is 2699 Ma.

Jackson pluton granodiorite *crosscuts* S_1 foliation and is itself not foliated

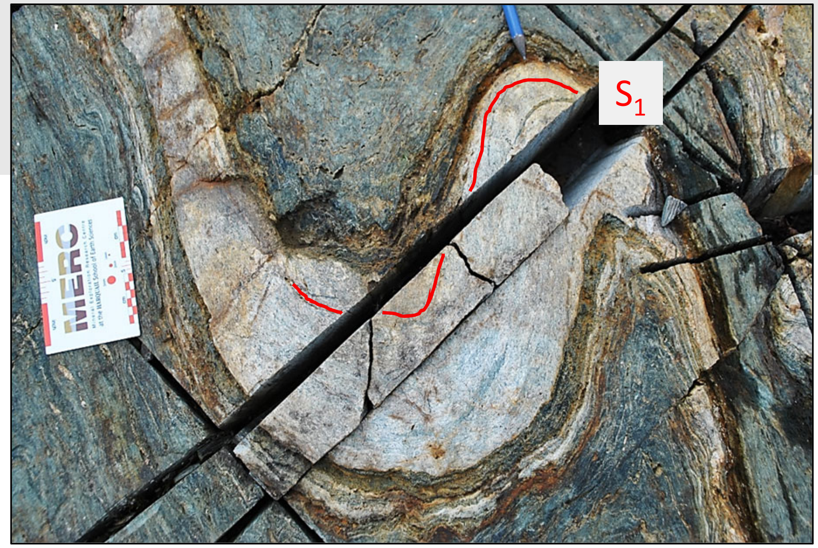
Crystallization age of Jackson pluton: 2684±3 Ma

Minimum age of D_1 is 2684±3 Ma.

D_1 occurred between 2699 Ma and 2684 Ma



U-Pb ages: Hamilton, 2019-2020; pers. comm.



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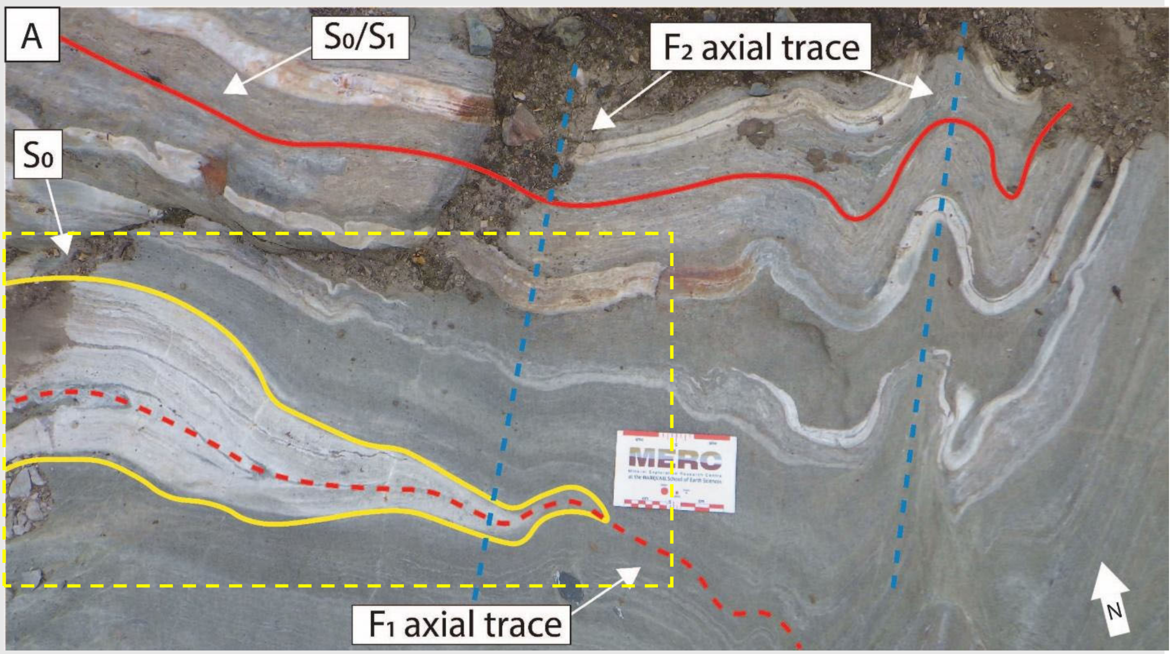
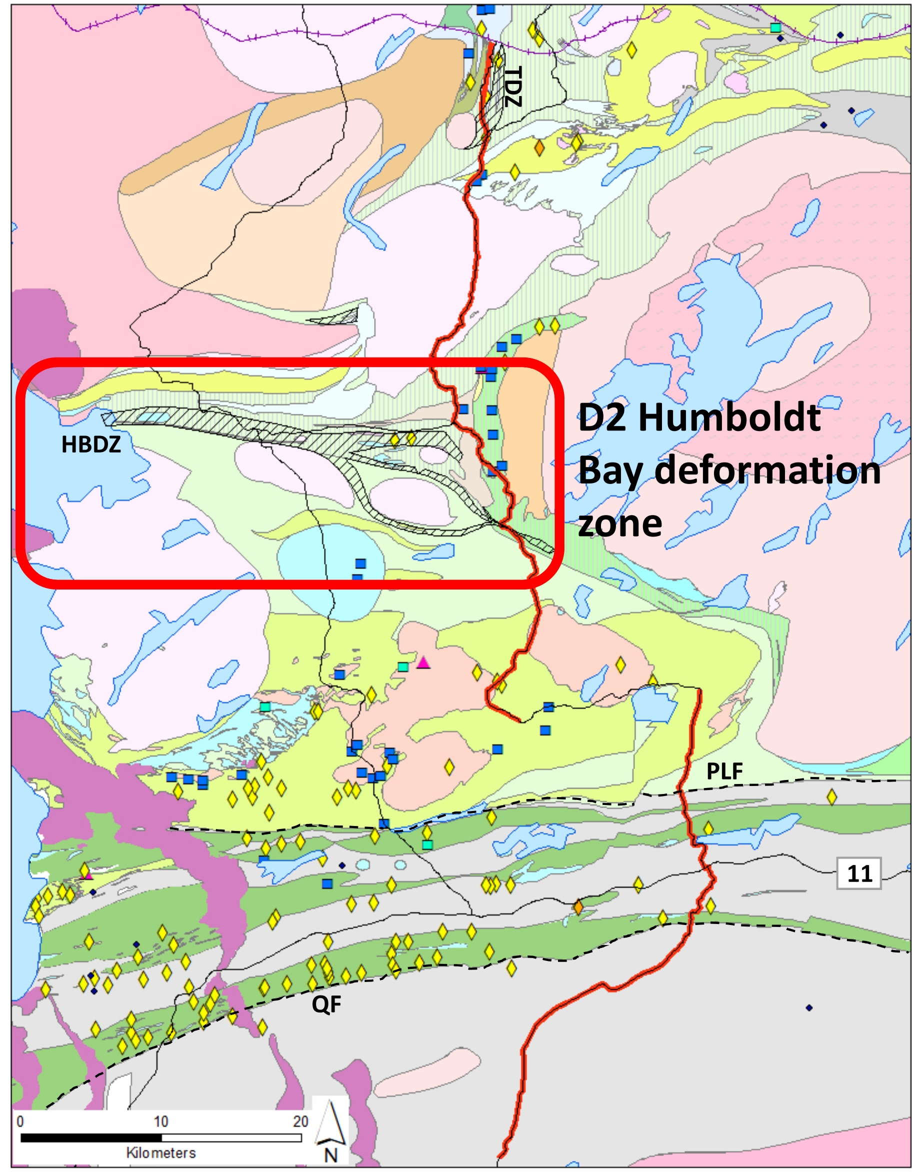
Structural Geology of the Onaman-Tashota Belt

D2 deformation event

Lunch outcrop in D1 Tashota deformation zone



Ben Mark (MSc, 2023)



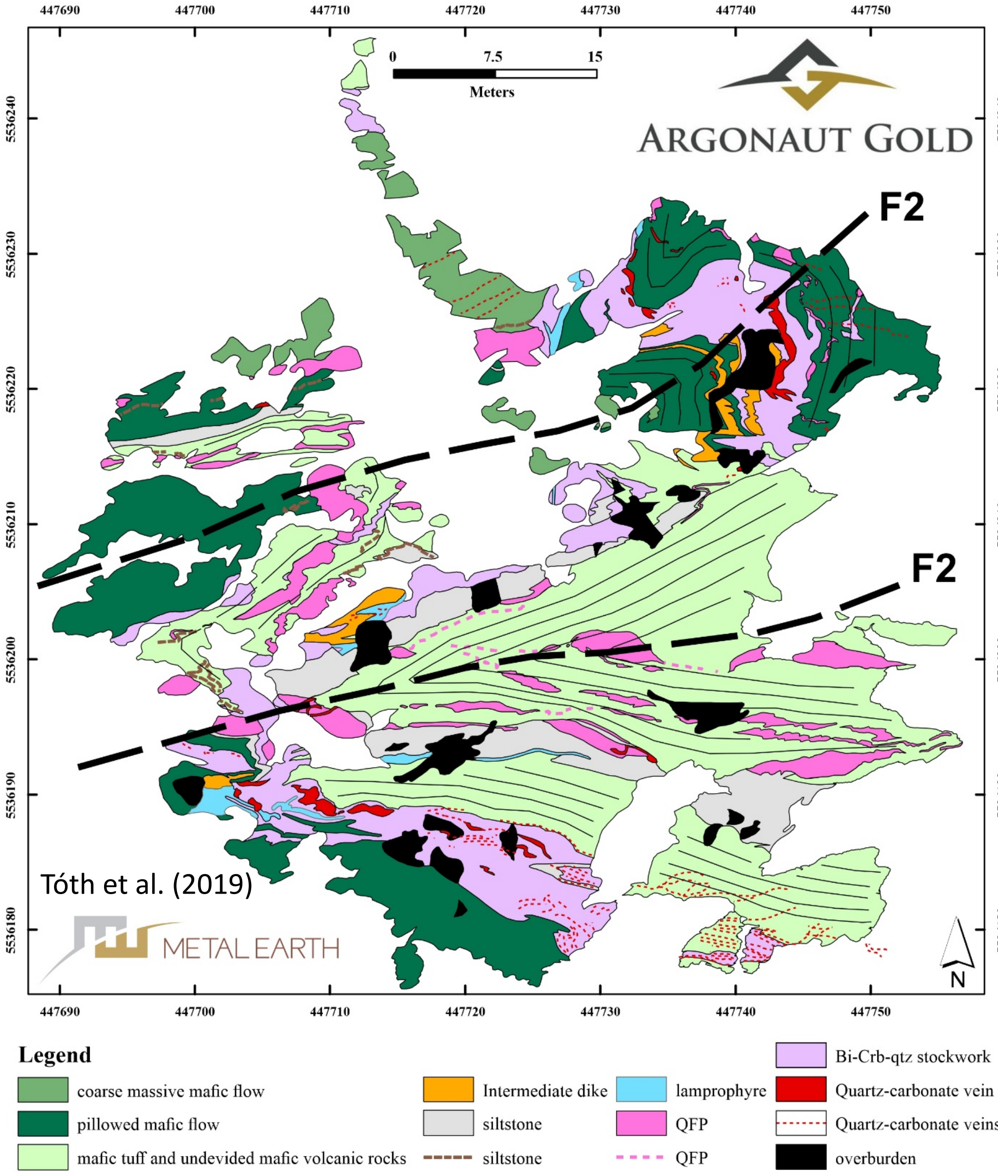
Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; OGS MDI July, 2018

D2 deformation event in OTB

N-S striking S1 foliation is transposed parallel to EW-striking F2 folds and S2 foliation along the Humboldt Bay deformation zone.

S2 foliation and F2 folds become the most prominent structures from the Humboldt Bay deformation zone to the Paint Lake Fault along the southern boundary of the Onaman-Tashota Belt.

D2 bracketed between 2699 Ma and 2667 Ma (^{40}Ar-^{39}Ar ages from amphibolite; Culshaw et al. 2006).



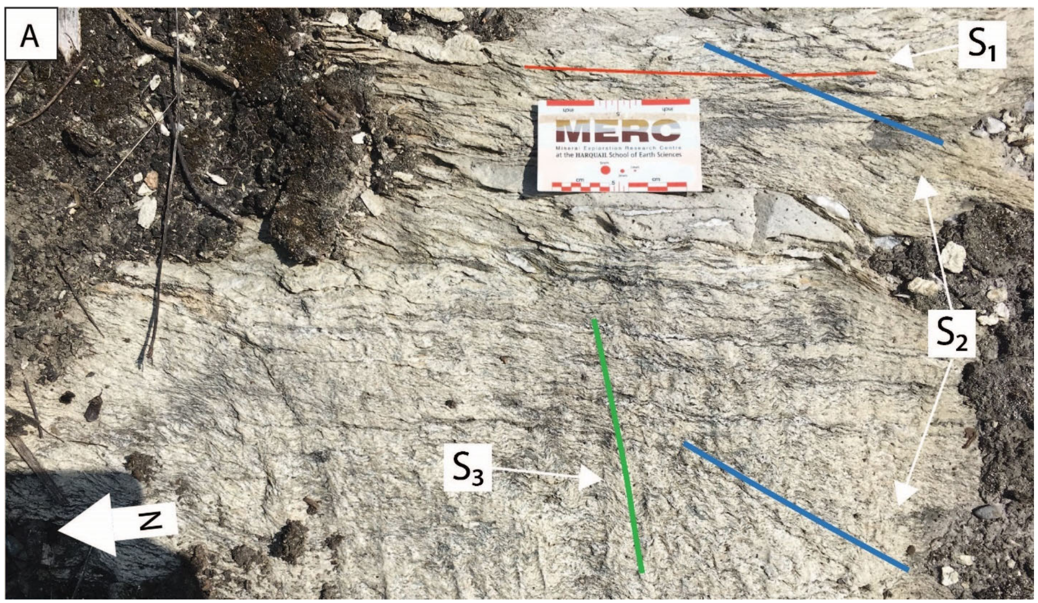
D_3 deformation event– OTB

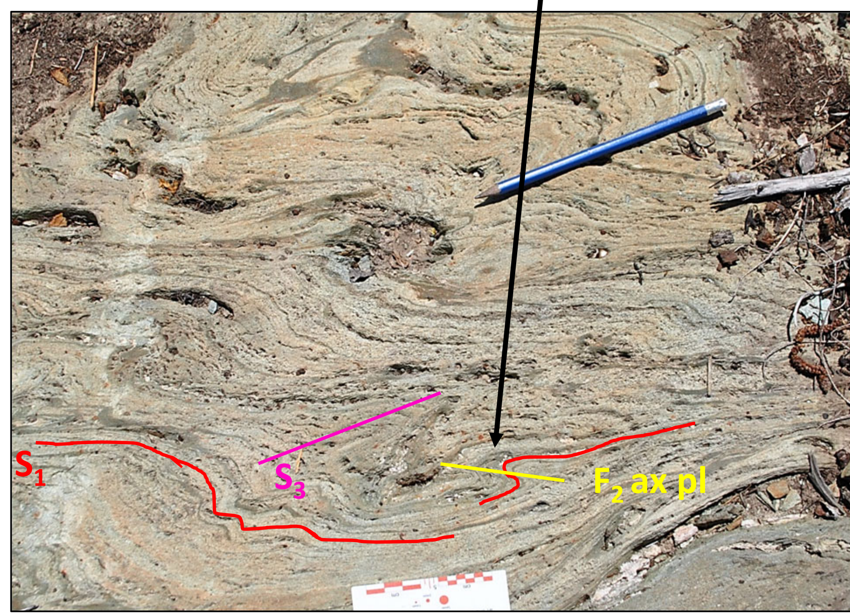
Expressed by Z-shaped F3 folds with an axial plane slaty cleavage or crenulation cleavage

EW-striking dextral faults or shear zones

< 2667 Ma in age

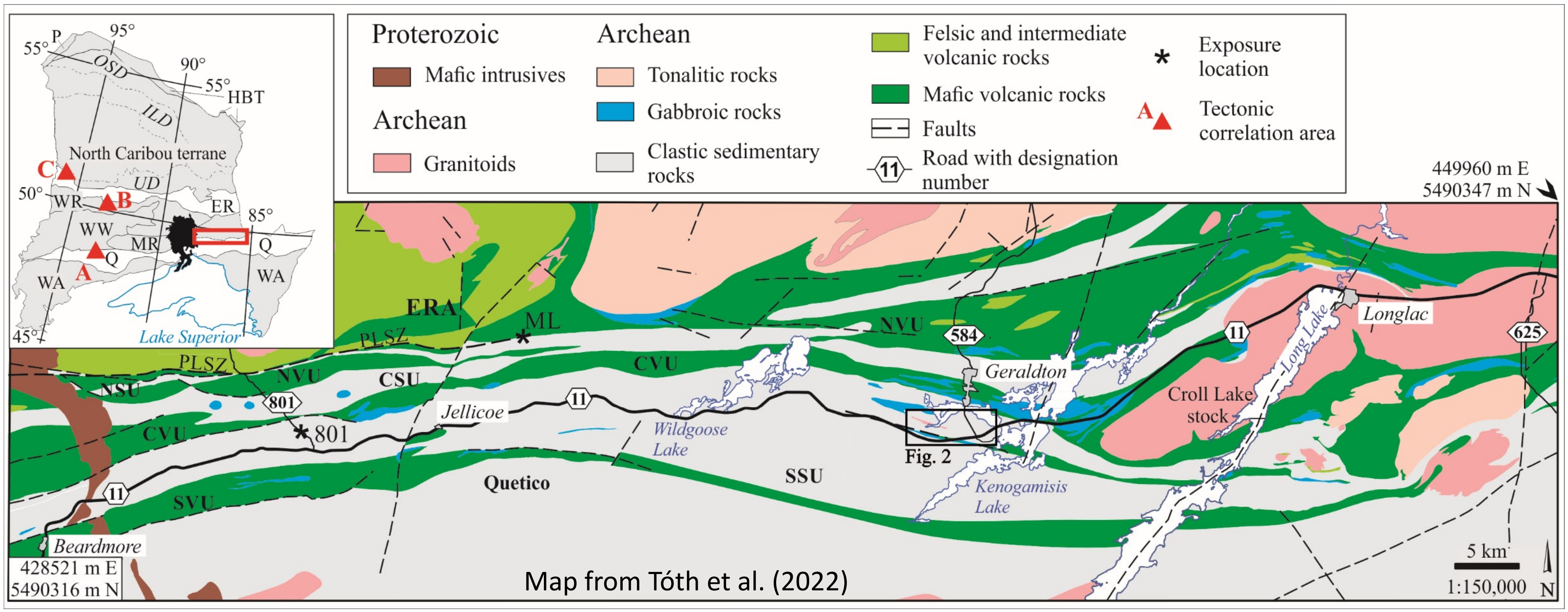
Ben Mark (MSc, in progress)





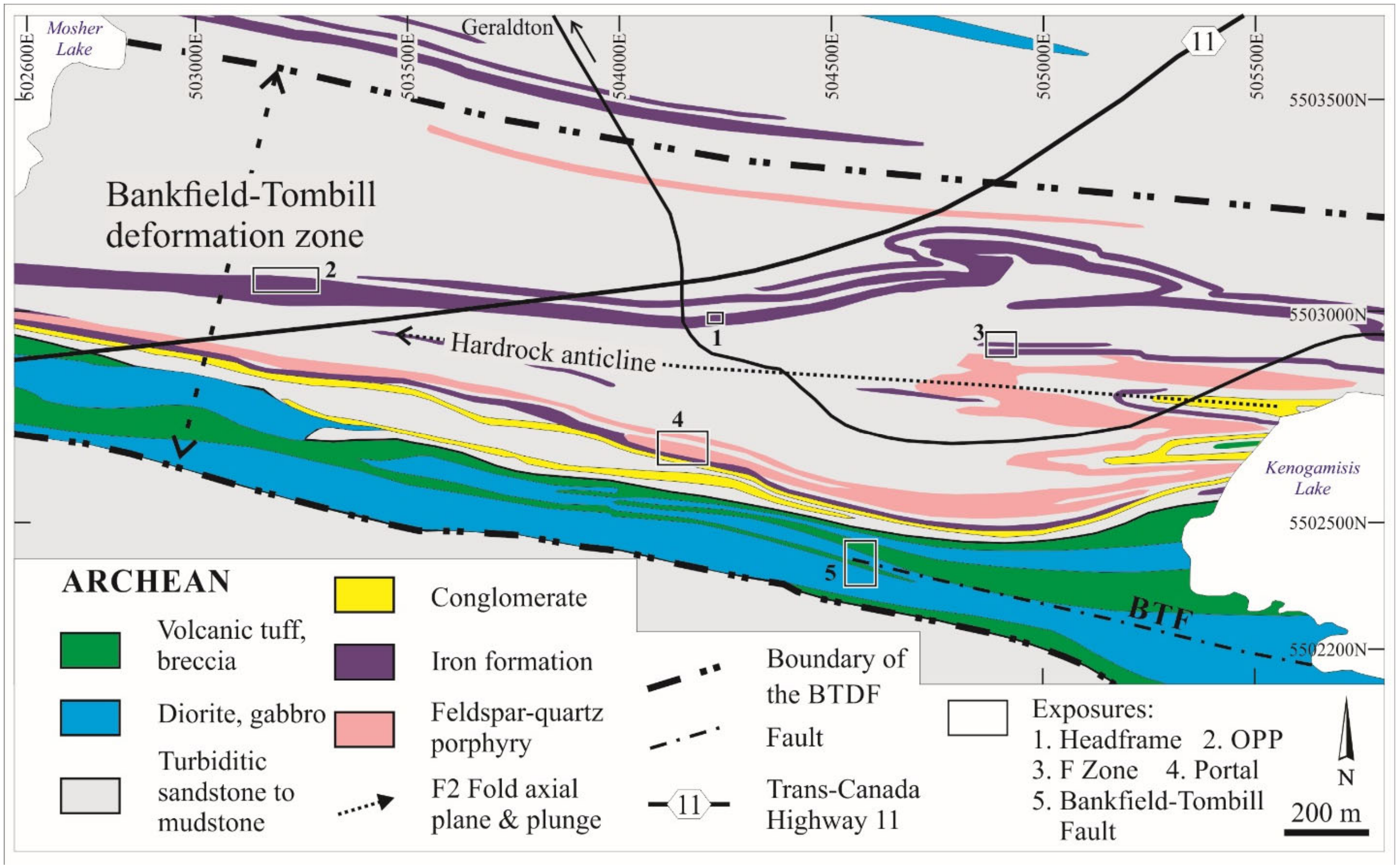
Structural Geology of the Beardmore-Geraldton Belt

The BGB consists of interleaved panels of sedimentary rocks and volcanic rocks, which are cut by the Croll Lake stock at the eastern end of the belt.



Map from Tóth et al. (2022)

All D1 to D3 structures are observed in the Geraldton area within the 1 km wide Bankfield-Tombill deformation zone.



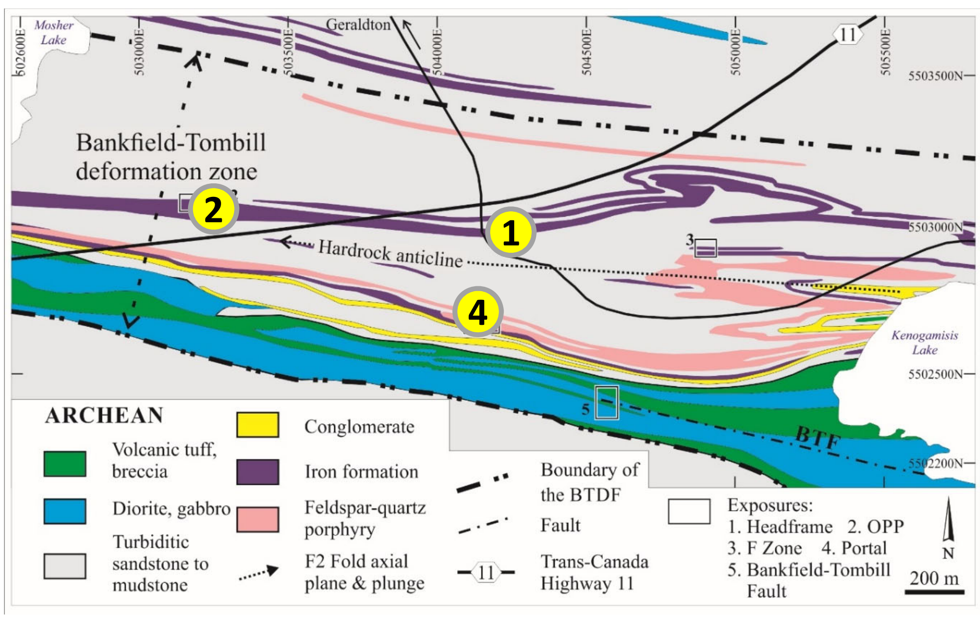
Tóth et al. (2023) JSG

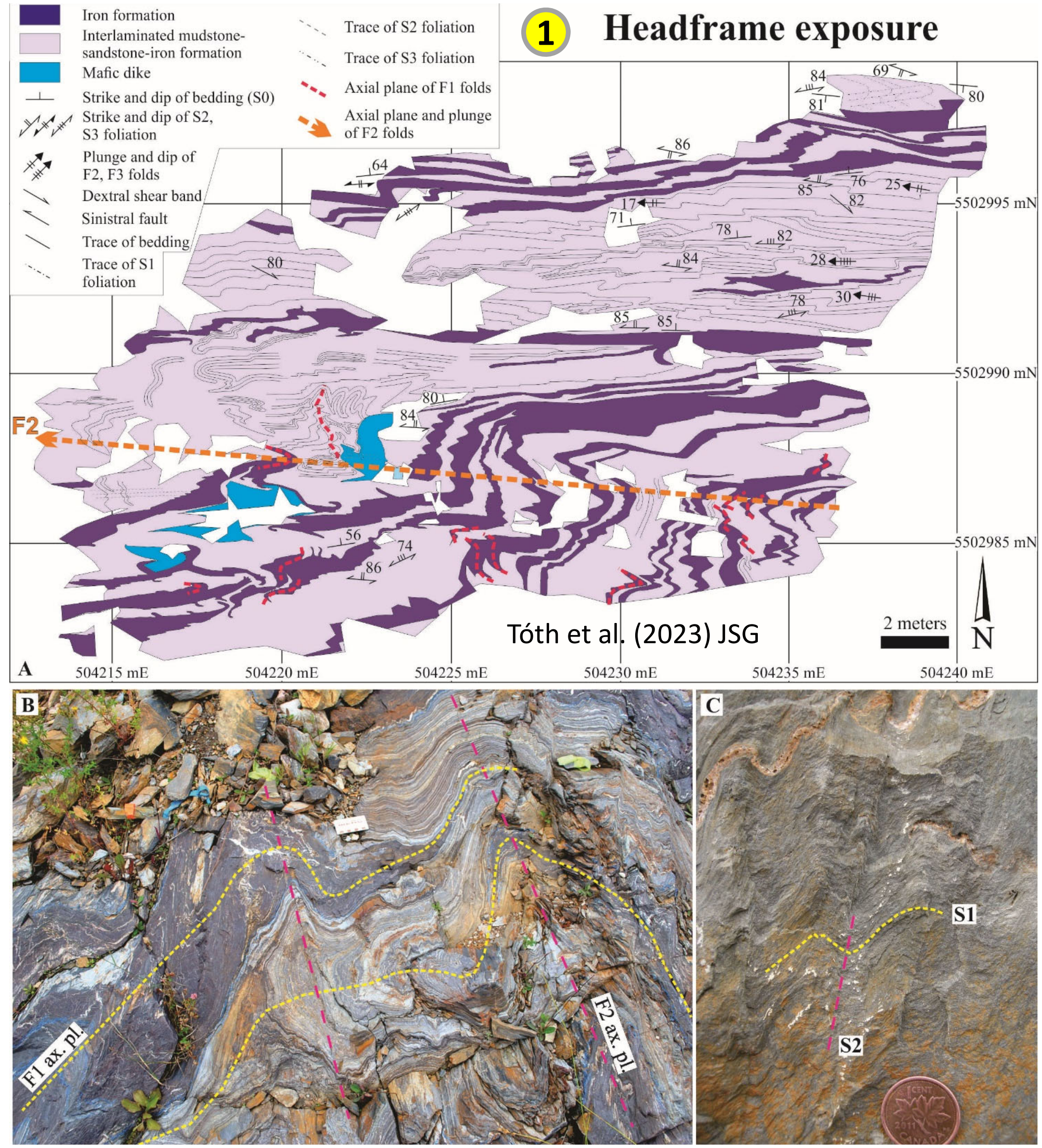
D1 deformation event

Isoclinal F1 folds with axial planar S1 foliation

Bedding-parallel in iron formation and sedimentary rocks

Observed in mafic dikes and QFP intrusions



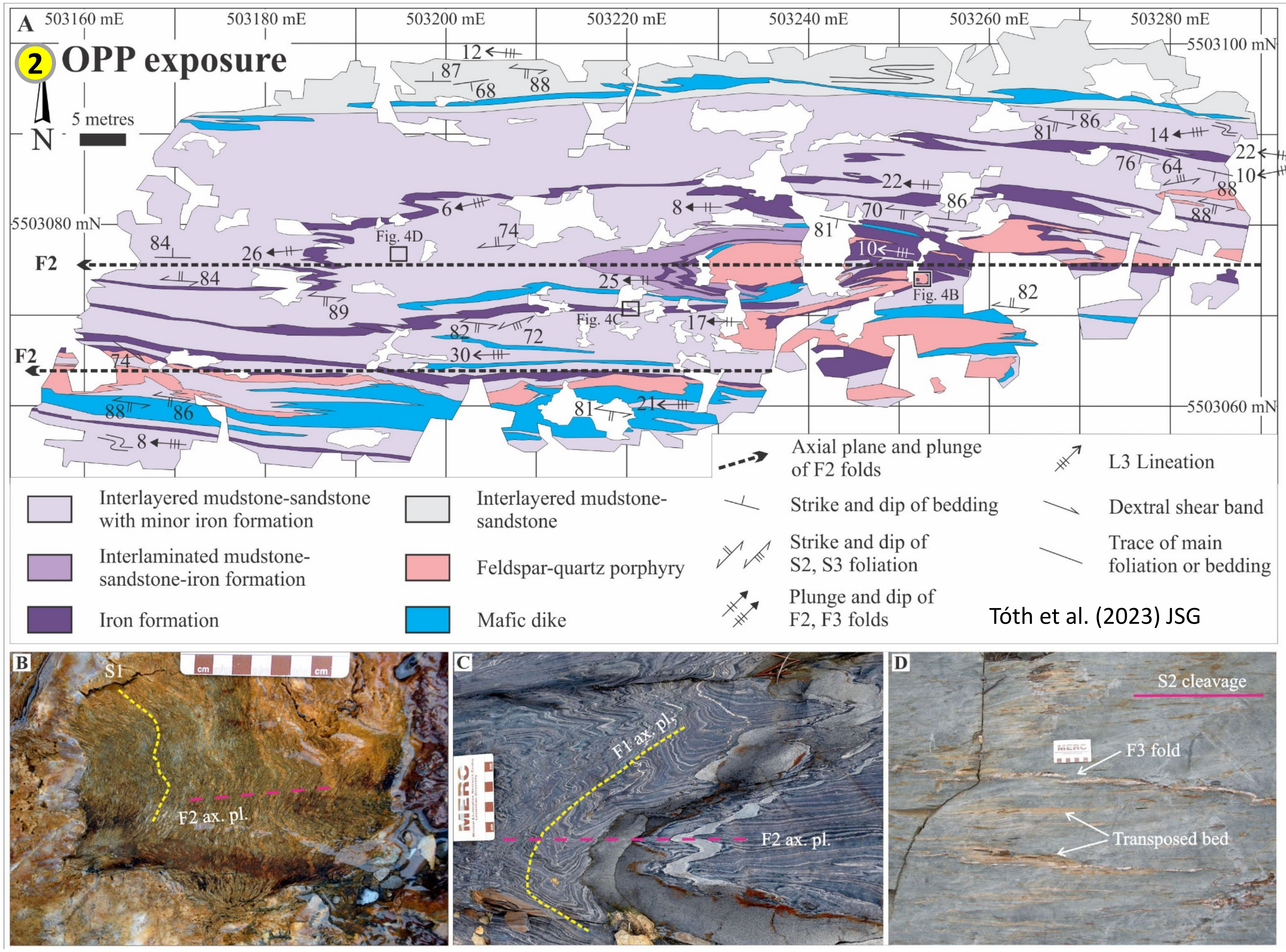


D2 deformation event

Development of D2 deformation zone and regional S2 foliation

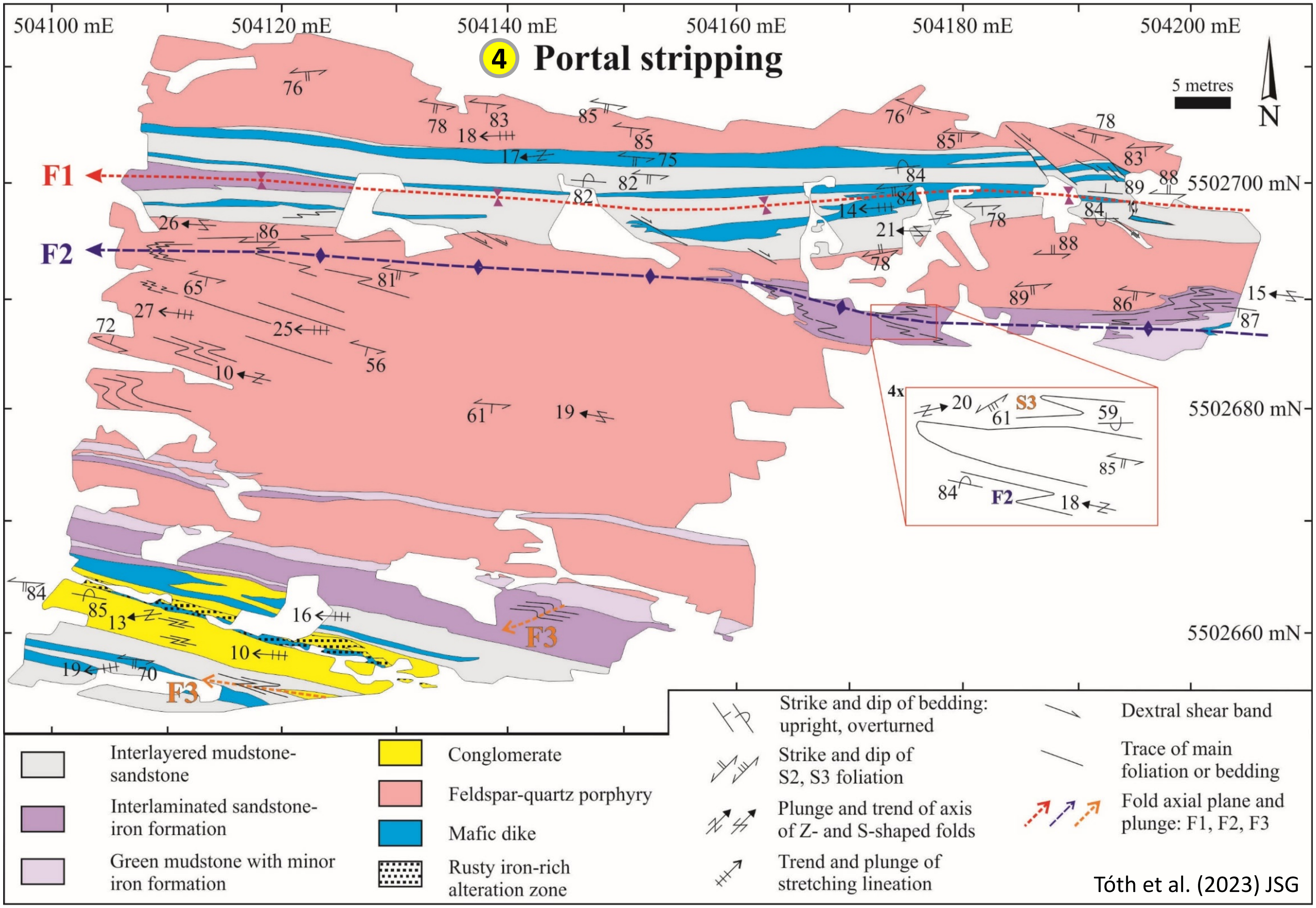
Refolding and transposition of F1 folds and S1 foliation

Observed in mafic dikes and QFP intrusions



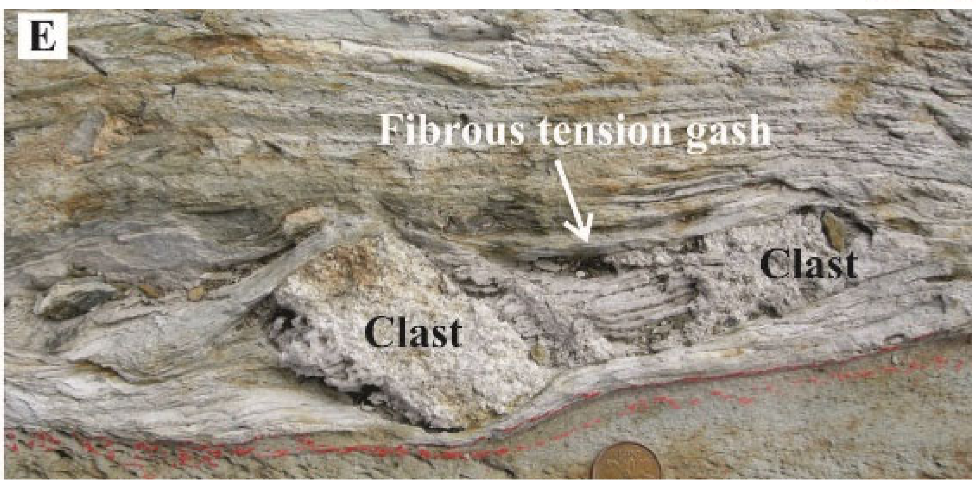
D3 deformation event

Dextral transpression and reactivation of D2 deformation zones



Tóth et al. (2023) JSG

Asymmetrical strain shadow around clast

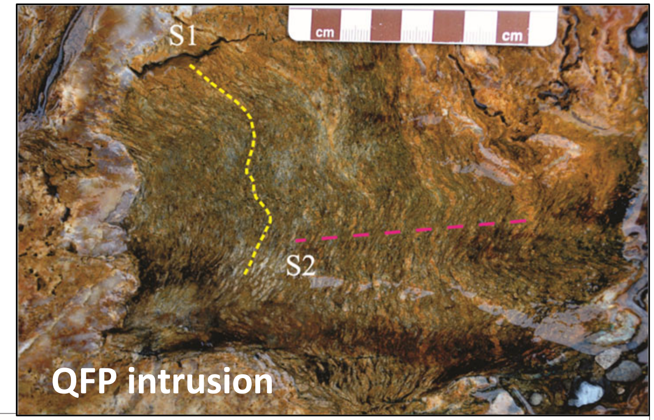


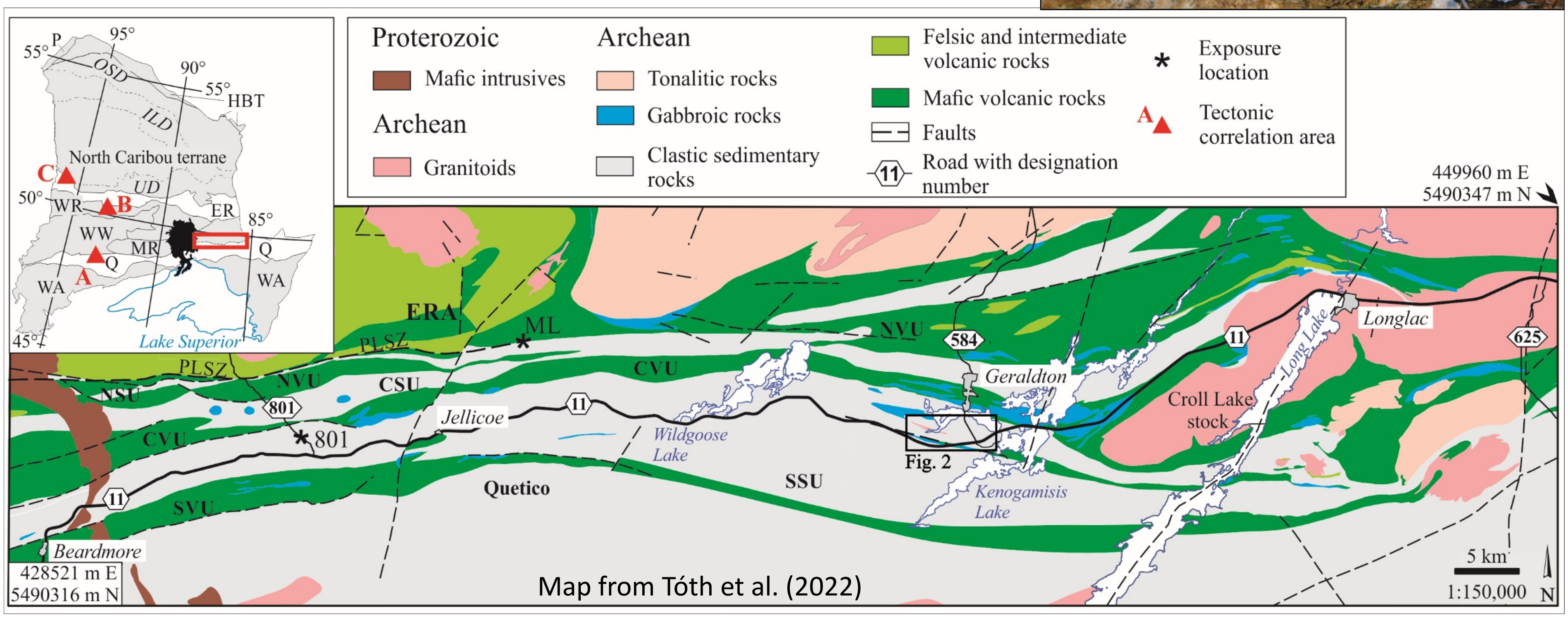
D3 dextral shear sense indicators

Chronological constraints on the deformation events in the Beardmore-Geraldton Belt

D1 is bracketed between 2694 Ma, S1-foliated QFP intrusion, and 2690 Ma, the age of the Croll Lake stock.

D2 and D3 events must be less than 2690 Ma.





Map from Tóth et al. (2022)

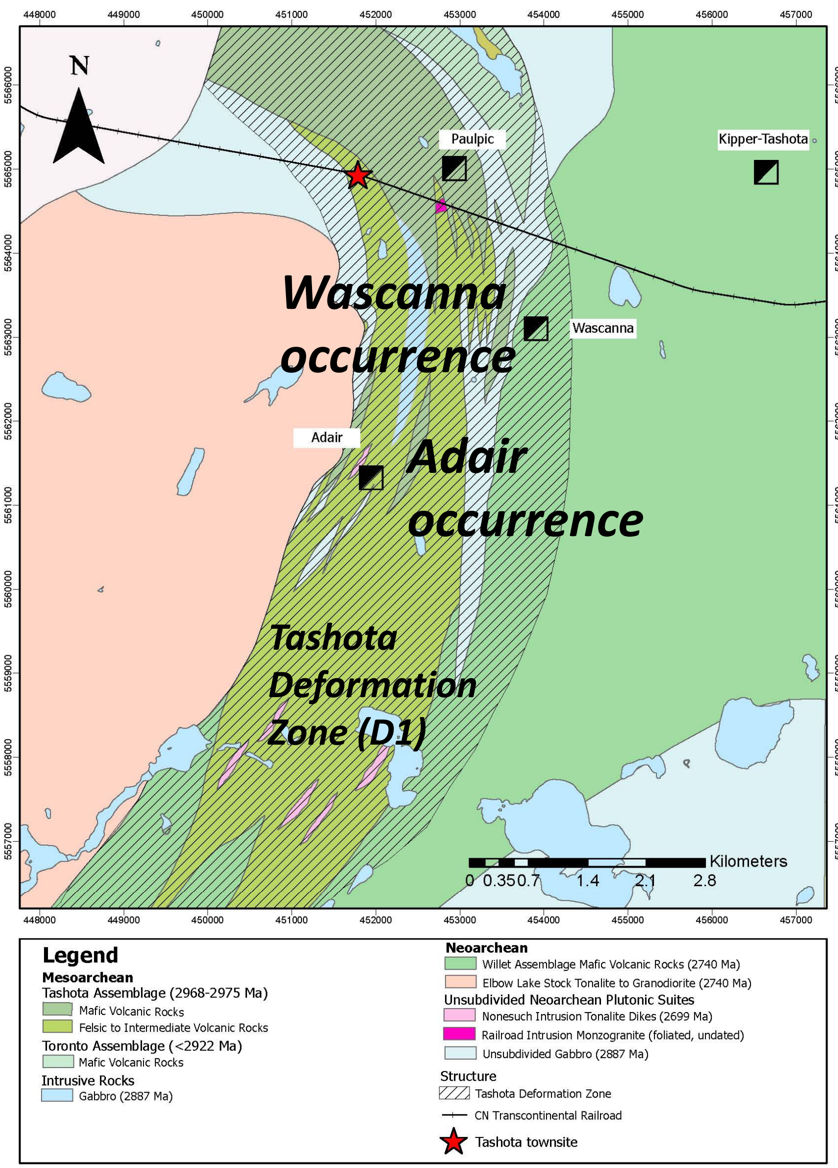
Comparison of structural geology of the OTB and the BGB

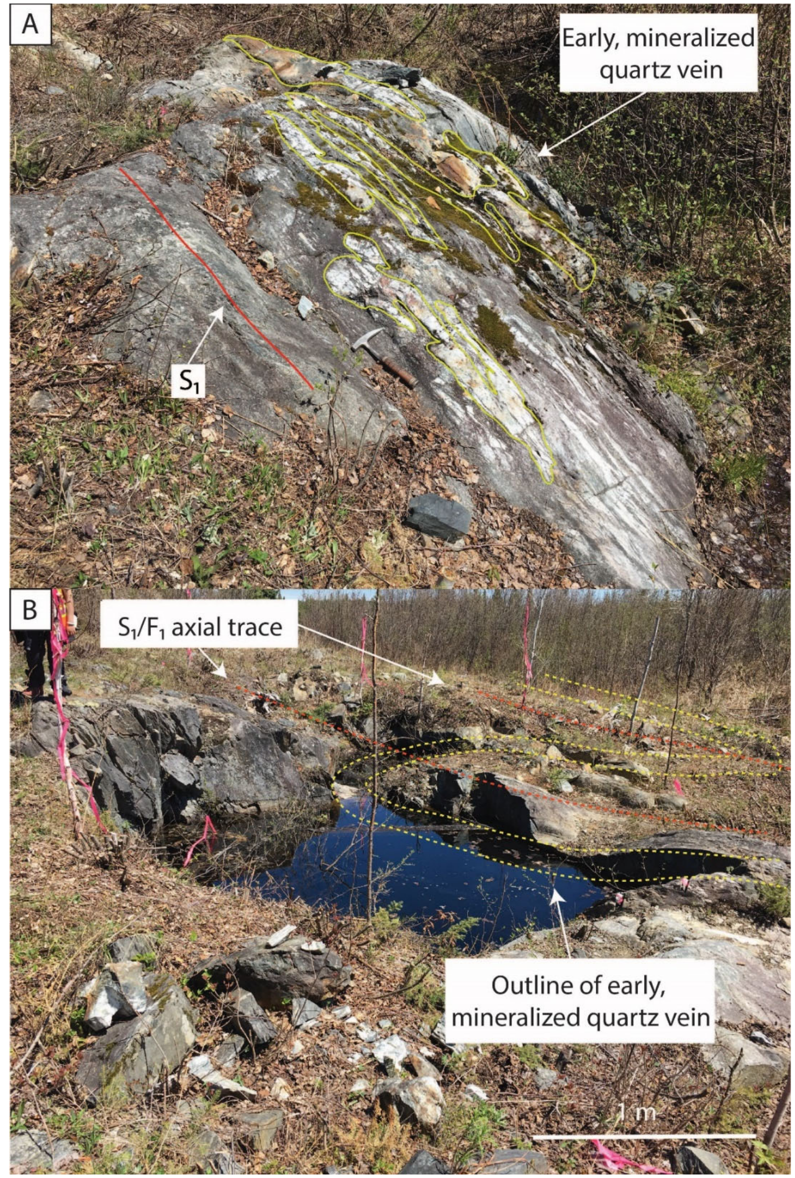
	Onaman-Tashota belt	*Beardmore-Geraldton belt*
D_1	Formation of **dome-and-keel architecture** charact… granitic… infoldin… the dom… <2699.1 ± 1.7 Ma - 2684 Ma	Formation of **linear accretionary belt** by thrust … ntary panels 2694+/-1 Ma – 2690 Ma
D_2	**Regional fold and E-striking S_2 foliation** **D2 deformation zones** (e.g. H… deformation zone) 2699 Ma - 2667 Ma	**Regional fold and E-striking S_2 foliation** …**zones** (e.g. Tombill-Bankfield …e) <2690 Ma
D_3	**Z-shaped F3 folds and minor E-striking dextral transcurrent fa…** <2667 Ma	**Dextral shearing, reactivation of D2 deformation** … <2690 Ma

Coeval development of the dome-and-keel Onaman-Tashota belt and linear accretionary Beardmore-Geraldton belt

Same

More significant in BGB

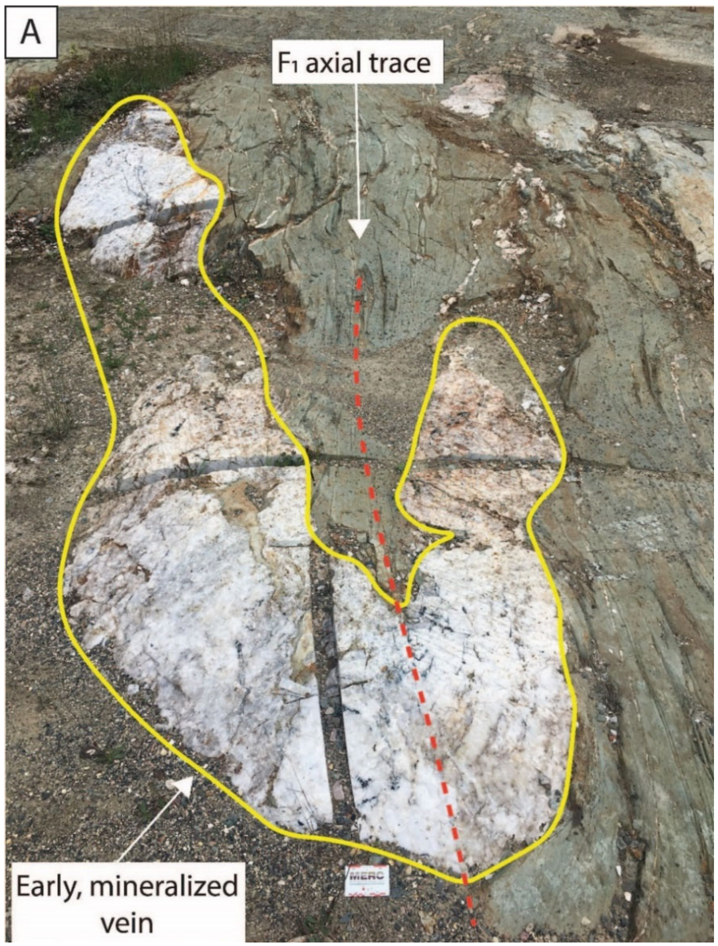


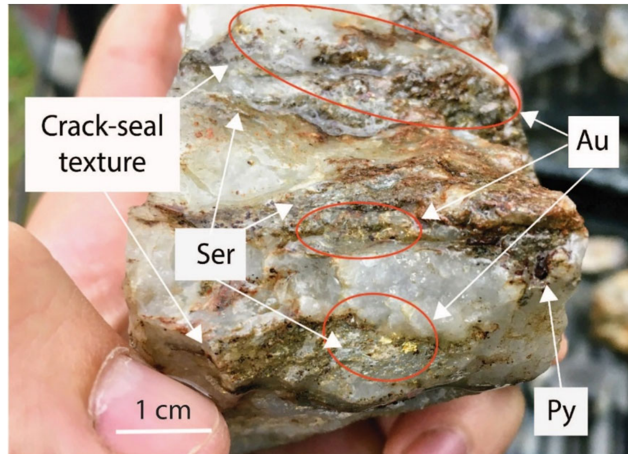


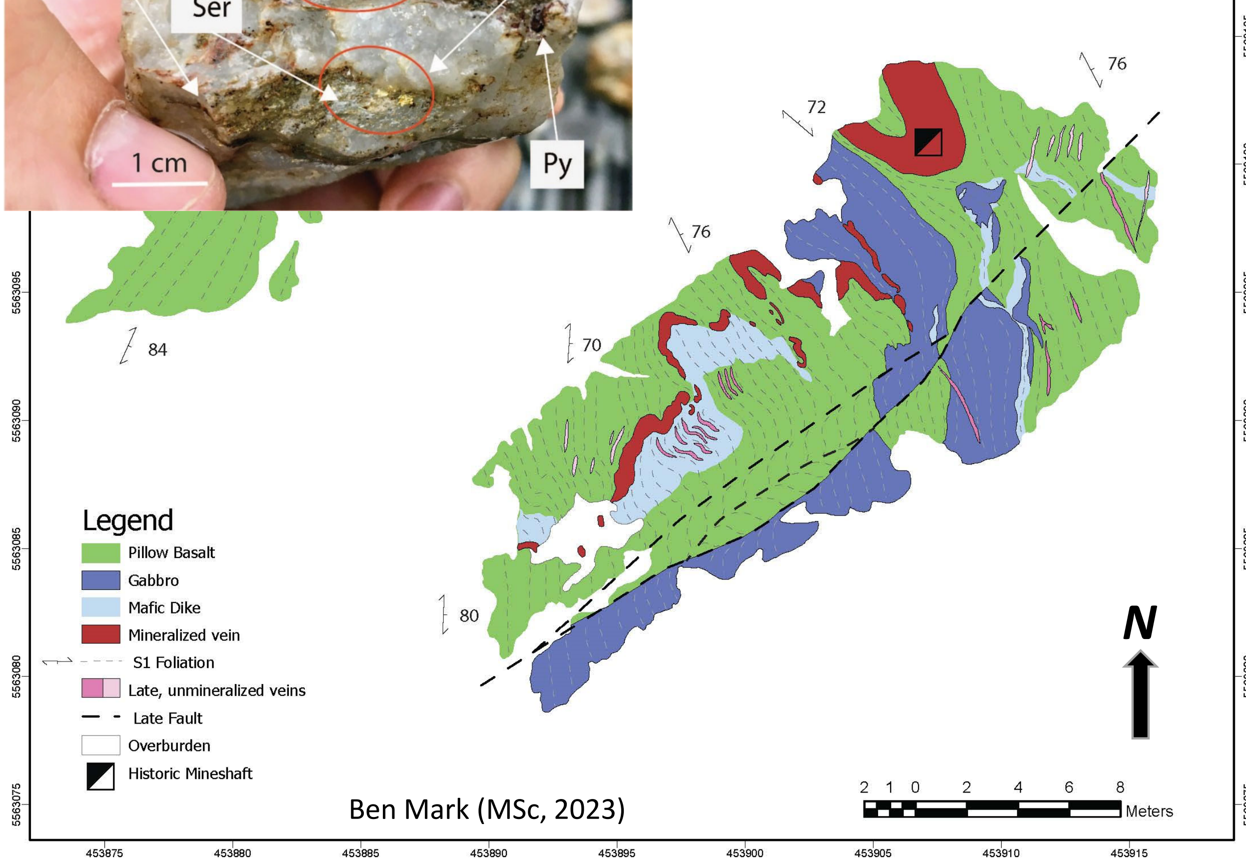
Gold in the Onaman-Tashota Belt

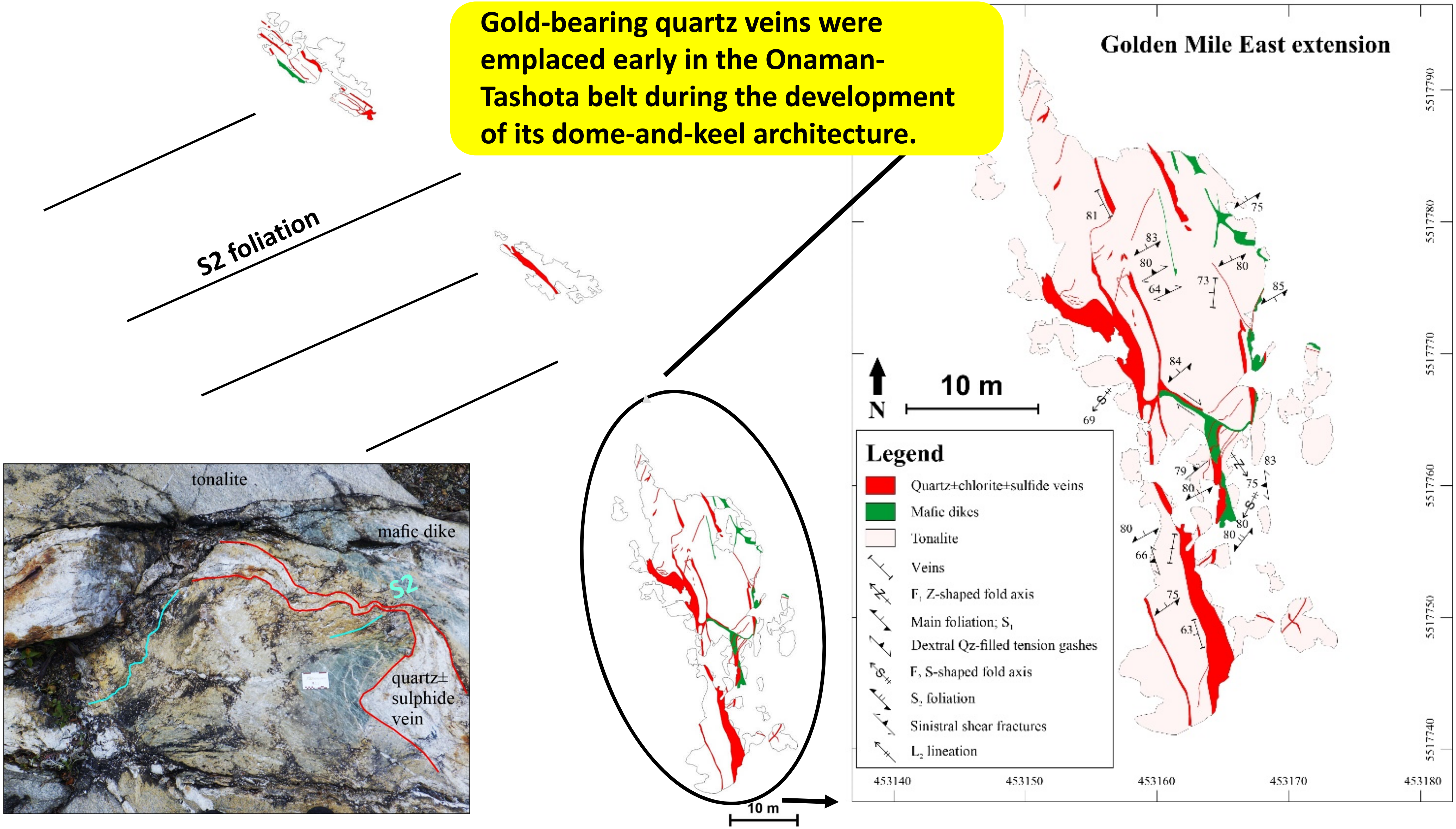
Ben Mark (MSc, 2023)

Wascanna ocurrence

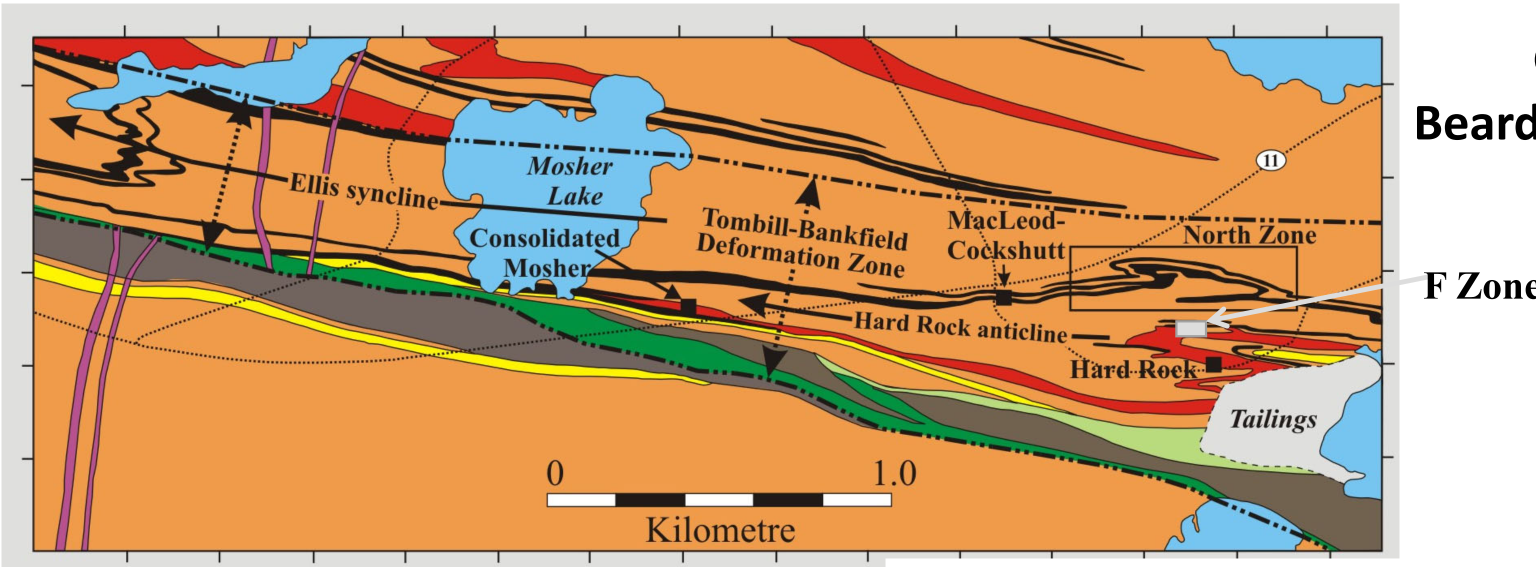


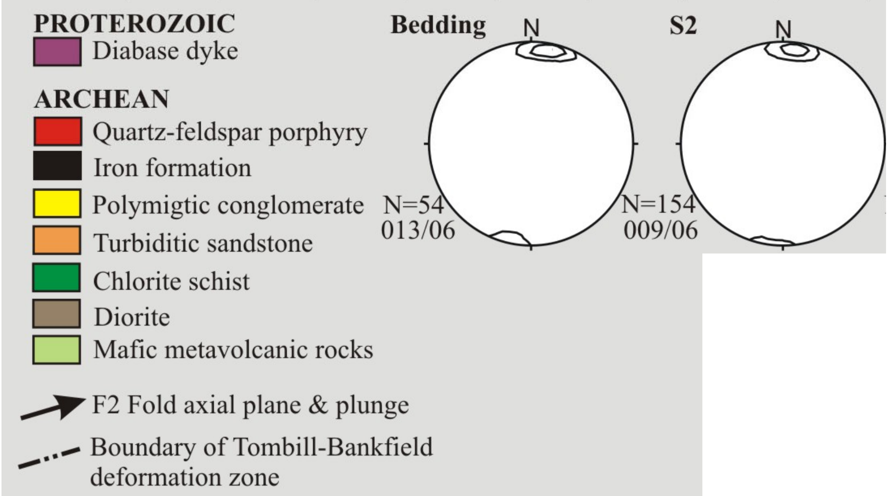




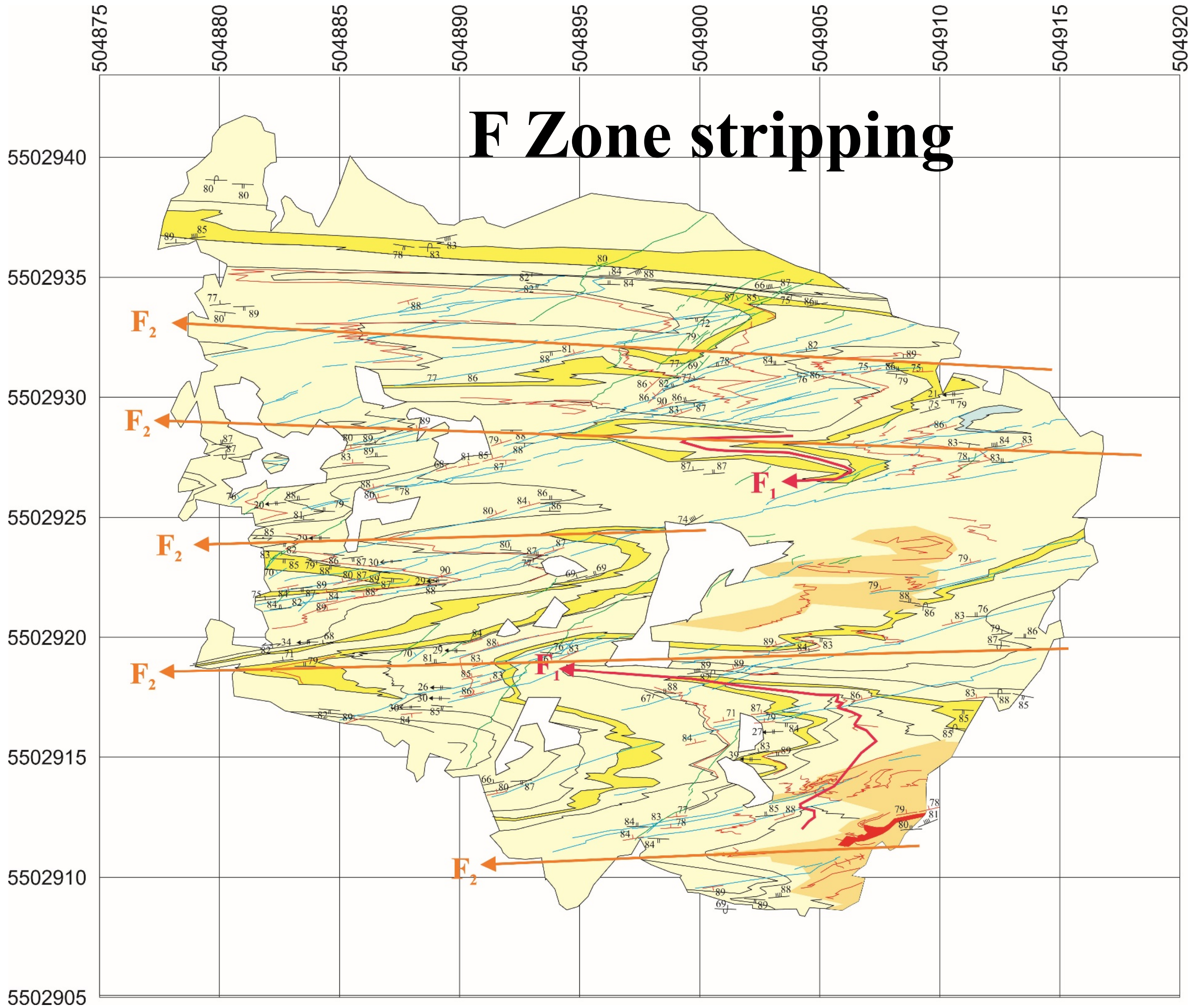

Gold-bearing quartz veins were emplaced early in the Onaman-Tashota belt during the development of its dome-and-keel architecture.
S2 foliation
tonalite
mafic dike
S2
quartz± sulphide vein
10 m
Golden Mile East extension
10 m
N
Legend
Quartz+chlorite+sulfide veins
Mafic dikes
Tonalite
Veins
F1 Z-shaped fold axis
Main foliation; S1
Dextral Qz-filled tension gashes
F2 S-shaped fold axis
S2 foliation
Sinistral shear fractures
L2 lineation
453140
453150
453160
453170
453180
5517790
5517780
5517770
5517760
5517750
5517740

Gold in the Beardmore-Geraldton belt



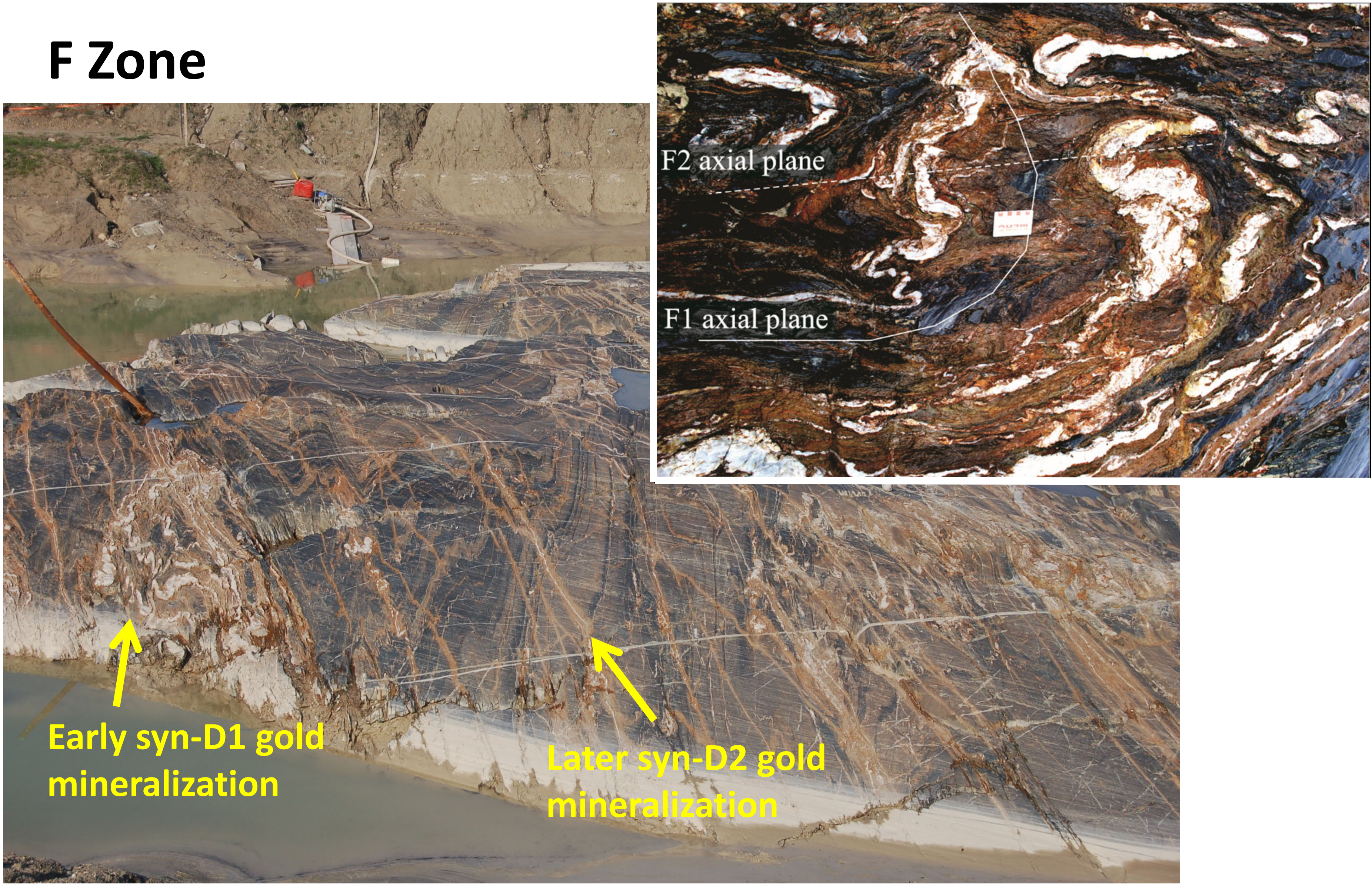


F Zone stripping

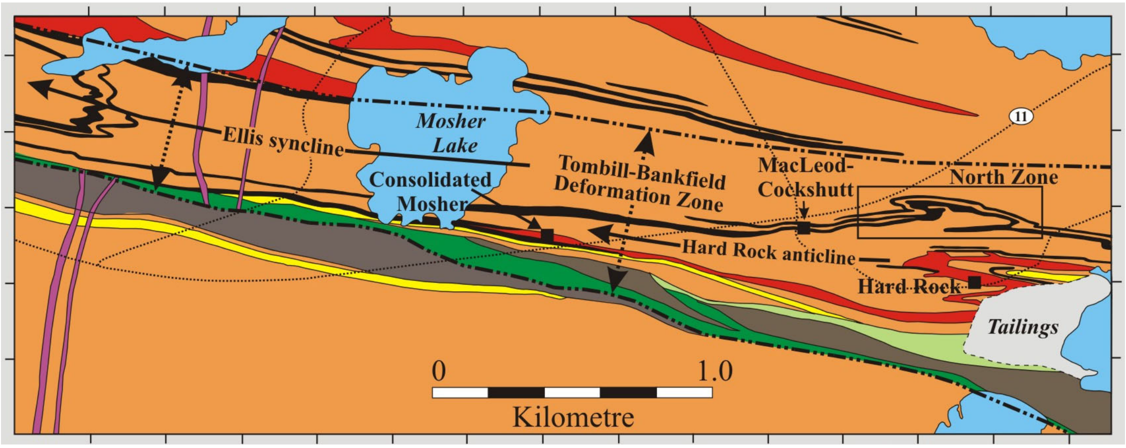


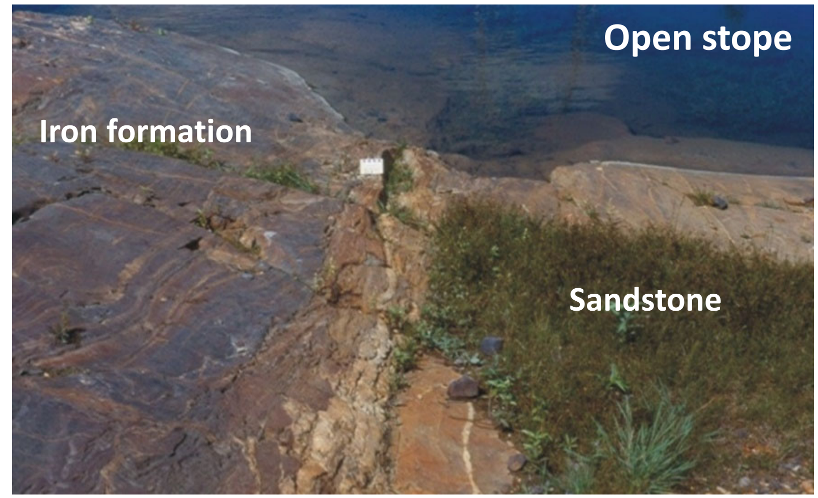
Tóth (PhD thesis 2019)

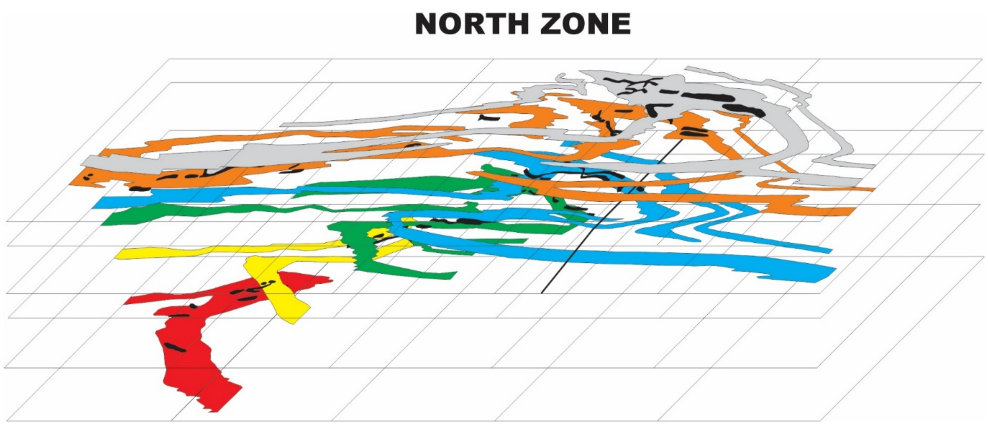
F Zone

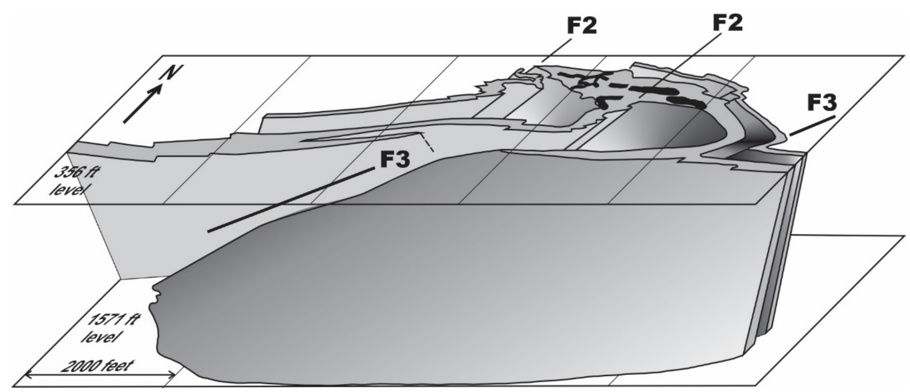

Early syn-D1 gold mineralization
Later syn-D2 gold mineralization
F2 axial plane
F1 axial plane

North Zone
Hard Rock Mine







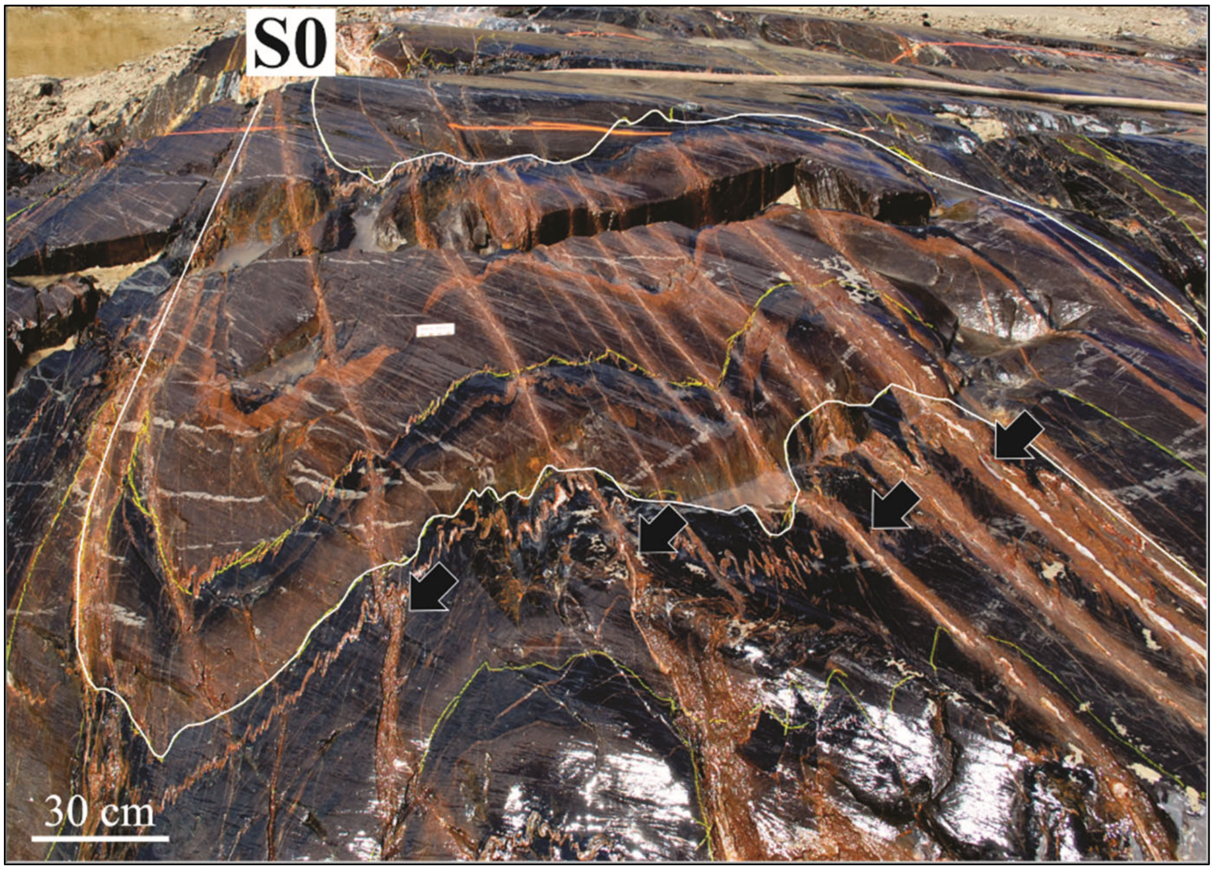


Lafrance et al. (2004)

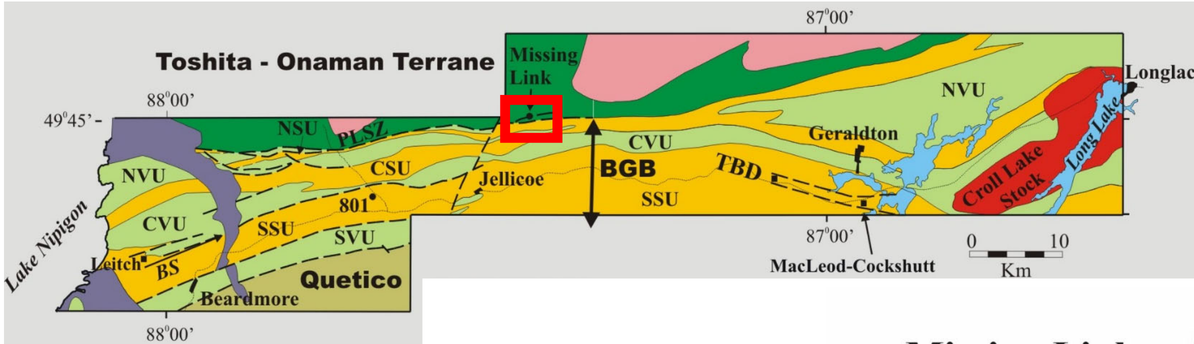
F Zone

Later syn-D2 auriferous veins

Extensional veins cutting across the axial plane of S-shaped F2 fold

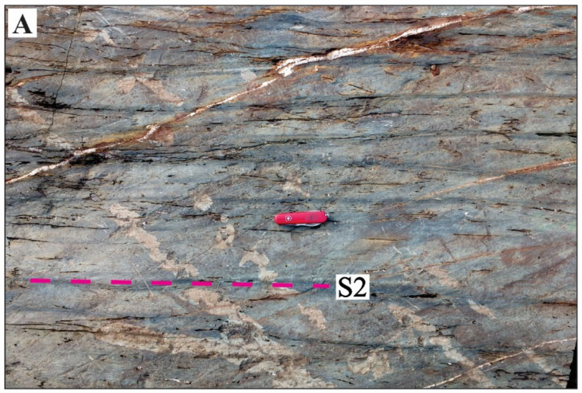


S-shaped folded extensional vein

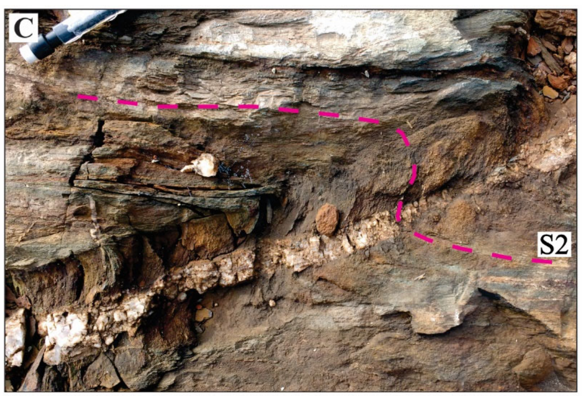


Missing Link gold occurrence along Paint Lake Fault

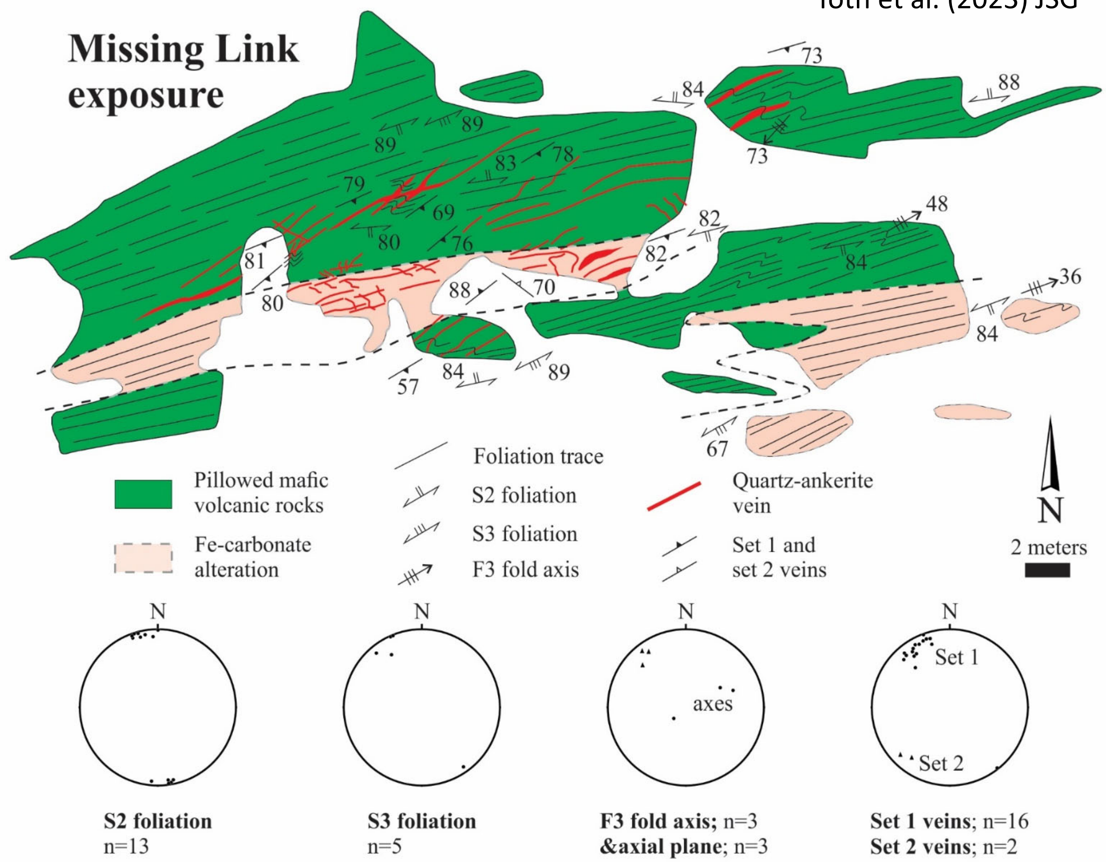
Tóth et al. (2023) JSG



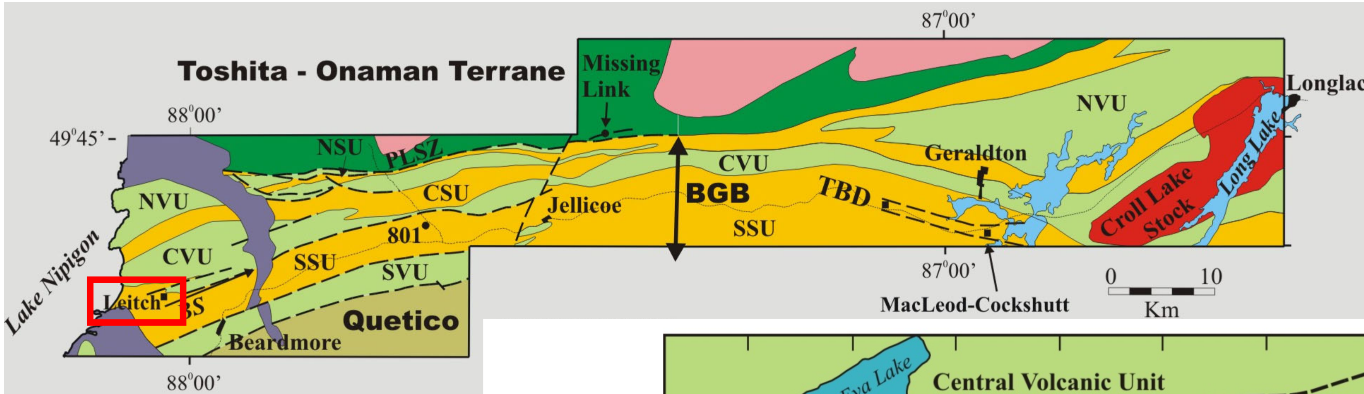
S2 Flattened pillows overprinted by S-folded extensional vein



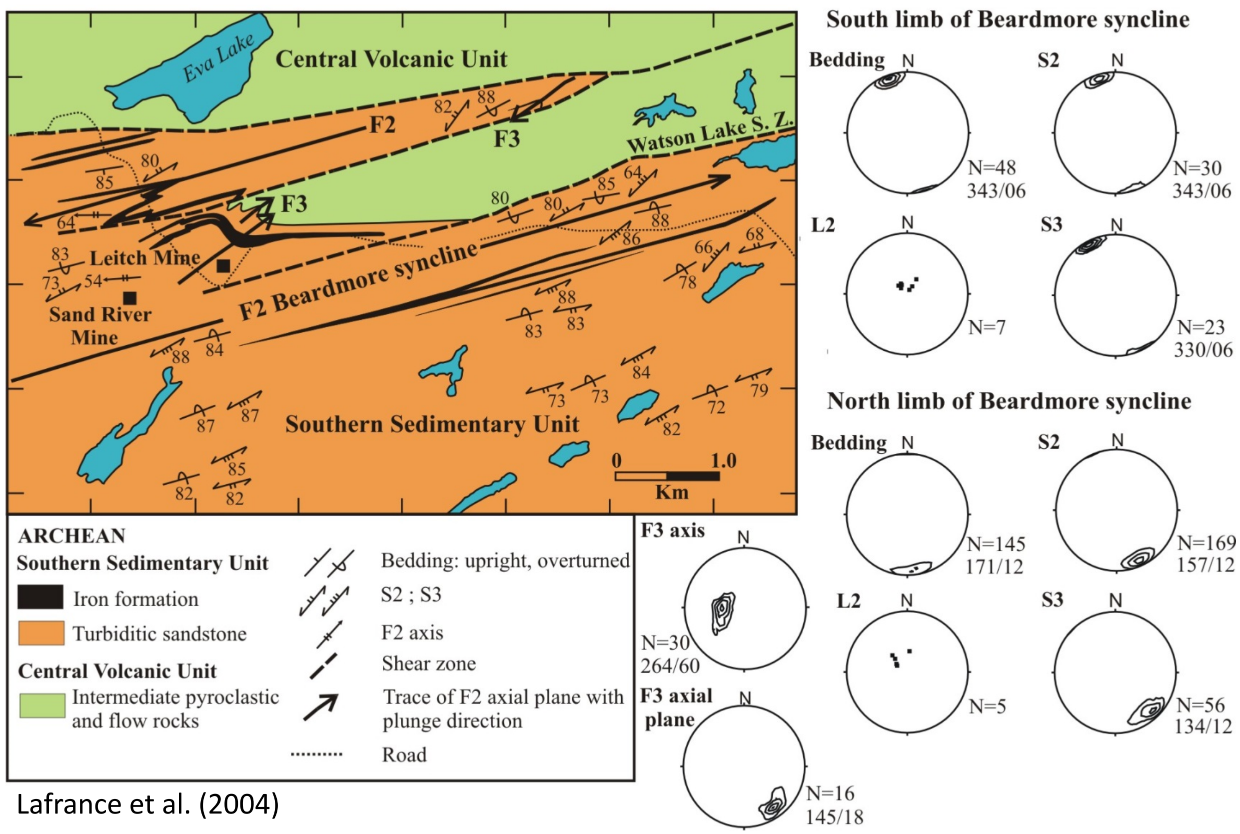
Dextral Z-shaped flanking structure along extensional vein



Leitch – Sand River Mine Western Beardmore-Geraldton Belt



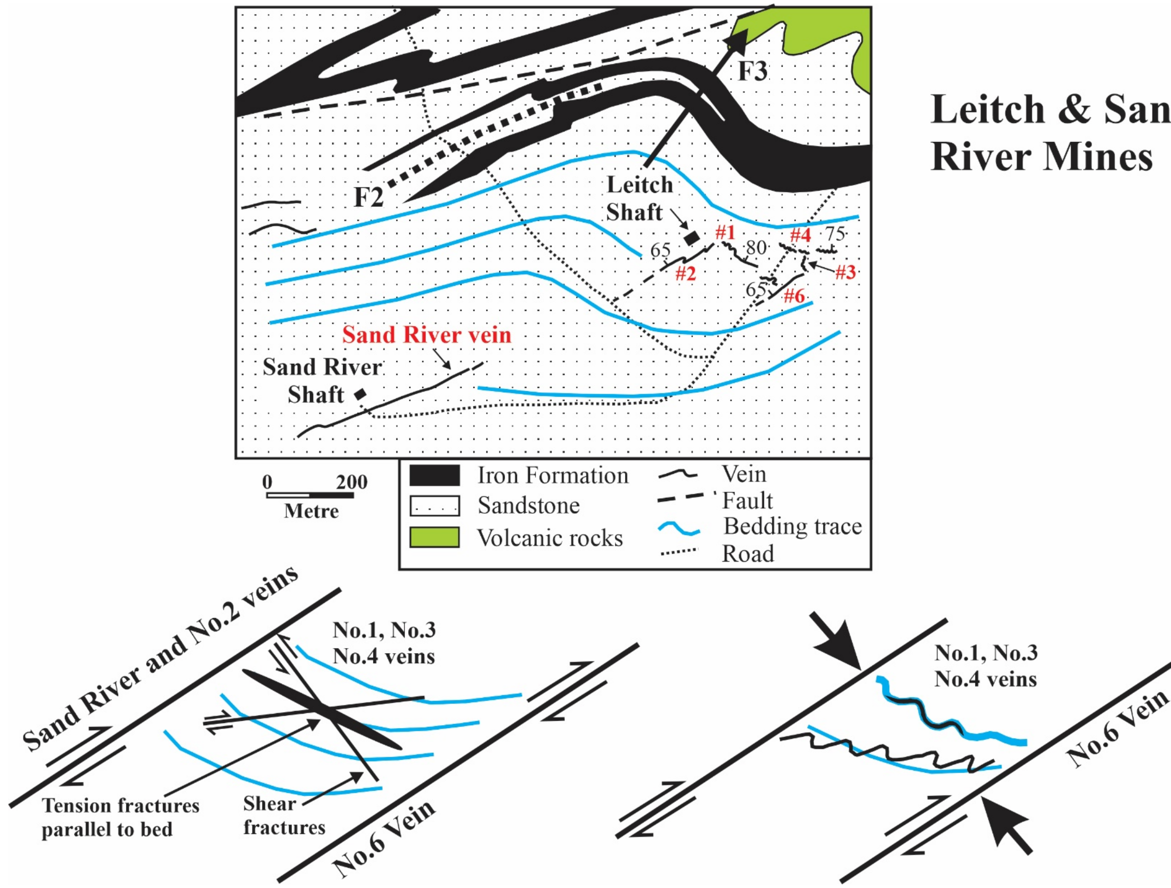
Z-shaped F3 fold parasitic to map-scale F3 fold hosting mineralization at the Leitch-Sand River mine



Lafrance et al. (2004)

Leitch-Sand River vein system emplaced during D3 dextral transpression across the Beardmore-Geraldton Belt

Leitch & Sand River Mines



Lafrance et al. (2004)

Comparison of gold occurrences in Onaman-Tashota Belt and Beardmore-Geraldton Belt

	Onaman-Tashota belt	*Beardmore-Geraldton belt*
Structural association	Deformation zones	Deformation zones and regional fold hinges
Structural chronology	D1 dome-and-keel development	D1 accretion along the southern margin of the Wabigoon subprovince D2 deformation zones and fold hinges D3 dextral transpression
Total production	<100,000 ounces gold	> 4 million ounces gold

Key Take-Aways

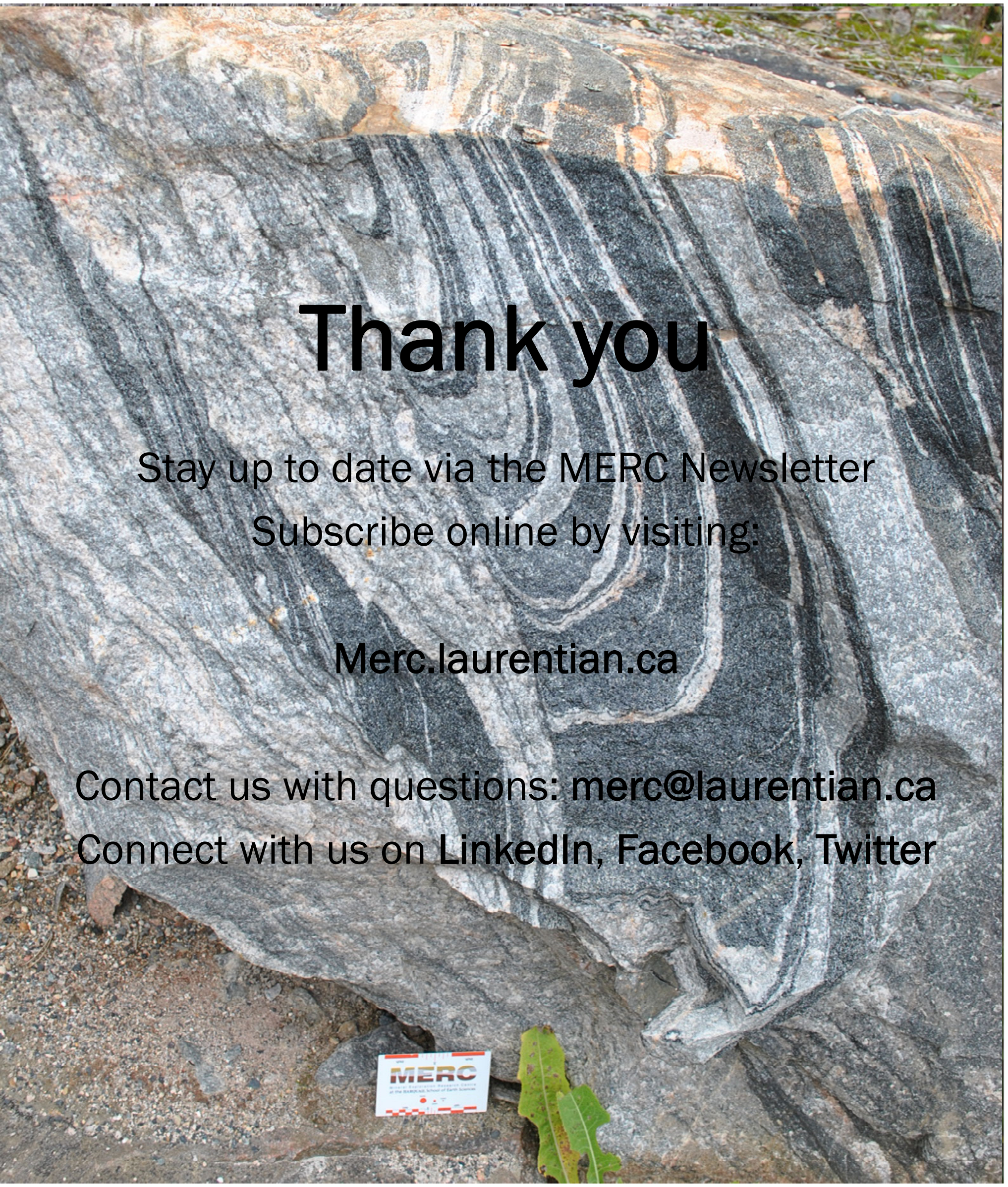
(1) The development of the **dome-and-keel** architecture in the Onaman-Tashota Belt was **coeval** with the development of the **linear accretionary** architecture of the Beardmore-Geraldton belt.

(2) Gold mineralization was emplaced early during the development of their dome-and-keel and linear accretionary architecture.

(3) The more gold-endowed Beardmore-Geraldton Belt coincides with more conductive (or less resistive) and less reflective steeply-dipping zone(s) on the combined Seismic-MT transect.

(4) The gold-endowed Beardmore-Geraldton Belt differs from the less-endowed Onaman-Tashota Belt by the presence of multiple steeply-dipping penetrating structures and their reactivation during multiple gold mineralizing events.

Linear accretionary belts are more prospective than dome-and-keel belts!



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