# Differential gold endowment in accretionary and dome-and-basin Archean greenstone belts

# Enrichissement différentiel en or des ceintures orogéniques d’accrétion et dôme-et-bassin d'âge Archéen

*Bruno Lafrance*

Congrès AEMQ XPLOR 2024

METAL EARTH

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

CANADA FIRST RESEARCH EXCELLENCE FUND Canada

Laurentian University Université Laurentienne
HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

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.

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES

Laurentian University Université Laurentienne HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

## 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

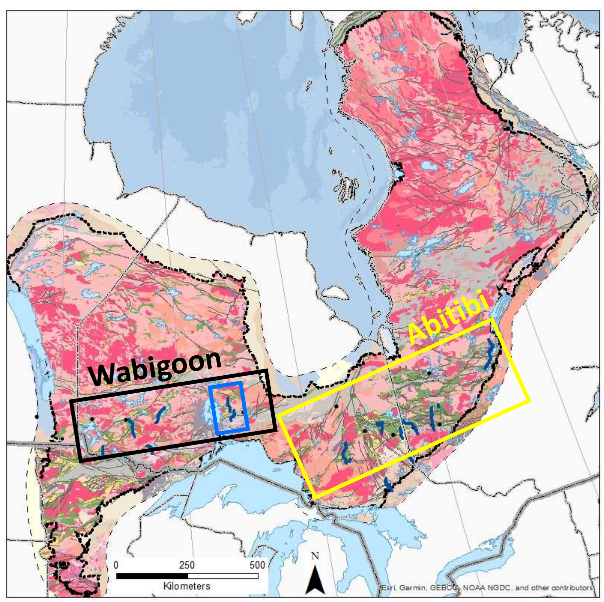
MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES

Laurentian University Université Laurentienne HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

## Transects were done across:

Endowed Abitibi Subprovince

Less endowed Wabigoon Subprovince

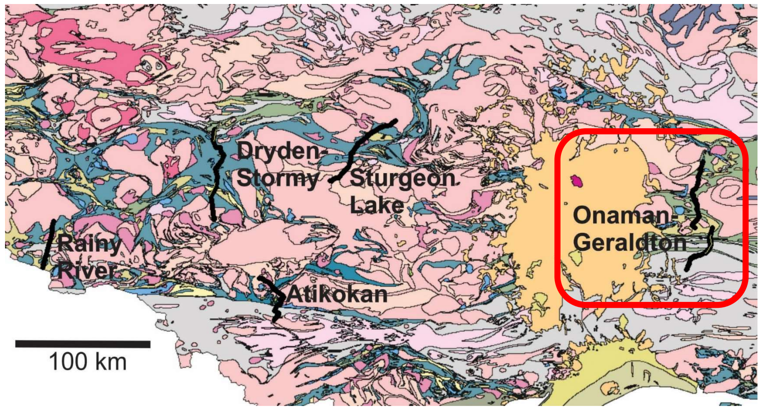



MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES

METAL EARTH

Laurentian University Université Laurentienne HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

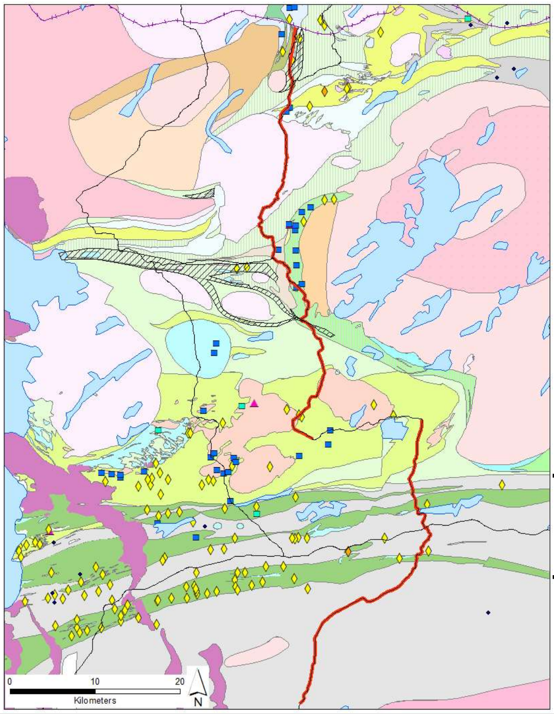
## Wabigoon Transects




**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)***

**Beardmore-Geraldton Belt (eastern Wabigoon Terrane)**

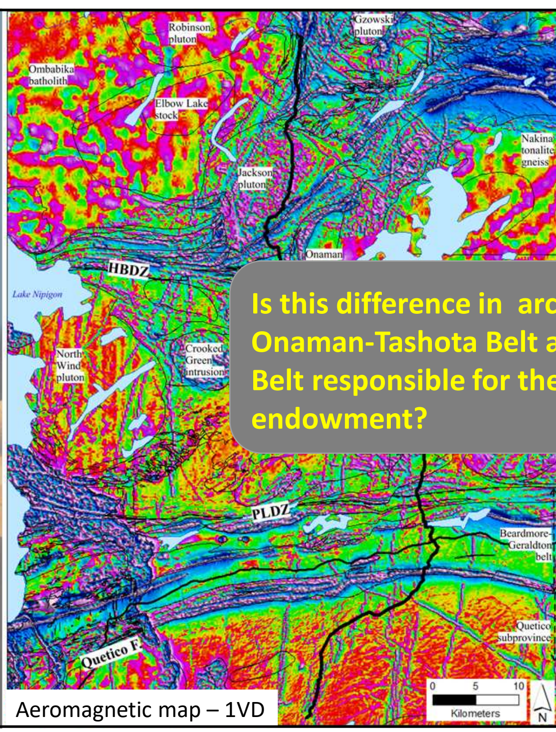
***(> 4 million ounces gold)***

**Quetico subprovince**

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

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




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)***

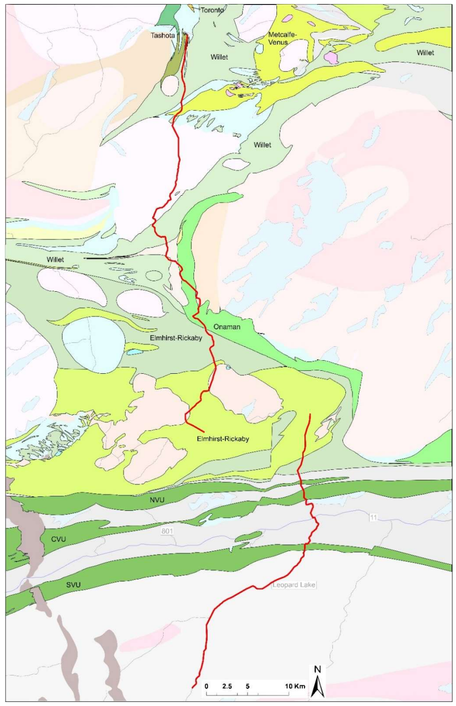
**Quetico subprovince**

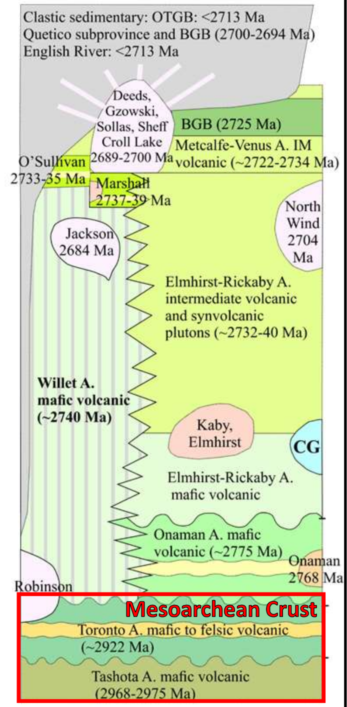
## Volcanic stratigraphy Onaman-Tashota Belt Beardmore-Geraldton Belt

**Onaman-Tashota Belt**
Mesoarchean
2975 Ma – 2922 Ma

Neoarchean
2775 Ma – 2722 Ma

**Beardmore-Geraldton Belt**
Neoarchean
2725 Ma




## *Neoarchean sedimentary assemblages*

### Onaman-Tashota Belt

Humboldt assemblage
<2713 Ma

Albert-Gledhill assemblage <2710 Ma

Conglomerate assemblage
<2707 Ma

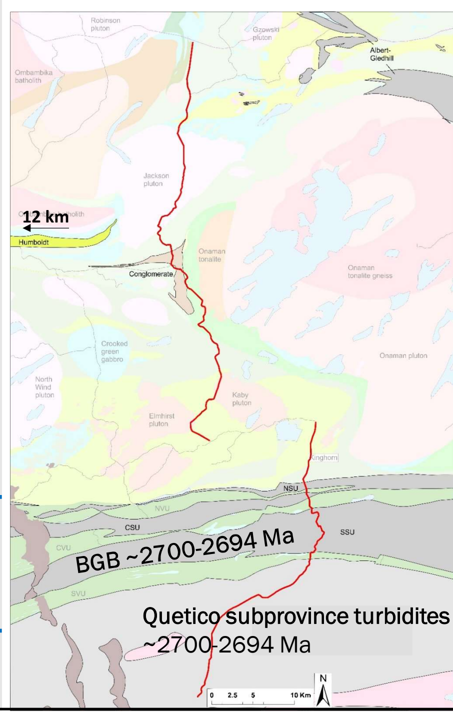
Humboldt-Nipigon conglomerate
<2671 Ma

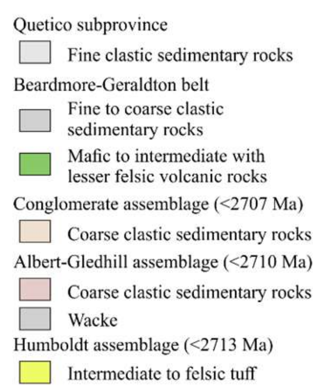
### Beardmore-Geraldton Belt

BGB metasedimentary rocks
~2700-2694 Ma

### Quetico Subprovince

Turbidites ~2700-2694 Ma




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

METAL EARTH

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**

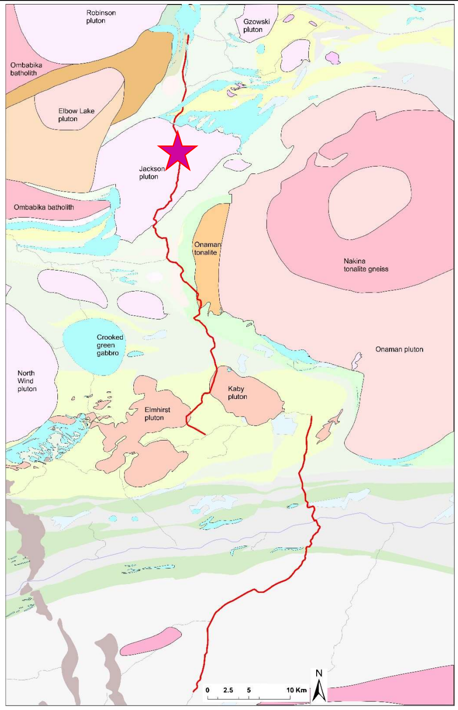
- **Onaman tonalite** 2768 Ma
- **Kaby pluton** 2734 Ma
- **Elmhirst pluton** 2731-2738 Ma
- **Crooked Green intrusion** 2732-2735 Ma
- **Elbow Lake** pluton 2722 Ma

**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

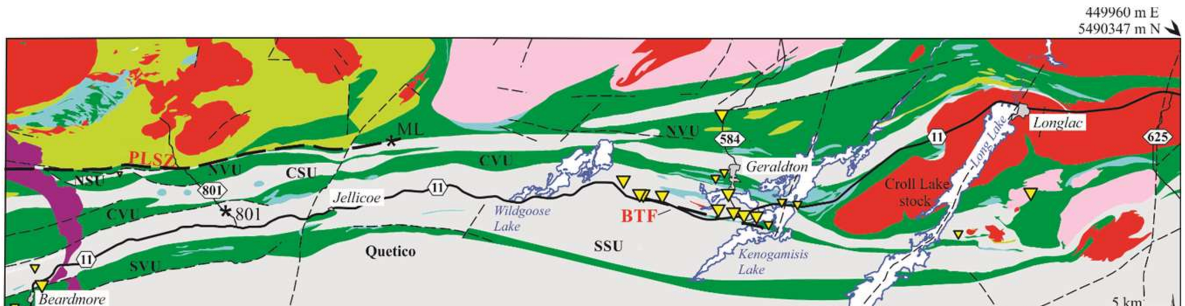
ARCHEAN
- Diorite to quartz diorite
- Tonalite to granodiorite
- Granodiorite to tonalite
- Tonalite to granodiorite

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

METAL EARTH

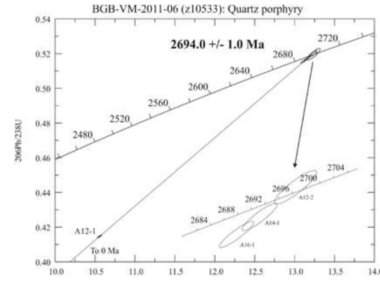
## Neoarchean intrusive rocks in the Beardmore-Geraldton Belt




Map from Tóth et al. (2022)

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

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




MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES

METAL EARTH

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

| | *Onaman-Tashota belt* | *Beardmore-Geraldton belt* |
|---|---|---|
| *Volcanism* | Neoarchean volcanism (2722- 2780 Ma)<br>Mesoarchean volcanism (2922 Ma -2975 Ma) | Neoarchean volcanism (ca. 2725 Ma) |
| *Sedimentation* | Turbidites and polymictic conglomerates<br>(2713 Ma - 2692 Ma) | Turbidites and polymictic conglomerates<br>(2700 Ma - 2694 Ma) |
| *Plutonism* | Neoarchean plutonism<br>Syn-volcanic pluton (2780 Ma – 2720 Ma)<br>Late syn-tectonic plutons (2700 Ma – 2680 Ma)<br>Mesoarchean plutonism (2922 Ma) | Neoarchean plutonism<br>Late syn-tectonic plutons<br>(2694- 2690 Ma) |

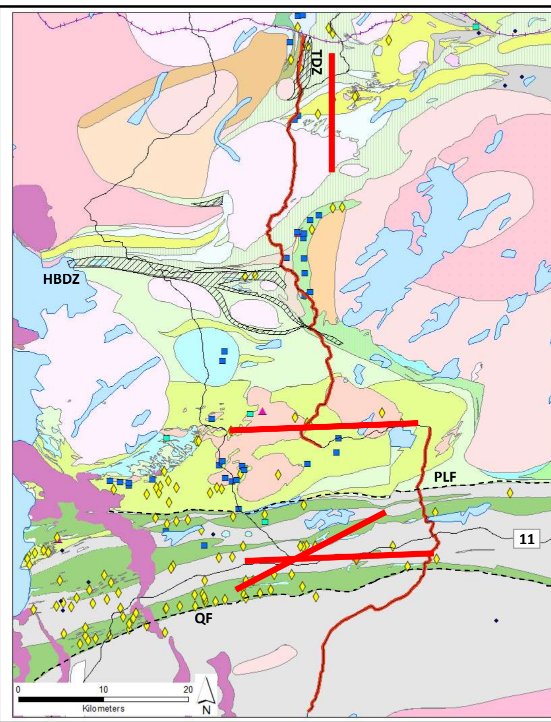
MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES — METAL EARTH — Laurentian University Université Laurentienne — HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

## 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*

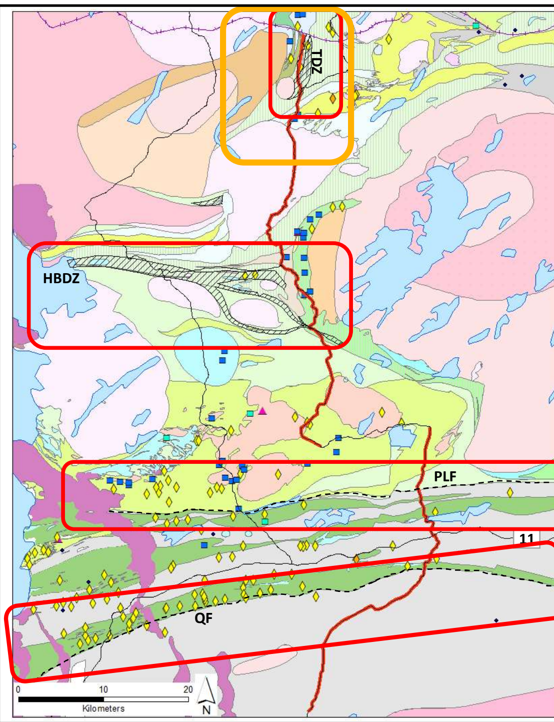
D1 Tashota deformation zone (TDZ)
- N-striking deformation along batholith-volcanic contact

D2 & D3 Humboldt Bay deformation zone (HBZD)
- E-striking deformation corridor <u>within</u> the OTB

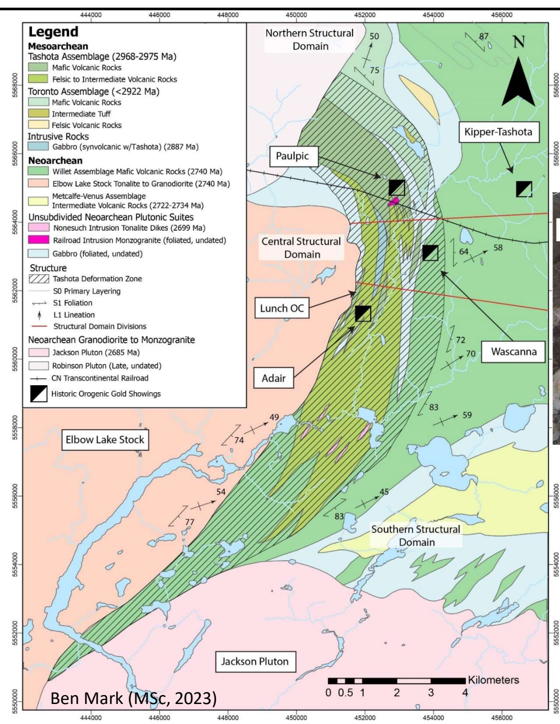
D2 & D3 Paint Lake Fault (PLF)
- E-striking deformation zone separating the BGB from the OTB

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

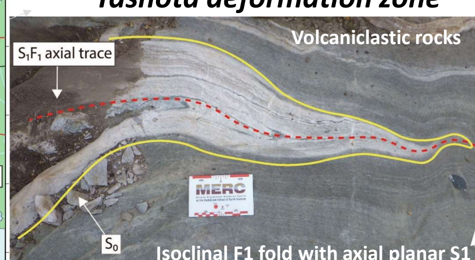



# Structural Geology of the Onaman-Tashota Belt




***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

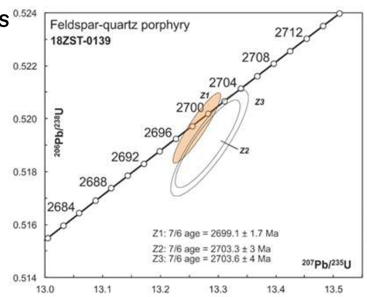
Maximum age of $D_1$ is 2699 Ma.

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





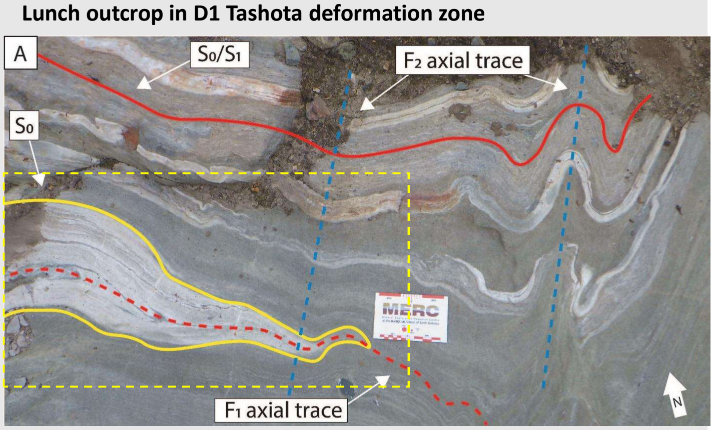

U-Pb ages: Hamilton, 2019-2020; pers. comm.

METAL EARTH

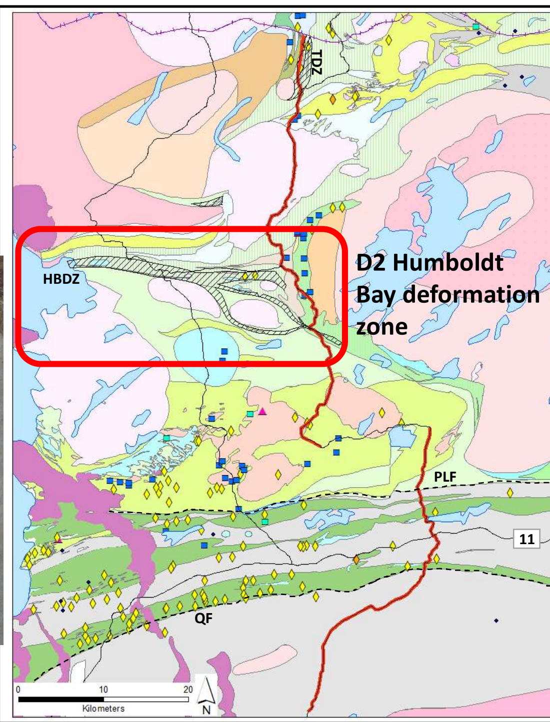
# Structural Geology of the Onaman-Tashota Belt

*D2 deformation event*

**Lunch outcrop in D1 Tashota deformation zone**




Ben Mark (MSc, 2023)



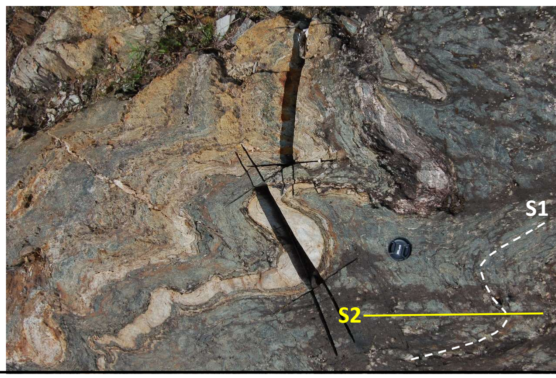

Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; OGS MDI July, 2018

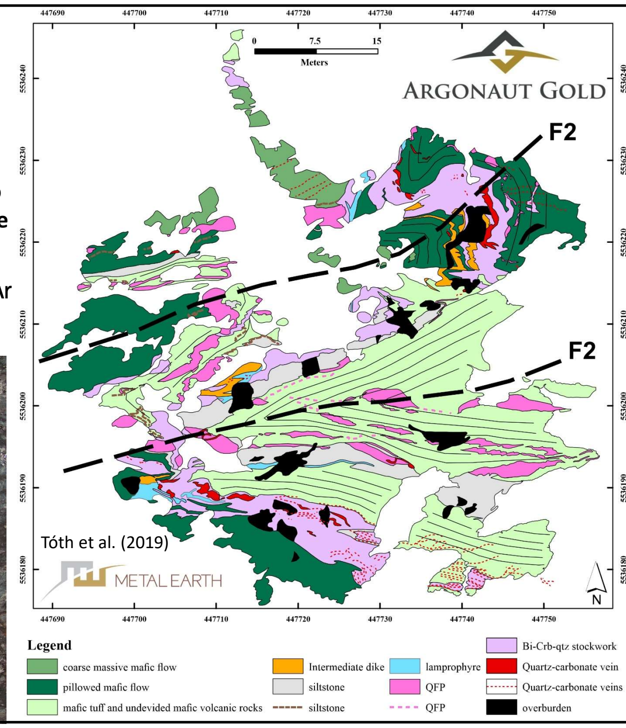
## *D2 deformation event in OTB*

**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).



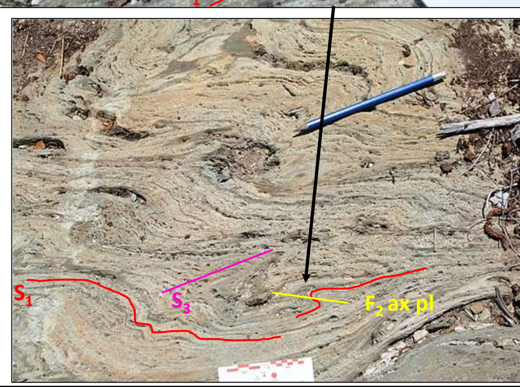

## $D_3$ deformation event– OTB

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

EW-striking dextral faults or shear zones

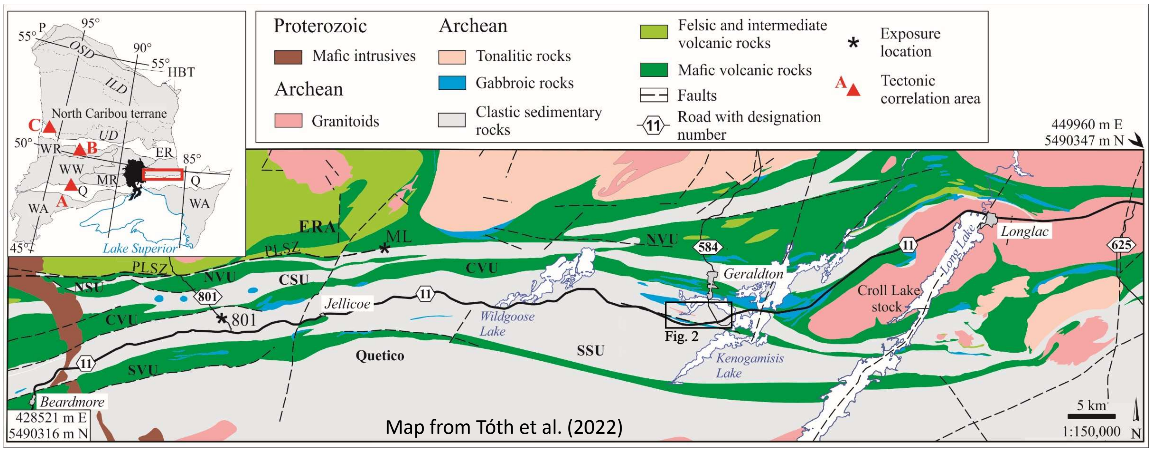
< 2667 Ma in age


Ben Mark (MSc, 2023)

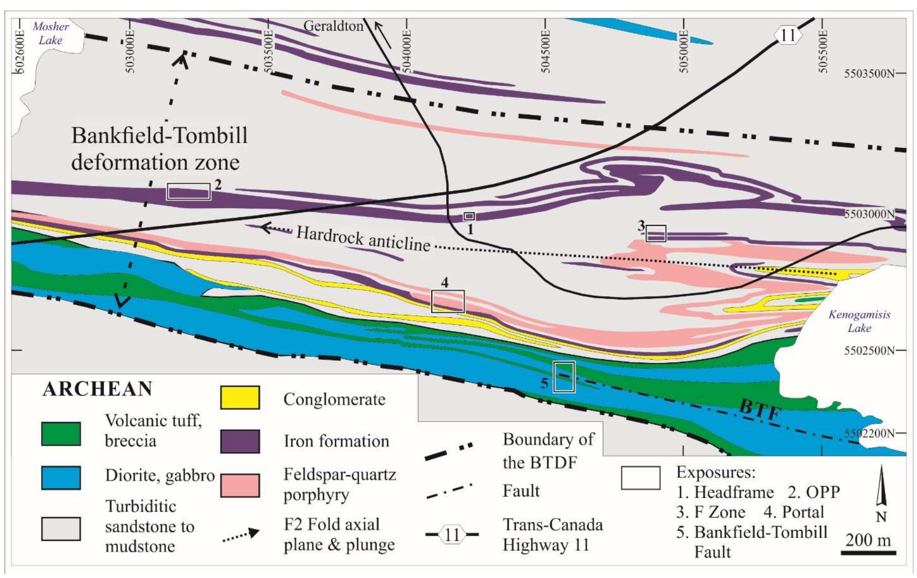
# Structural Geology of the Beardmore-Geraldton Belt

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.**



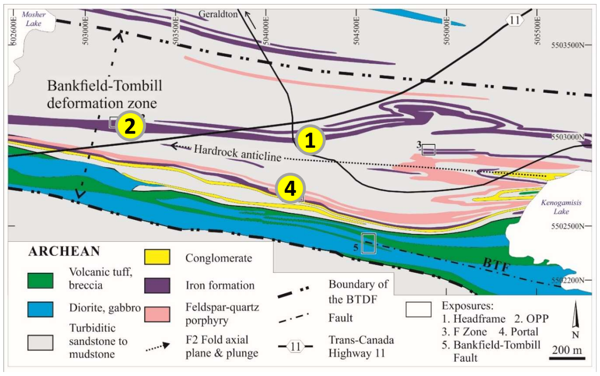

Tóth et al. (2023) JSG

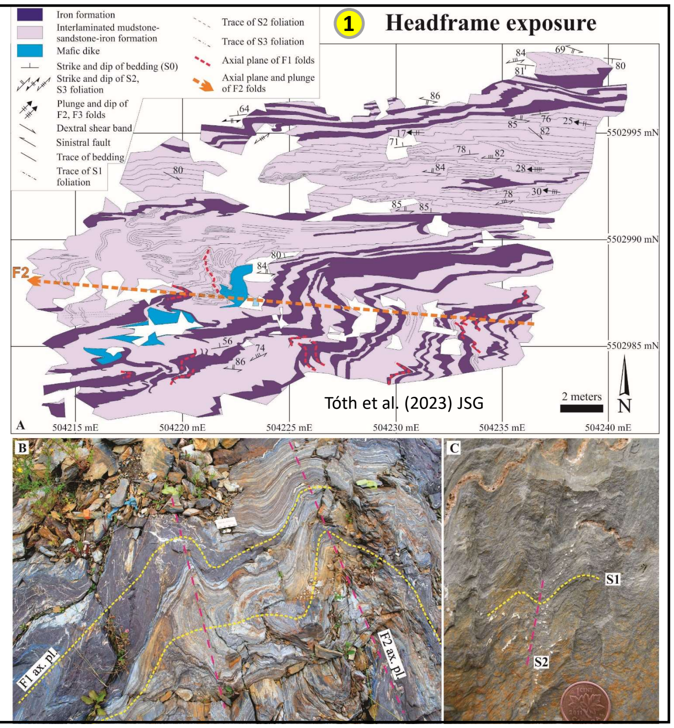
## D1 deformation event

Isoclinal F1 folds with axial planar S1 foliation

Bedding-parallel in iron formation and sedimentary rocks

Observed in mafic dikes and QFP intrusions



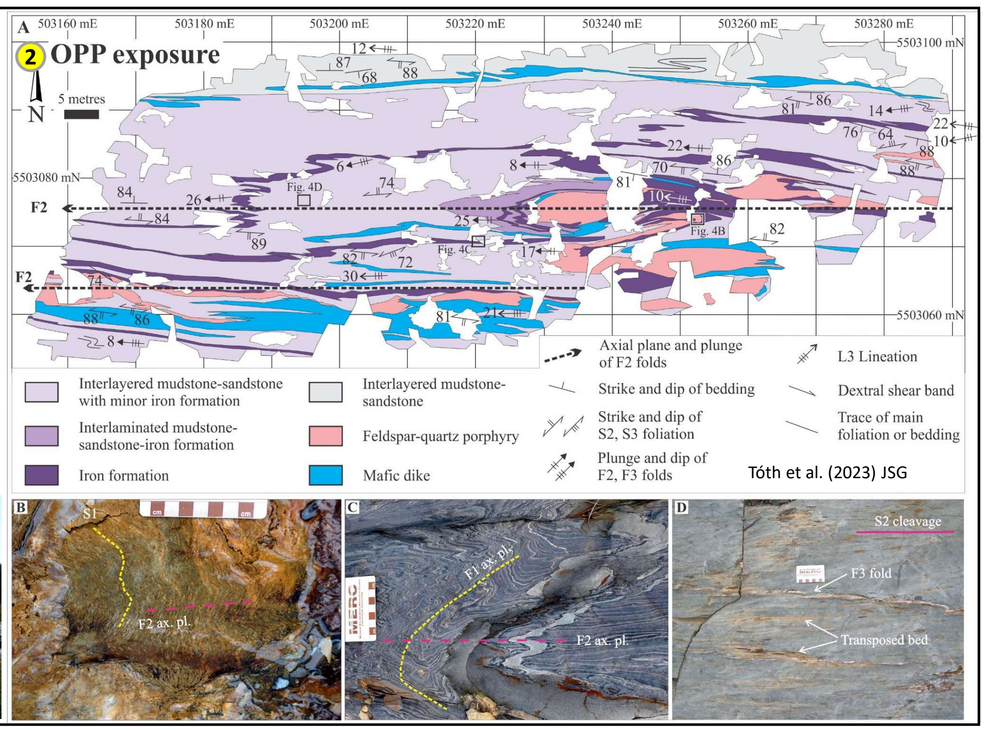




## D2 deformation event

Development of D2 deformation zone and regional S2 foliation

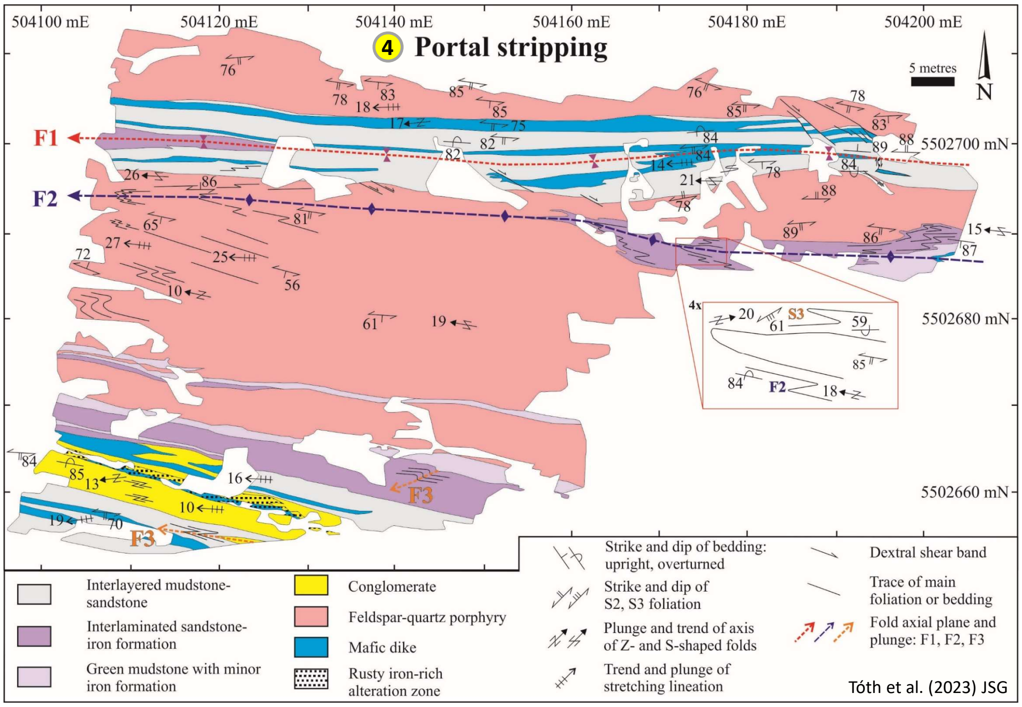
Refolding and transposition of F1 folds and S1 foliation

Observed in mafic dikes and QFP intrusions

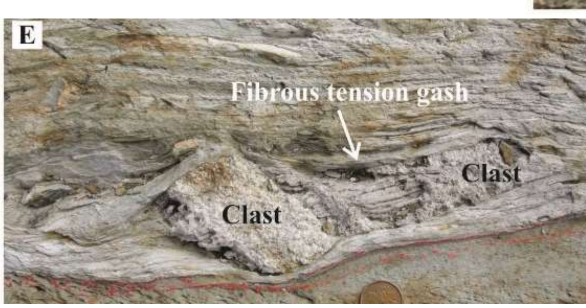


**D3 deformation event**

Dextral transpression and reactivation of D2 deformation zones




**Asymmetrical strain shadow around clast**

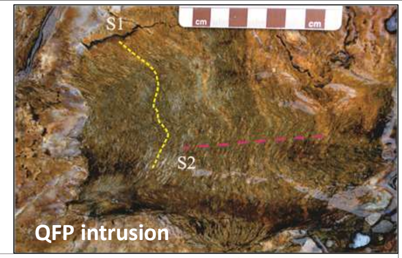



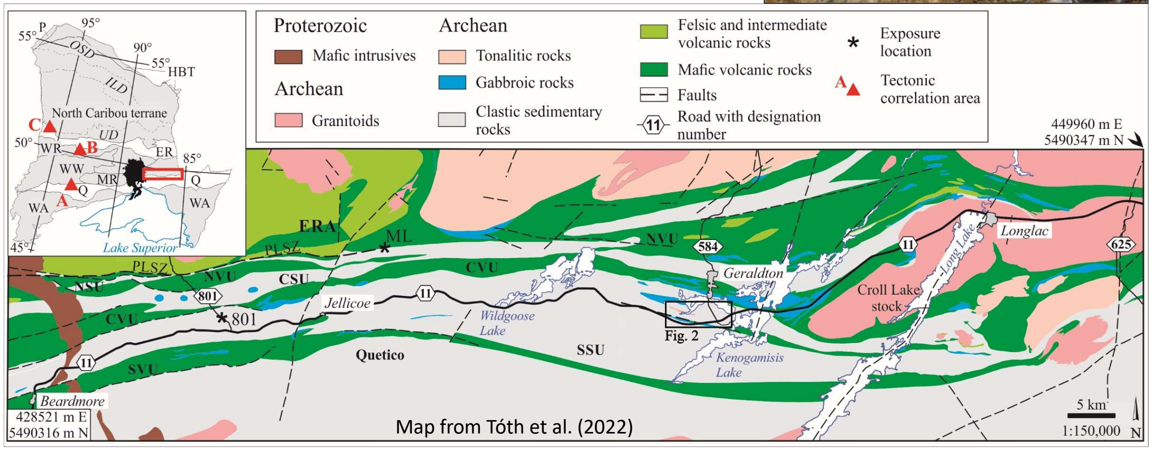

**D3 dextral shear sense indicators**

## 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)

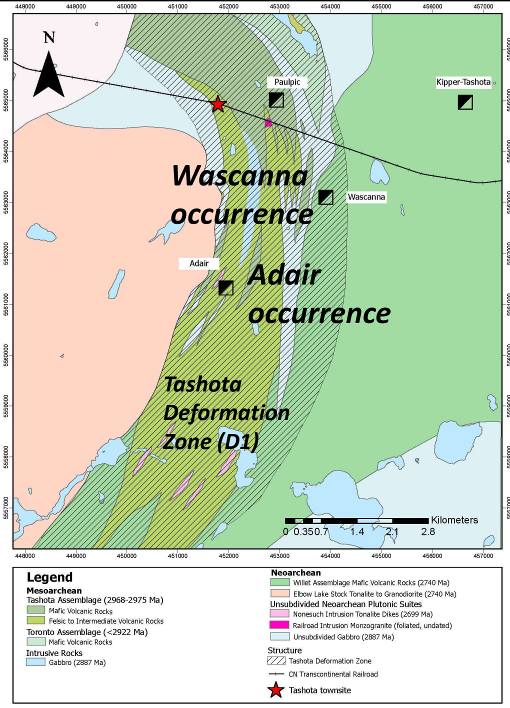
## Comparison of structural geology of the OTB and the BGB

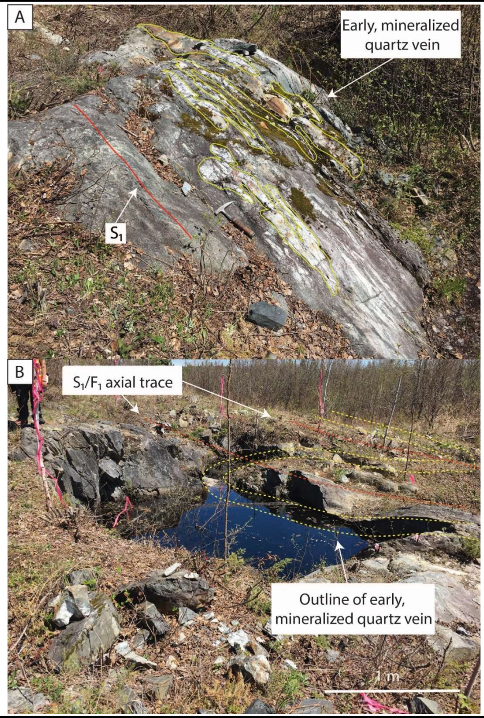
| | Onaman-Tashota belt | Beardmore-Geraldton belt |
|---|---|---|
| $D_1$ | Formation of **dome-and-keel architecture** charact... granitic... infoldir... the do... <br><2699.1 ± 1.7 Ma - 2684 Ma | Formation of **linear accretionary belt** by thrust ... ntary panels <br>2694+/-1 Ma – 2690 Ma |
| $D_2$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

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

***Same***

***More significant in BGB***

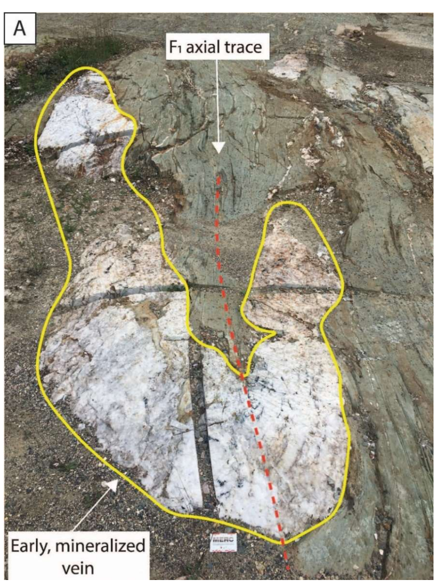


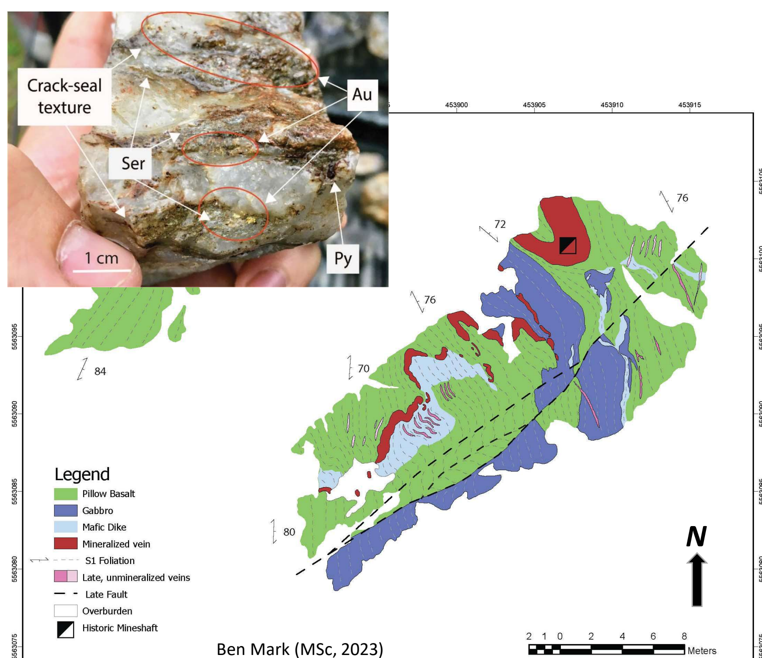




## Gold in the Onaman-Tashota Belt

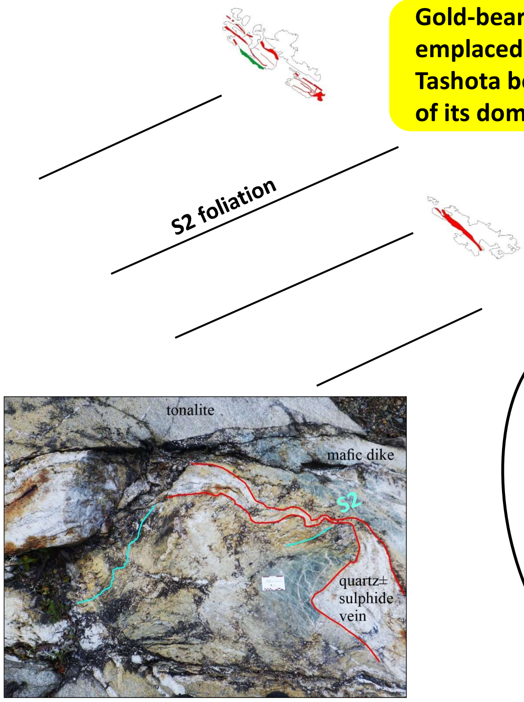
Ben Mark (MSc, 2023)

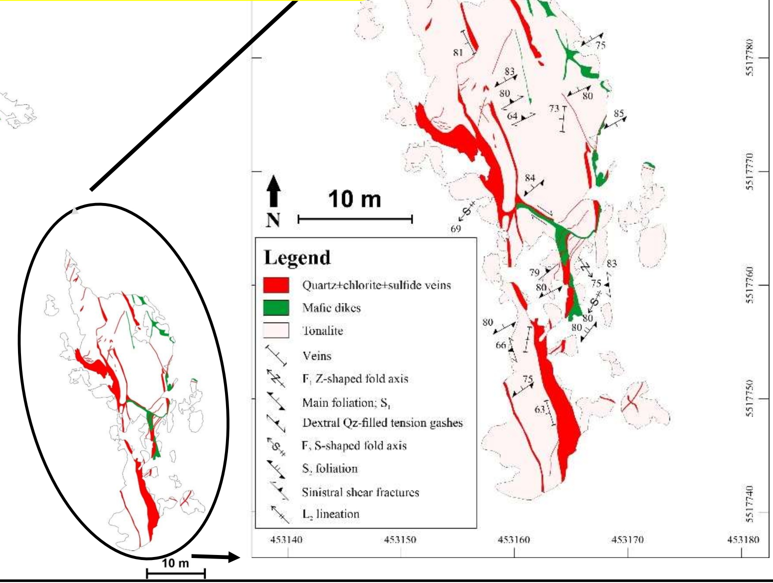
## *Wascanna ocurrence*



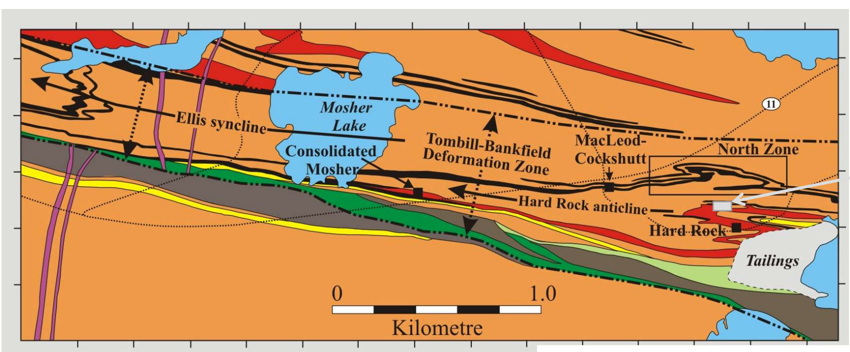



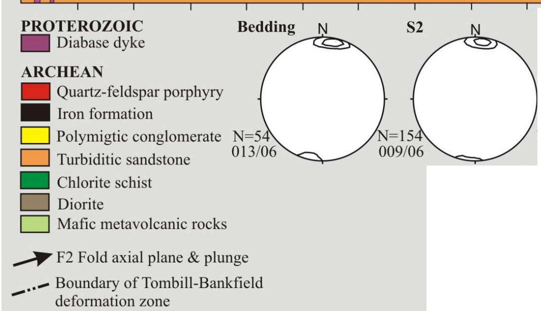
**Gold-bearing quartz veins were emplaced early in the Onaman-Tashota belt during the development of its dome-and-keel architecture.**



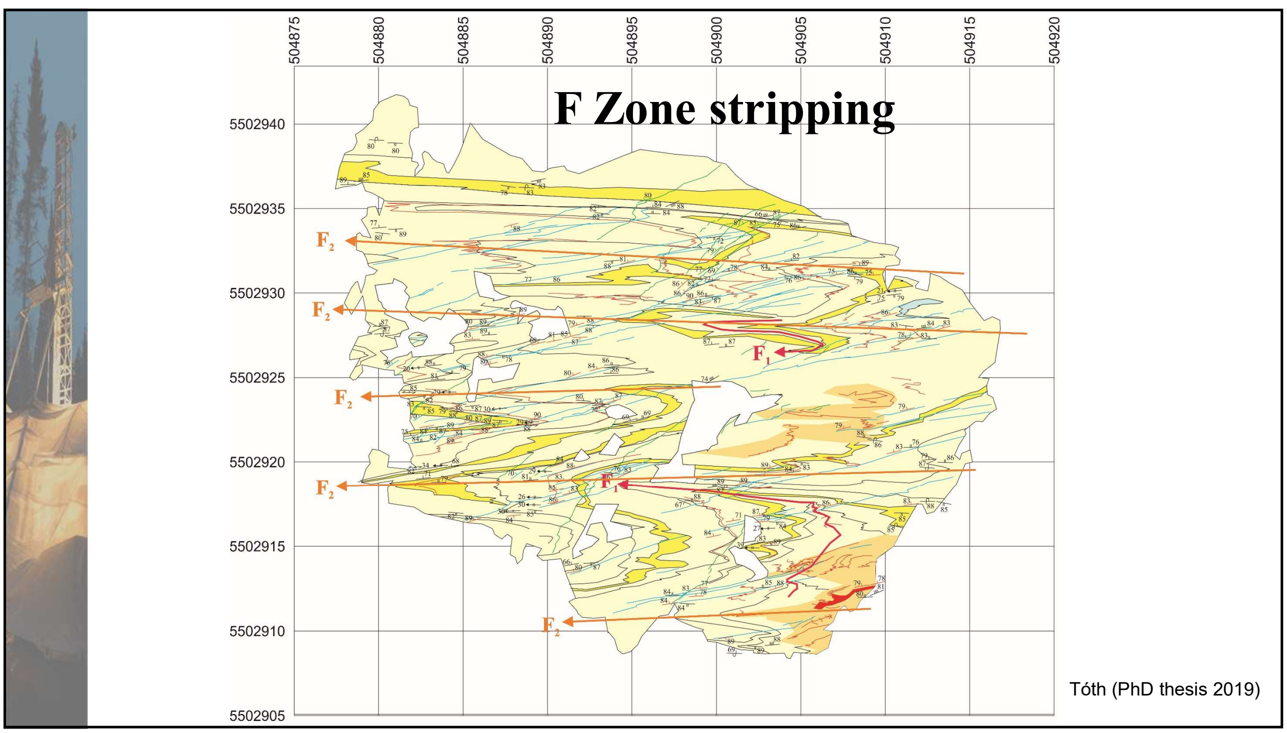




## Gold in the Beardmore-Geraldton belt

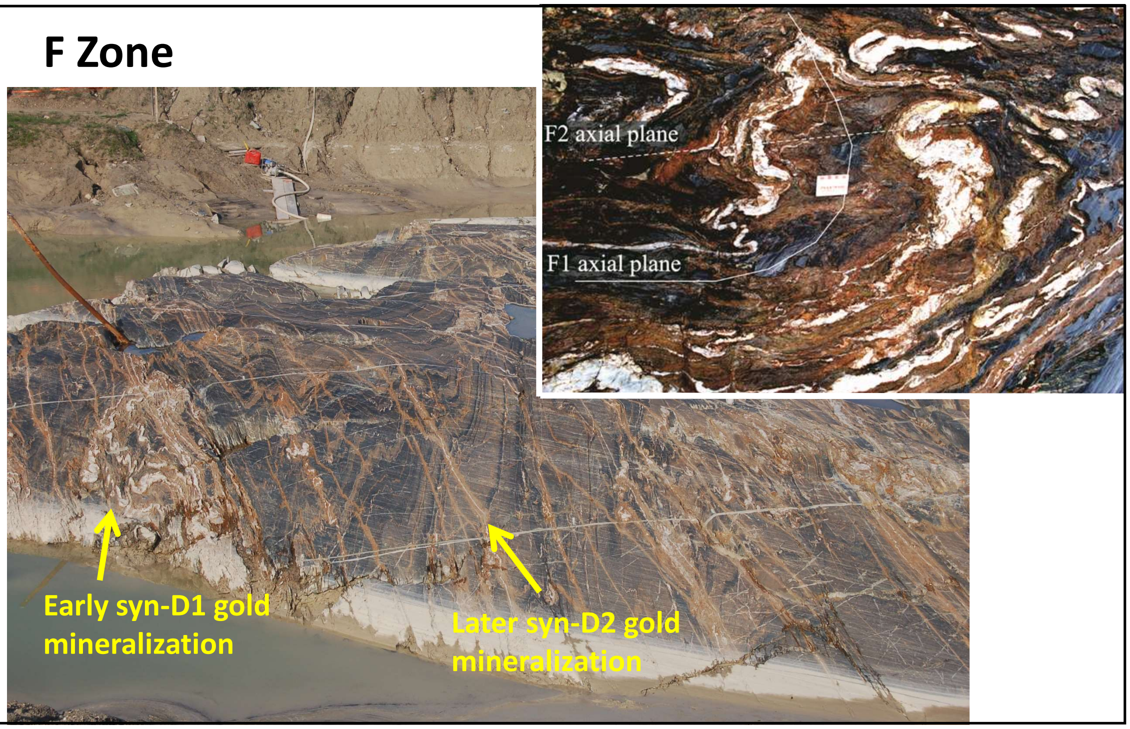


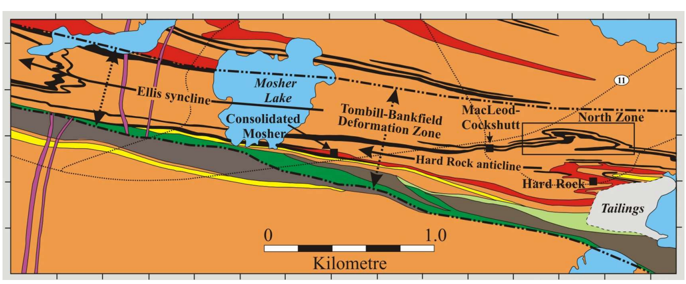

From Equinox Gold website
N
Pit
Plant Site
New Highway 11
Waste Rock
Storage Area
~200m

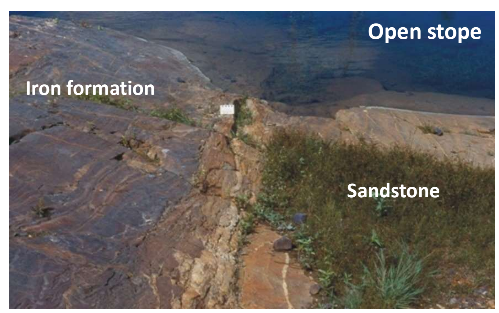

F Zone stripping
504875
504880
504885
504890
504895
504900
504905
504910
504915
504920
5502940
5502935
5502930
5502925
5502920
5502915
5502910
5502905
F2
F1
Tóth (PhD thesis 2019)

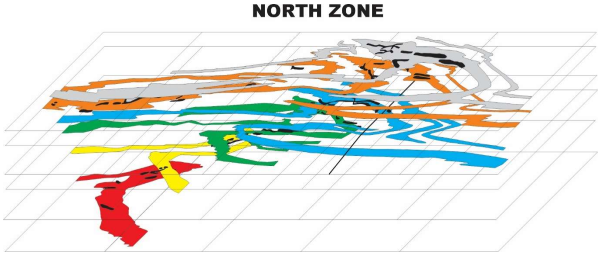
# F Zone

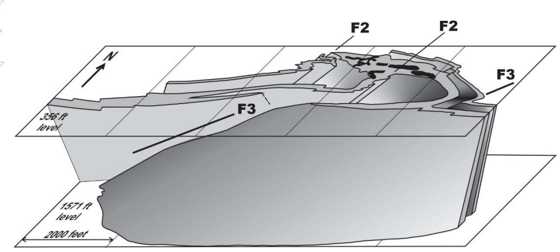



# North Zone
# Hard Rock Mine



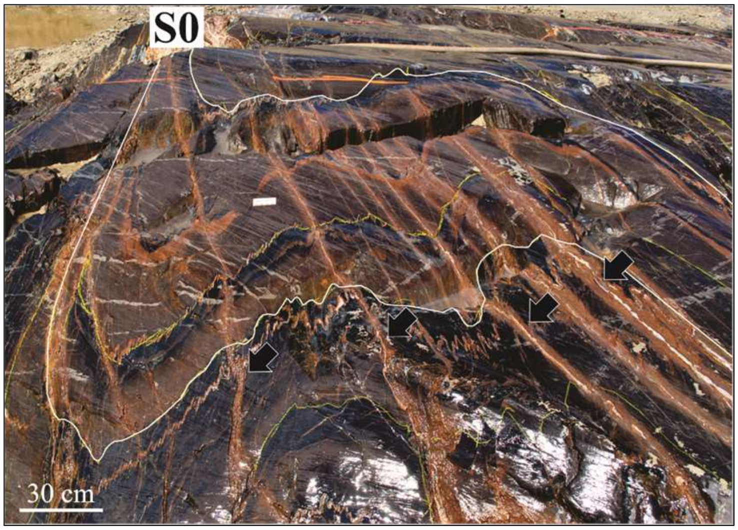




Lafrance et al. (2004)

# F Zone

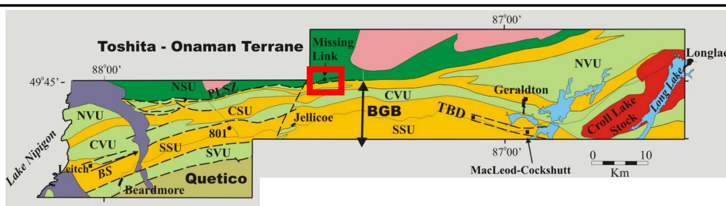
*Later syn-D2 auriferous veins*

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





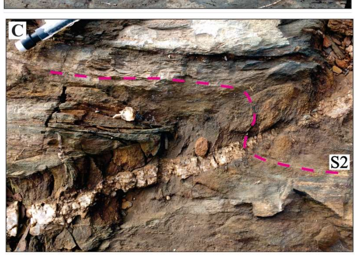

S-shaped folded extensional vein



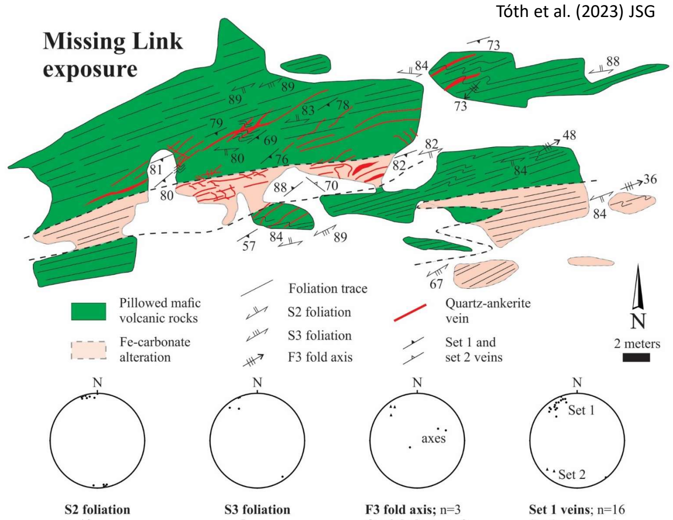

## Missing Link gold occurrence along Paint Lake Fault

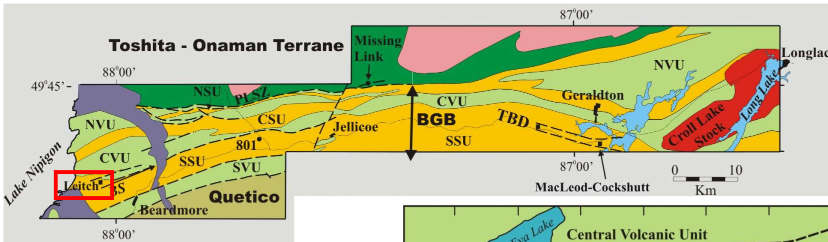
Tóth et al. (2023) JSG


S2 Flattened pillows overprinted by S-folded extensional vein

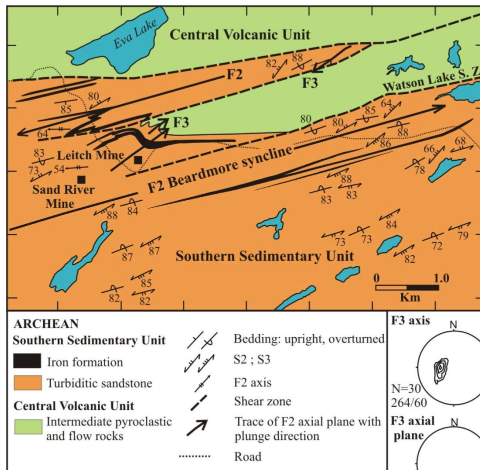


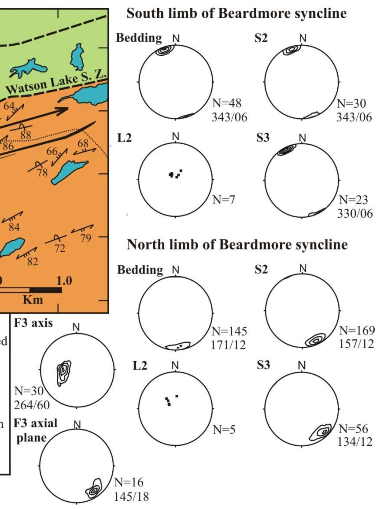

Dextral Z-shaped flanking structure along extensional vein






# Leitch – Sand River Mine Western Beardmore-Geraldton Belt

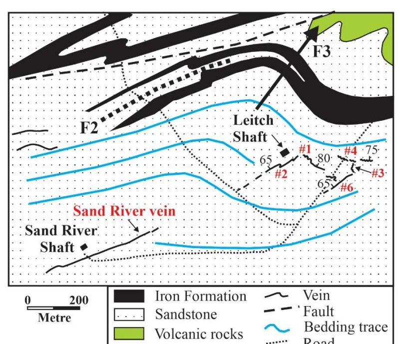



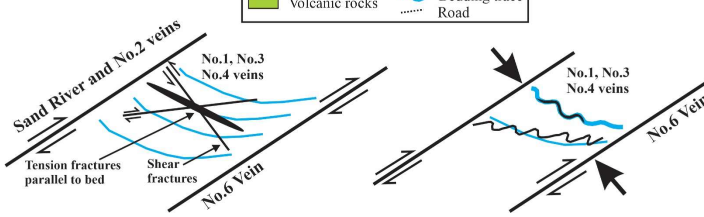

**Z-shaped F3 fold parasitic to map-scale F3 fold hosting mineralization at the Leitch-Sand River mine**

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<br>D2 deformation zones and fold hinges<br>D3 dextral transpression |
| *Total production* | <100,000 ounces gold | > 4 million ounces gold |

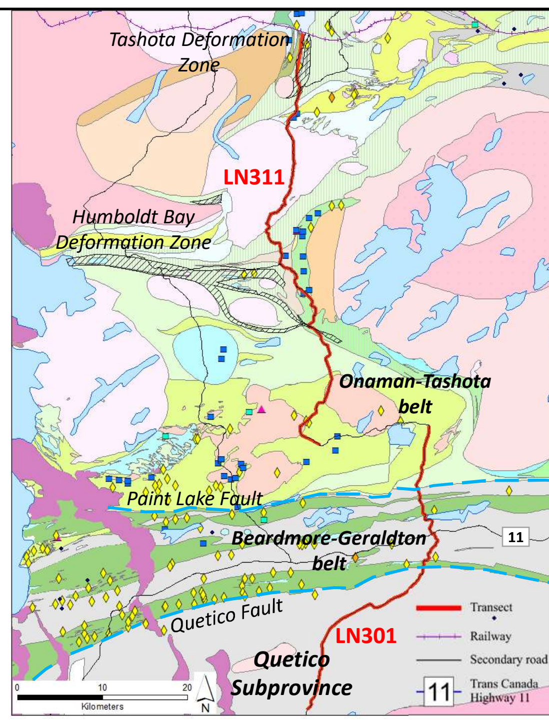
MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES | METAL EARTH | Laurentian University Université Laurentienne | HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

## Seismic and Magnetotelluric (MT) Transect

### *Transect Lines in Red*

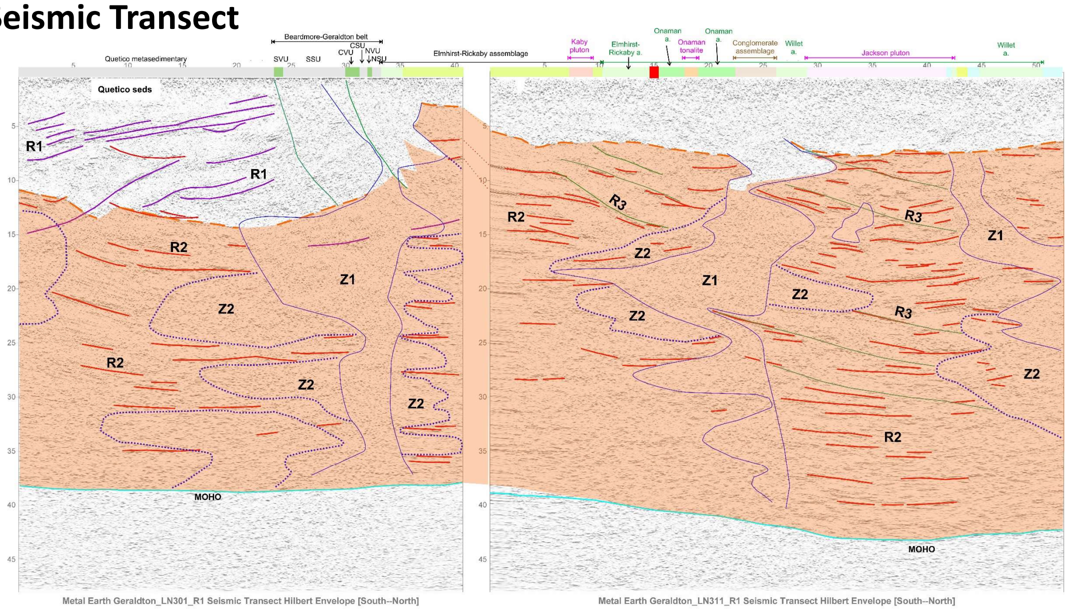
LN301 and the first 25 km of LN311 cut across east-trending stratigraphy.

The last 25 km of LN311 are oblique and at 45° to stratigraphy.

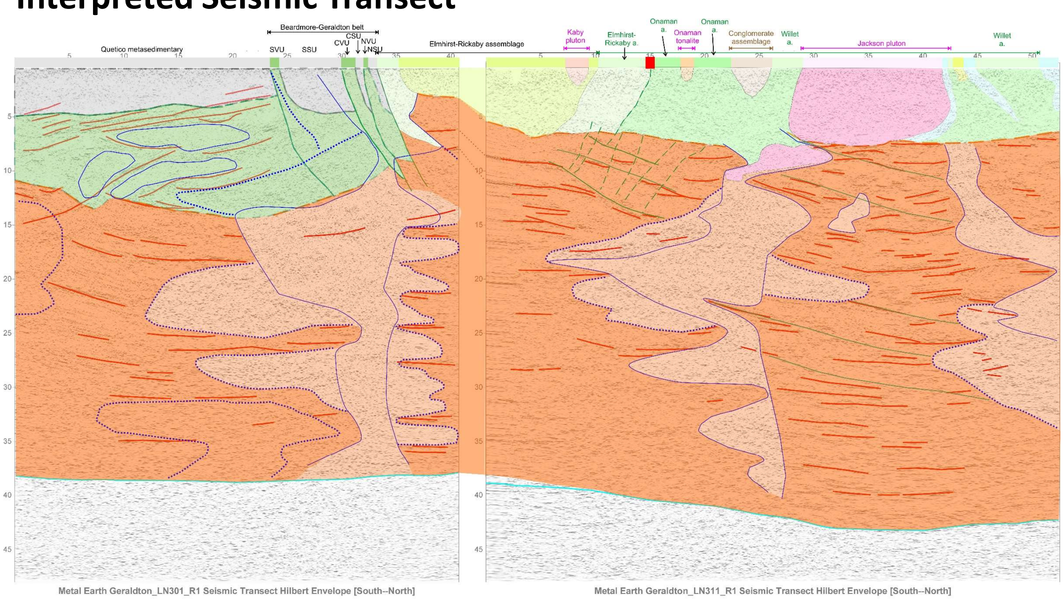



Compiled from Stott et al., 2002; Hart et al., 2002a,b,c; Lemkow et al., 2005; Bjorkman 2017

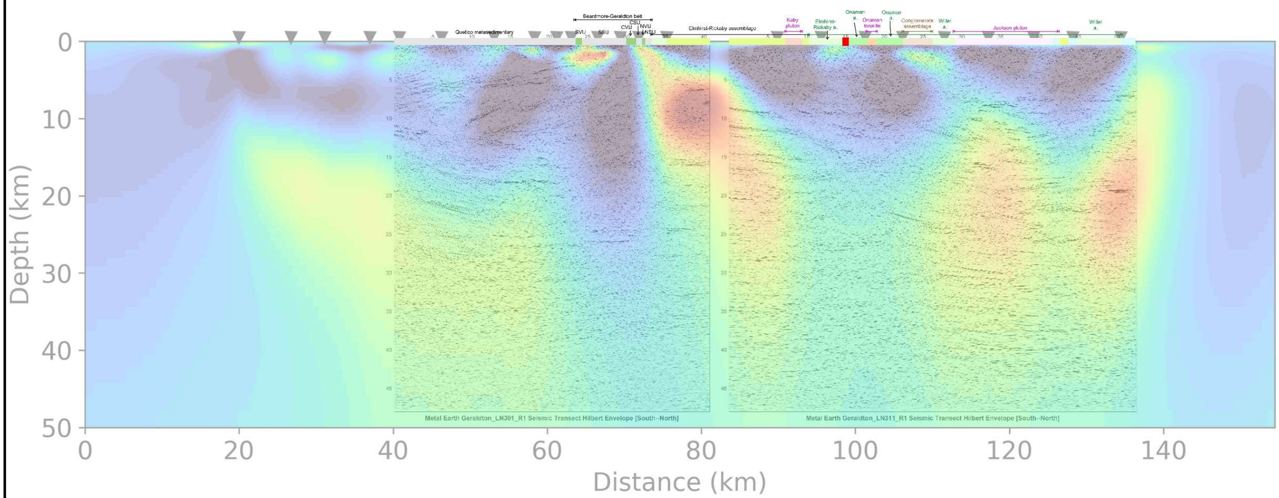
# Seismic Transect




# Interpreted Seismic Transect

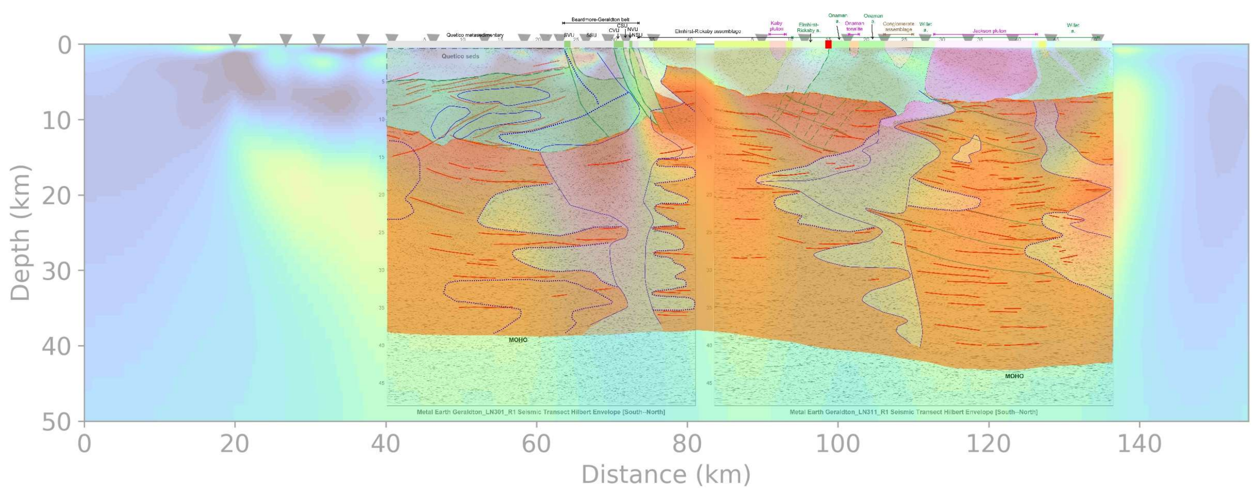


## MT Transect





## Seismic and MT Transect




## 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.

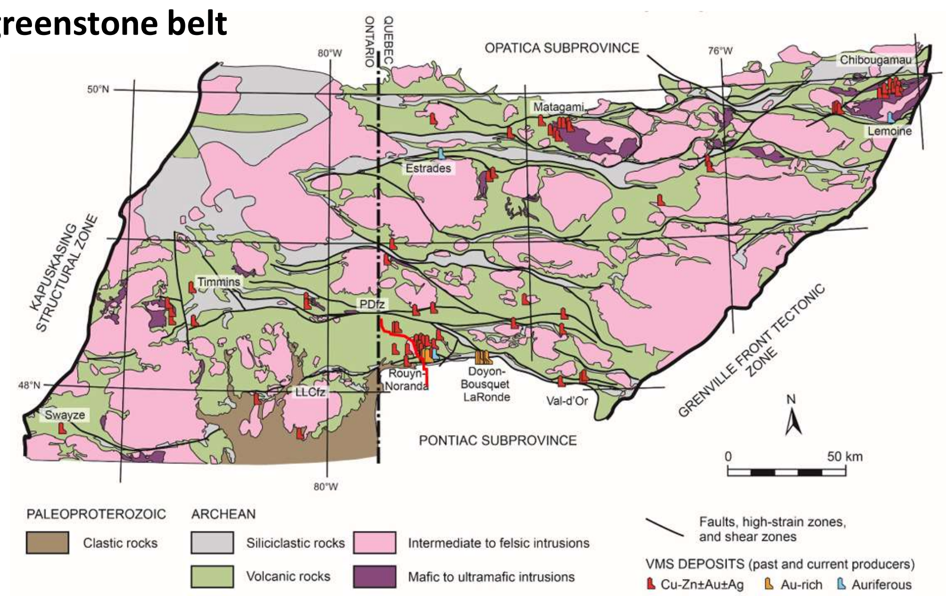
(3) The more gold-endowed Beardmore-Geraldton Belt coincides with more conductive (or less resistive) and less reflective steeply-dipping zone(s) on the combined Seismic-MT transect.

(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!***

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES · METAL EARTH · Laurentian University Université Laurentienne · HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

## Abitibi greenstone belt

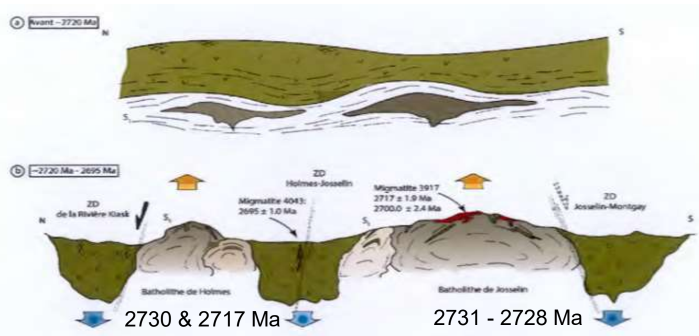



Modified from Monecke et al. (2017) – *Reviews in Economic Geology, v. 19, p. 7-49*

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES · METAL EARTH · Laurentian University Université Laurentienne · HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

# Structural evolution of the northern Abitibi

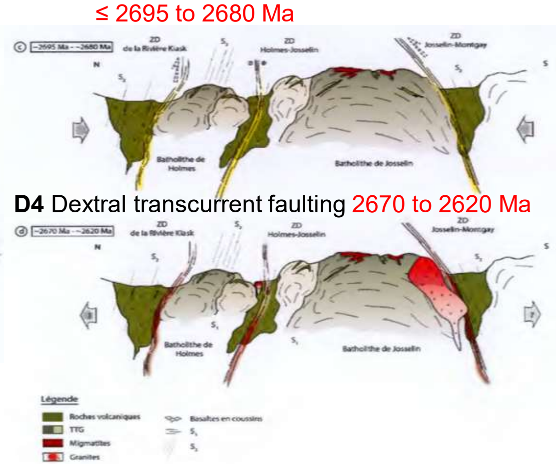
***Lebel-sur-Quévillon*** ***Attic Complex***




D1-D2 Dome-and-keel formation
≤ 2720 to 2695 Ma

Nicolas Revelli PhD thesis 2021 UQAM

**D3** Formation of EW regional folds and foliation
≤ 2695 to 2680 Ma

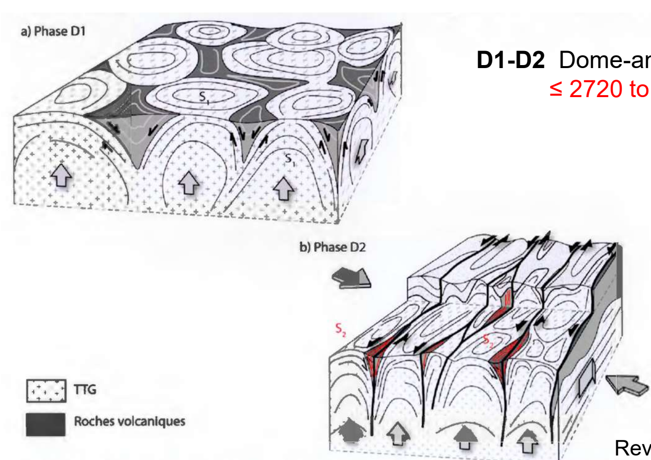


**D4** Dextral transcurrent faulting 2670 to 2620 Ma

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES · METAL EARTH · Laurentian University Université Laurentienne · HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

# Structural evolution of the northern Abitibi

***Lebel-sur-Quévillon*** ***Attic Complex***



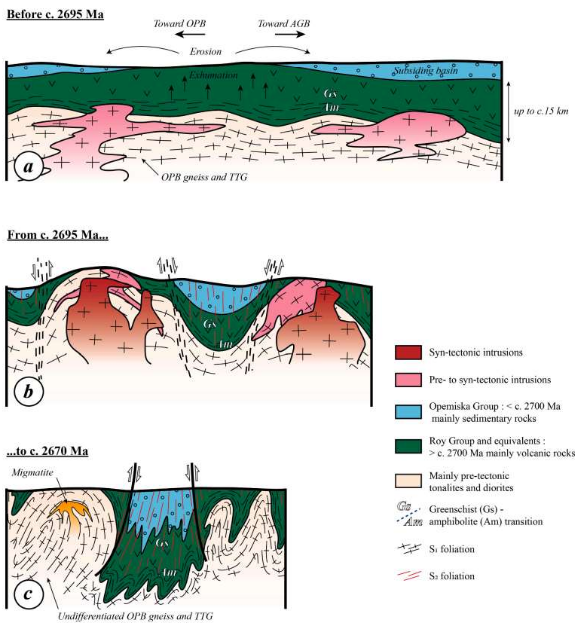

**D1-D2** Dome-and-keel
≤ 2720 to 2695 Ma

**D3** Formation of EW regional folds and foliation
≤ 2695 to 2680 Ma

Revelli (2021) PhD thesis UQAM *Diagram after Vidal et al. (2009)*

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES · METAL EARTH · Laurentian University Université Laurentienne · HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

# Structural evolution of the northern Abitibi




**D3** Formation of EW regional folds and foliation
≤ 2695 to 2670 Ma

Daoudene et al. (2022) Precambrian Research

MERC AT THE HARQUAIL SCHOOL OF EARTH SCIENCES — METAL EARTH — Laurentian University Université Laurentienne — HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE

# Thank you

Stay up to date via the MERC Newsletter
Subscribe online by visiting:

Merc.laurentian.ca

Contact us with questions: merc@laurentian.ca
Connect with us on LinkedIn, Facebook, Twitter

METAL EARTH

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

CANADA FIRST RESEARCH EXCELLENCE FUND — Canada

Laurentian University Université Laurentienne — HARQUAIL SCHOOL OF EARTH SCIENCES ÉCOLE DES SCIENCES DE LA TERRE — MERC Mineral Exploration Research Centre