PDAC MARCH 5-8 2023 THE WORLD'S PREMIER MINERAL EXPLORATION & MINING CONVENTION

PDAC short course: New geophysical and geological insights into how crustal architecture influences the gold and base metal endowment of Precambrian terranes

Crustal Architecture of the Sturgeon-Savant Lakes region and implications for VMS endowment

Chong Ma

Research Associate, Metal Earth, Harquail School of Earth Sciences, Laurentian University, Sudbury, Canada

Collaborators:
Mostafa Naghizadeh[1], Ademola Adetunji[1], Jeffrey Marsh[1], Robert W. D. Lodge[2], David Snyder[1], Mike Hamilton[3] Ross Sherlock[1]

1 Laurentian University; 2 University of Wisconsin-Eau Claire; 3 University of Toronto

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Outline

PART I
Geophysical constraints on the crustal architecture of the Sturgeon-Savant Lakes region

PART II
Geologic and geochemical constraints on the volcanism of the Sturgeon Lake greenstone belt

PART III
Implications for VMS endowment in the region

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PART I

Geophysical constraints on the crustal architecture of the Sturgeon-Savant Lakes region

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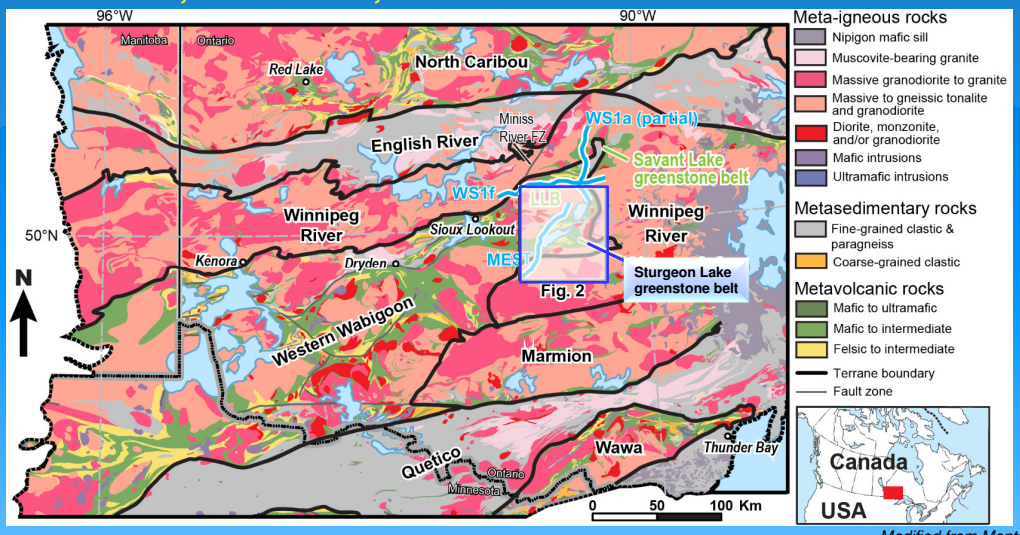
Superior craton, NW Ontario, Canada



Modified from Montsion et al. (2018)

- **Composite, tectonically stable crust of continental & oceanic terranes**
- **Western Wabigoon terrane (WWT):** oceanic terrane, with many greenstone belts dominated by meta-volcanic & sedimentary rocks
- **Winnipeg River terrane (WRT):** continental terrane, dominated by

MEST = **Metal Earth Sturgeon transect** WS1a, WS1f = Lithoprobe transects

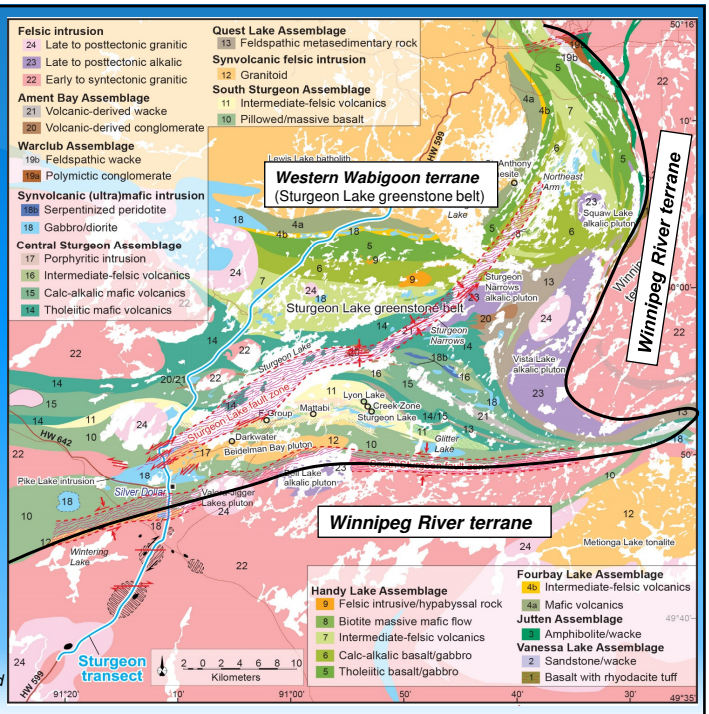
Metal Earth Sturgeon transect

Western Wabigoon terrane (WWT)

- ❑ Four volcanic assemblages (2780–2720 Ma)
- ❑ Numerous syn-volcanic intrusions
- ❑ Regionally folded with local intense fabrics
- ❑ Two major fault zones

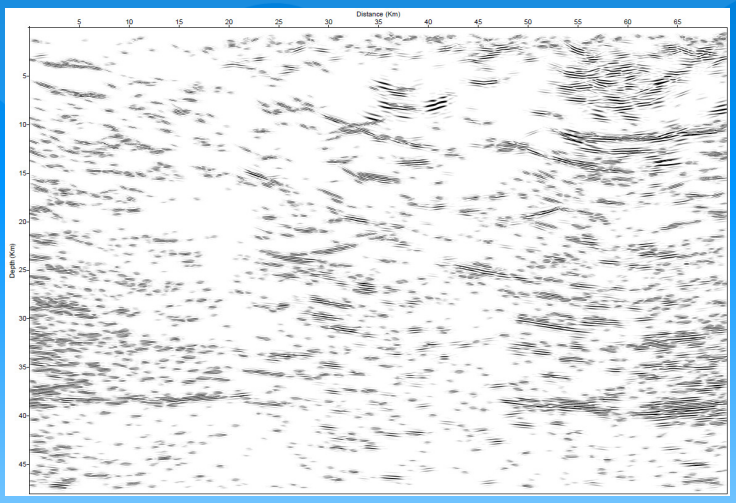
Winnipeg River terrane (WRT)

- ❑ Paleo- to Mesoarchean (up to 3300 Ma) basement rocks
- ❑ Intruded by Neoarchean granitoids of 2710–2660 Ma



Map modified after Sanborn-Barrie and Skulski (2005) and Stone et al. (2002)

Seismic reflections



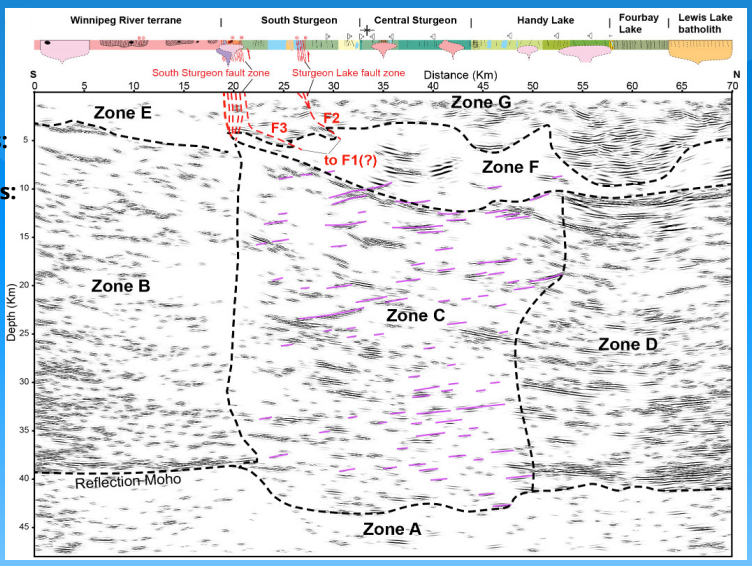
Seismic reflections

Zone A: mantle

Zones B, C, D, E, F :
- **Prominent reflections:** gneissic & mafic rocks
- **Poorly reflective zones:** granitic rocks

Zone G:
- Minimum thickness of the greenstone belt

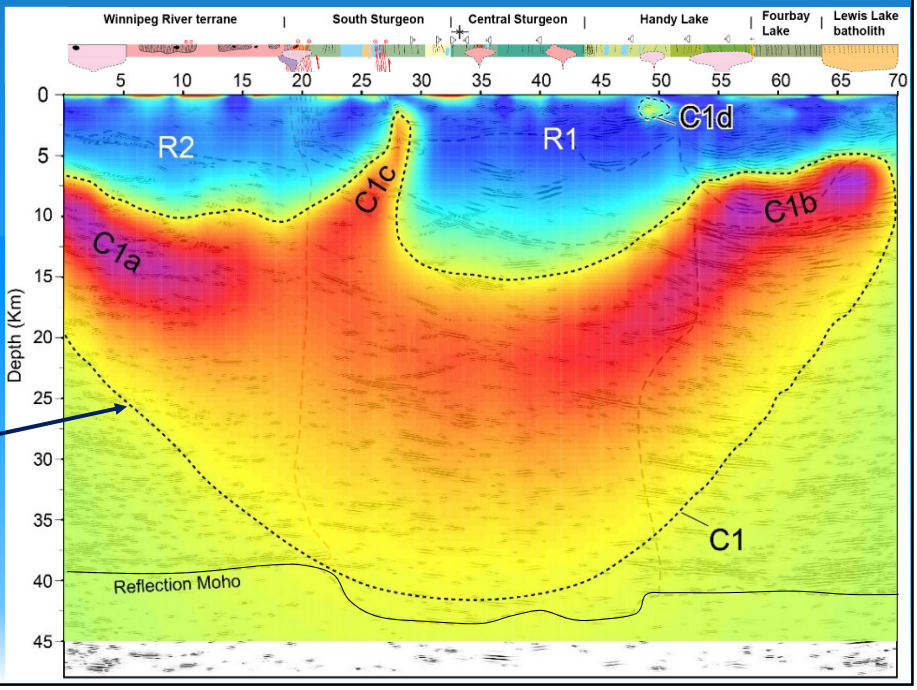
Greenstone belt basal boundary:
- Beneath Zone G & above the Zone F reflectors
- **Thrust fault zone**



The south-dipping reflectors in Zone C: mafic-ultramafic dikes imaged by out-of-plane seismic ray

An apparent crustal root (only beneath the mafic dikes): the middle part of Moho with deeper depths, possibly due to partial melting of mantle rocks that would result in interlayered felsic and mafic rocks that are similar in reflectivity to that of the lower crust

Magnetotelluric data

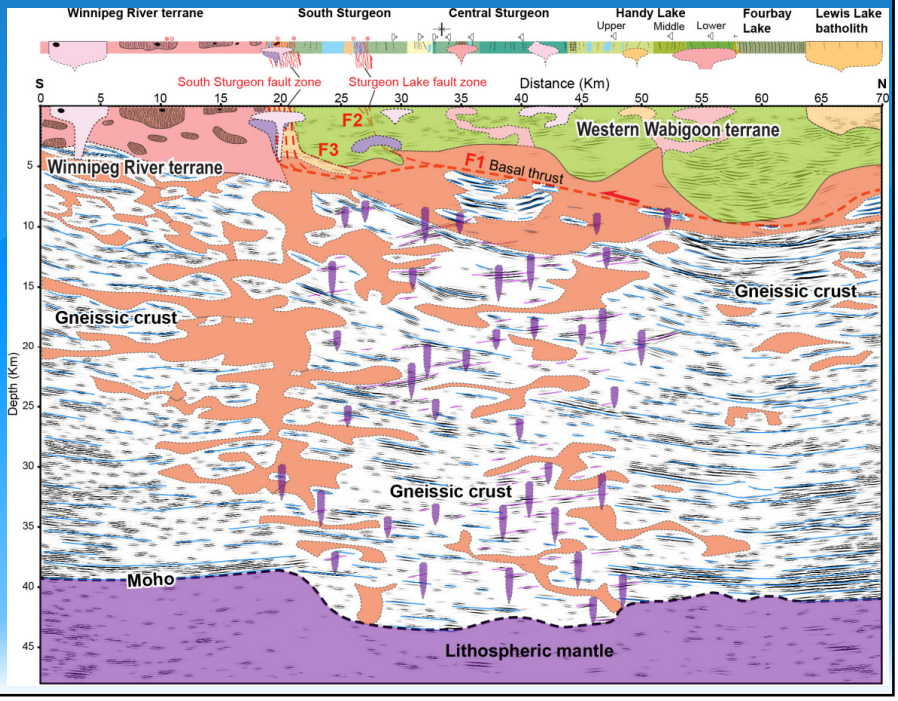


Trans-crustal conductor

Interpretation: Extensive partial melting of crustal rocks and the mantle rocks at the seismic crustal root

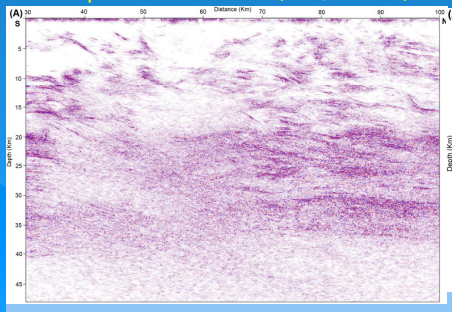
Interpretation
of crustal structures beneath the study area

- ❑ 5–10 km thick greenstone belt
- ❑ Inferred basal thrust
- ❑ Gneissic basement
- ❑ Extensively overprinted by Neoarchean syn- to post-tectonic magmatism that facilitated the formation of trans-crustal conductivity

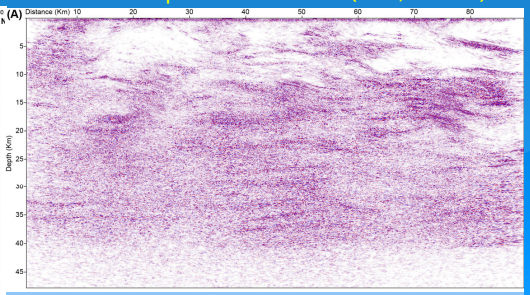


Interpretation
of reprocessed *Lithoprobe* data in the region

Lithoprobe **WS1a** line (N-S, 70 km)

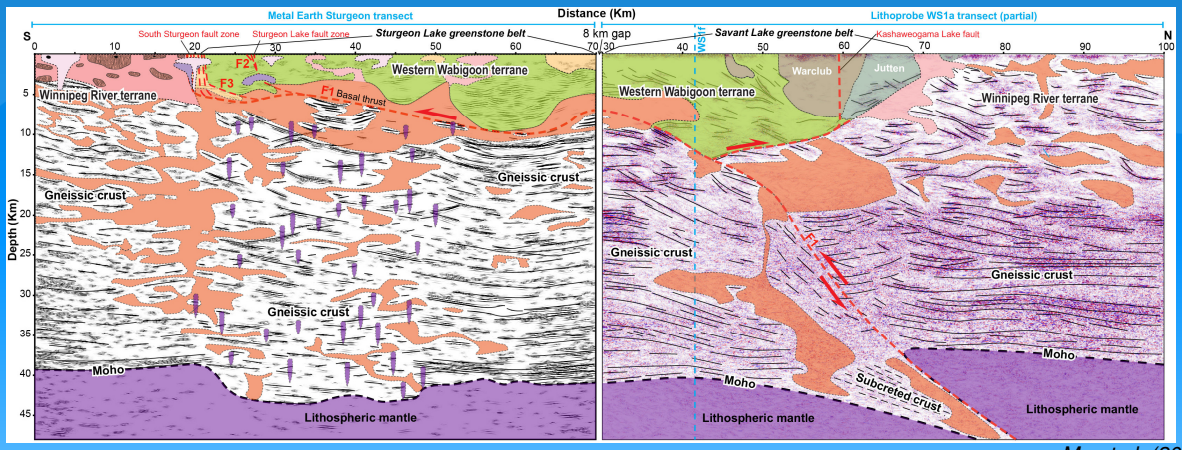


Lithoprobe **WS1f** line (E-W, 90 km)



Interpretation of regional crustal architecture

Composite crustal section (Metal Earth transect + Lithoprobe transect)

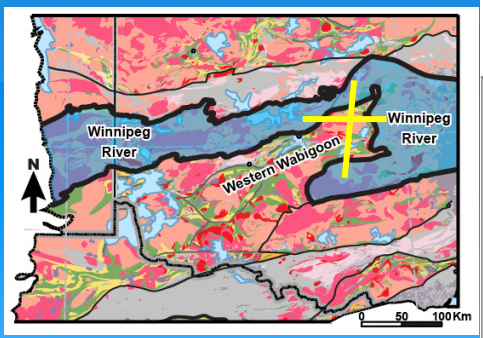


Ma et al. (2021)

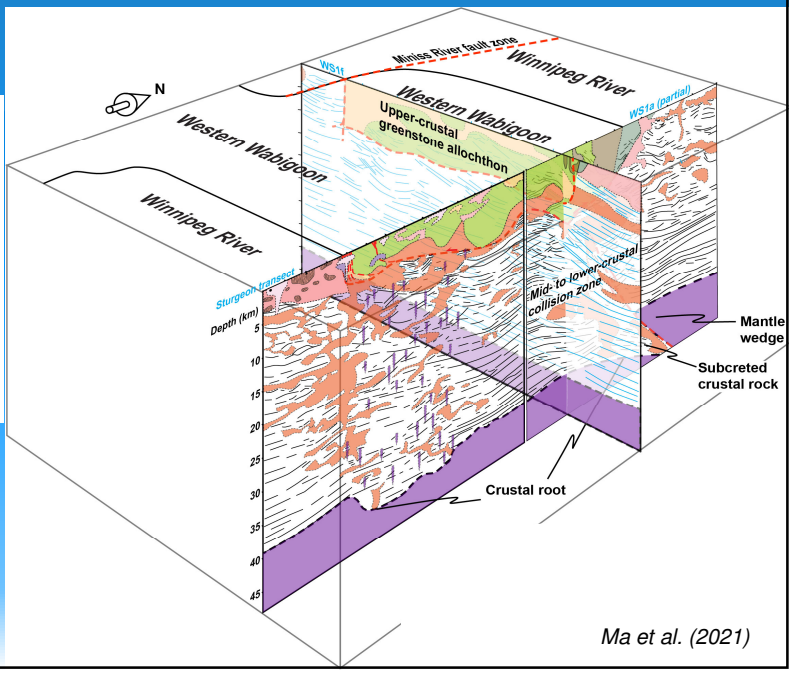
- ❑ Allochthonous greenstone belt as a 5–10 km thick thrust sheet in the upper crust
- ❑ Collision zone in the mid- to lower-crust
- ❑ A trans-crustal fault zone across the collision zone and beneath the greenstone belt
- ❑ Deeper Moho beneath the greenstone belt
- ❑ Subcreted crust beneath a mantle wedge

Interpretation of crustal architecture

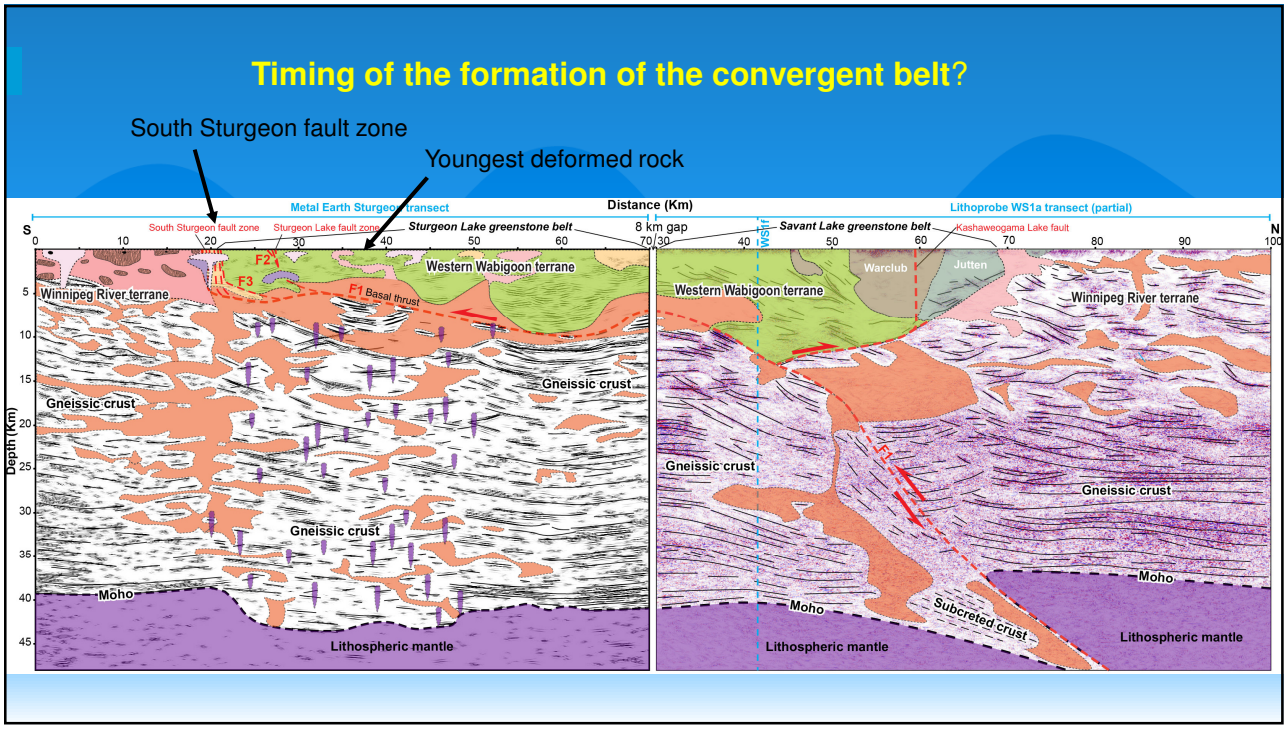
3D crustal structure

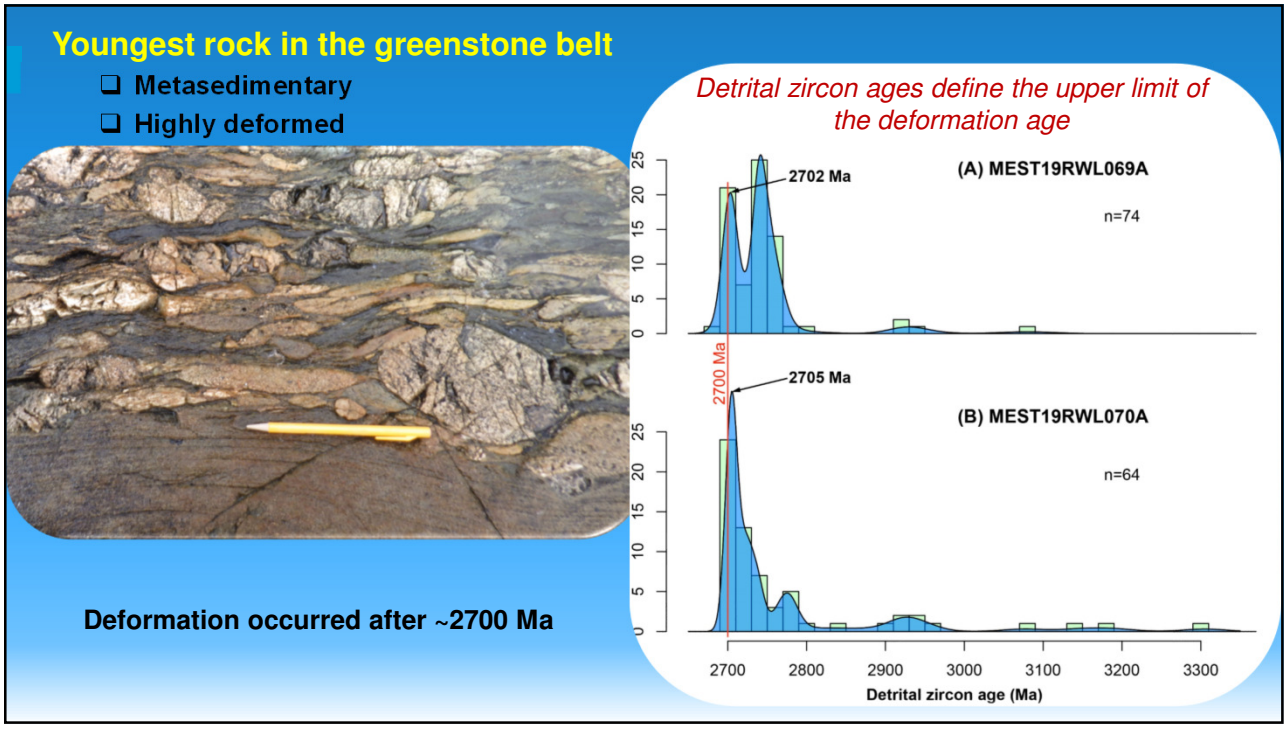


- ❑ A Neoarchean convergent belt between the WRT and WWT



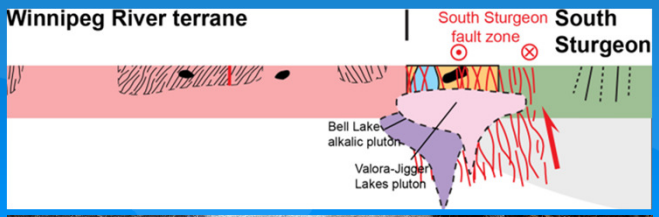
Ma et al. (2021)


Timing of the formation of the convergent belt?
South Sturgeon fault zone
Youngest deformed rock
Metal Earth Sturgeon transect
Distance (Km)
Lithoprobe WS1a transect (partial)
South Sturgeon fault zone
Sturgeon Lake fault zone
Sturgeon Lake greenstone belt
8 km gap
Savant Lake greenstone belt
Kashaweogama Lake fault
S
N
WSB
Western Wabigoon terrane
Winnipeg River terrane
Warclub
Jutten
F1
F2
F3
Basal thrust
Gneissic crust
Moho
Lithospheric mantle
Subcreted crust
Depth (Km)

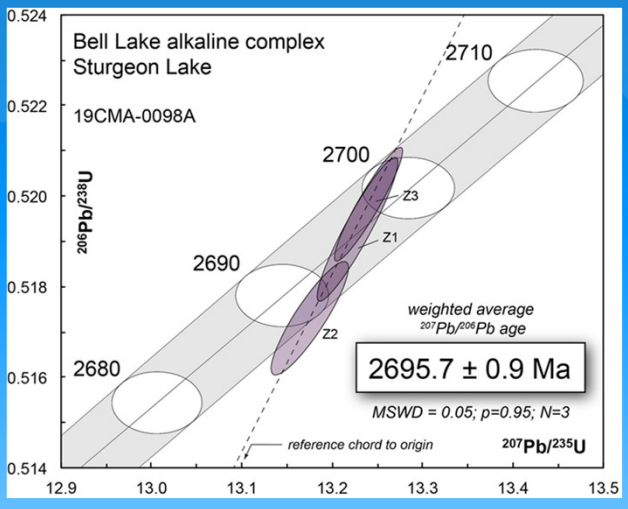

Youngest rock in the greenstone belt
Metasedimentary
Highly deformed
Deformation occurred after ~2700 Ma
Detrital zircon ages define the upper limit of the deformation age
(A) MEST19RWL069A
n=74
2702 Ma
(B) MEST19RWL070A
n=64
2705 Ma
2700 Ma
Detrital zircon age (Ma)

Non-deformed plutons in South Sturgeon fault zone

Emplacement of the stitching pluton define the lower limit of the deformation age



High precision U-Pb geochronology of zircon



The Jack Satterly Geochronology Lab at the University of Toronto

The main deformation ended around 2696 ± 1 Ma

Formation of the convergent belt largely occurred between ca. 2700 and 2696 Ma

PART II

Geologic and geochemical constraints on the volcanism of the Sturgeon Lake greenstone belt

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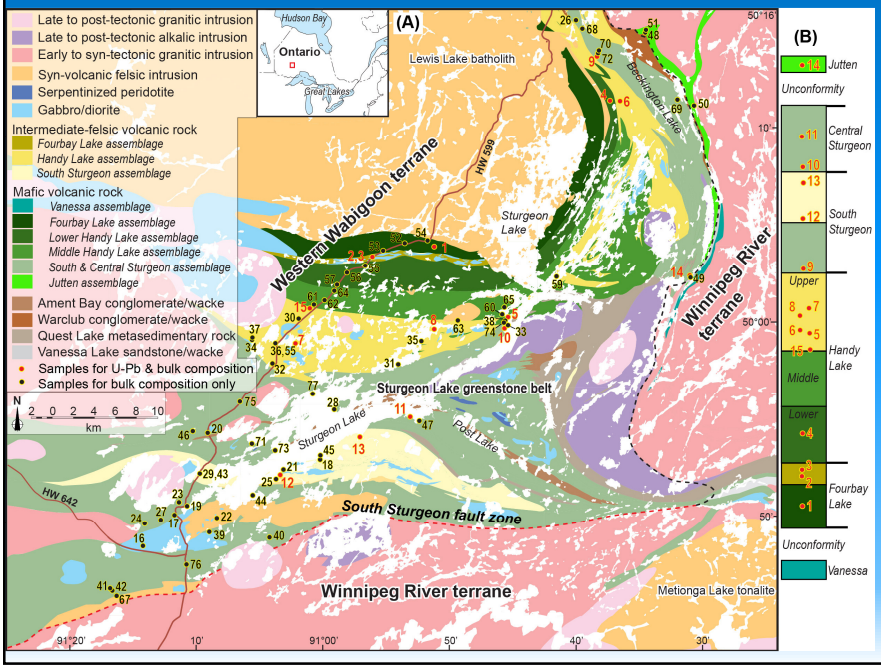
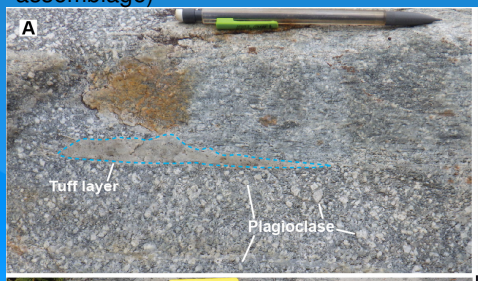
Mafic to felsic volcanic volcanism



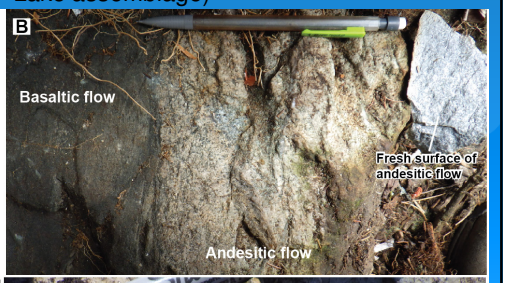
- Bulk composition of 77 mafic, intermediate, & felsic volcanic samples
- In-situ U-Pb, Lu-Hf, and trace element of zircon from 14 intermediate & felsic volcanic samples

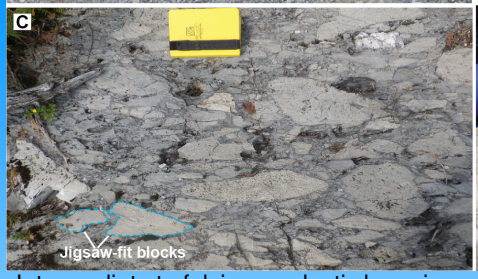
Zircon-bearing volcanic rocks

Plagioclase-phyric, andesitic lapilli tuff enclosing a tuff sliver (Fourbay Lake assemblage)



Quartz- and biotite-phyric, andesitic flow interbedded in basaltic flow (Lower Handy Lake assemblage)





Intermediate to felsic pyroclastic breccia (Upper Handy Lake assemblage)

Strongly foliated, sericitized, quartz-phyric, felsic lapilli tuff (South Sturgeon assemblage)

Whole-rock geochemistry

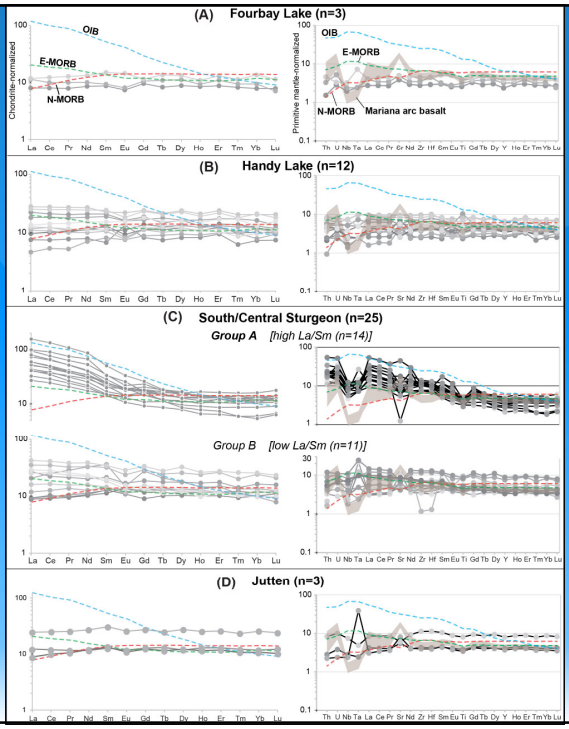
- Mafic volcanic samples

❑ Rare Earth Element patterns
❑ Trace element compositions

- Most basalts are characterized as N-MORB to enriched N-MORB
- Only exception: High La/Sm basalts of the South/Central assemblages (from E-MORB sources that were affected by metasomatism)

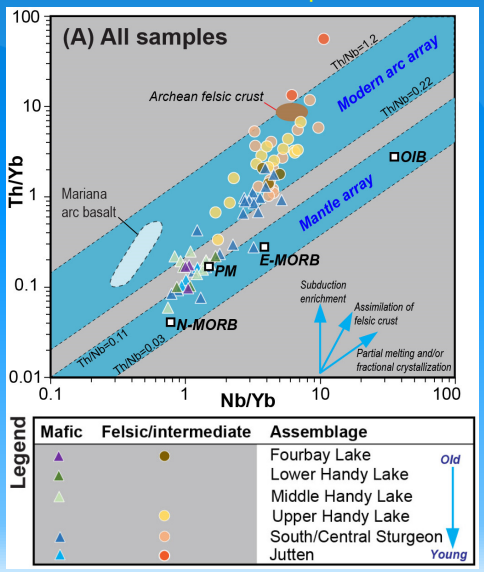
Old (2780 Ma)

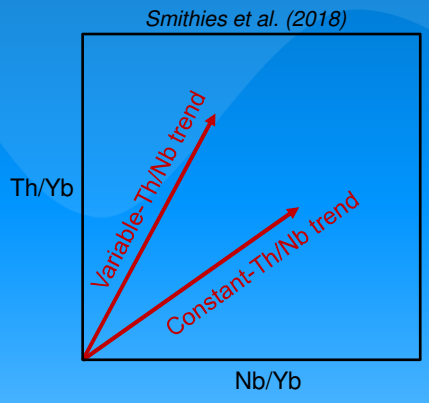
Young (2705 Ma)



Whole-rock geochemistry

All volcanic samples

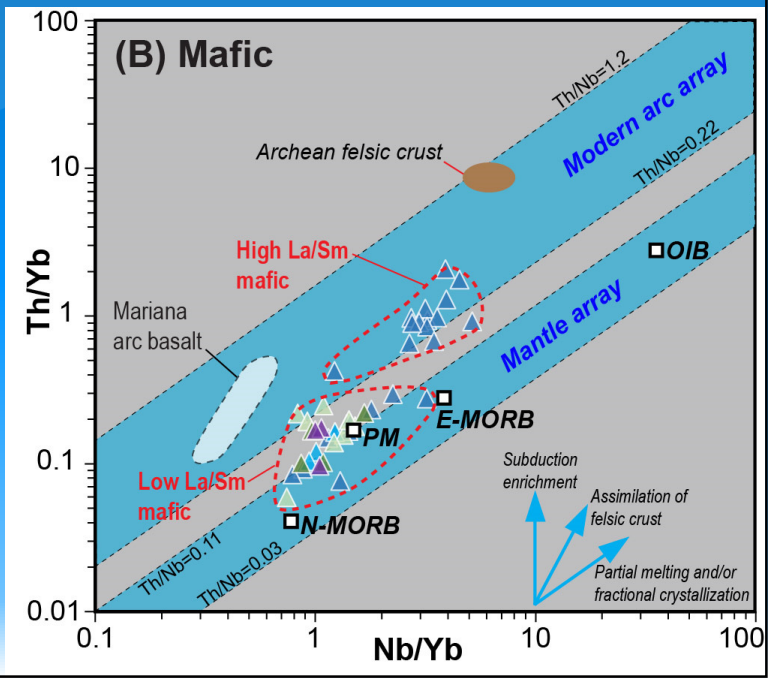




Whole-rock geochemistry

- Mafic volcanic samples

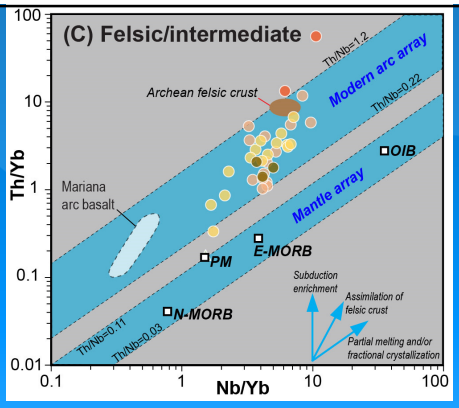
- Two constant-Th/Nb trends represented by two geochemically distinctive groups of basalts
  - Low La/Sm
  - High La/Sm

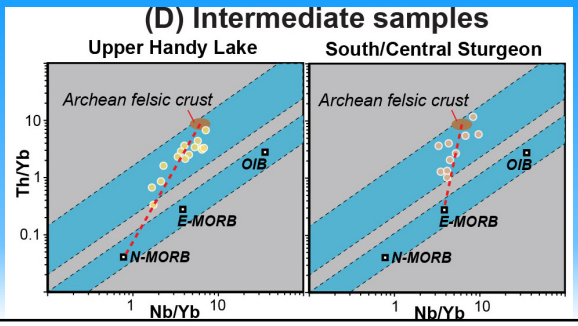


Whole-rock geochemistry

- Felsic & intermediate volcanic samples

- A broad variable-Th/Nb trend represented by intermediate volcanic rocks
- Samples from different assemblages may show different slops: mixing between crustal and various mantle components

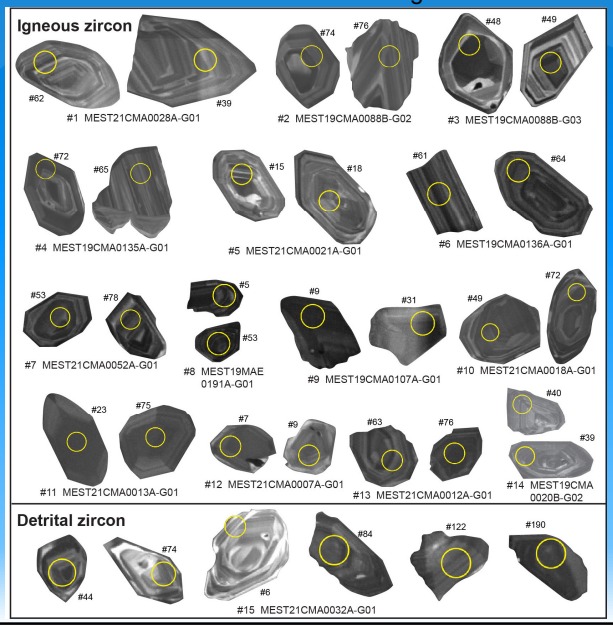




Example zircon from felsic-intermediate volcanic rocks

- Euhedral to subhedral
- Oscillatory zoning
- Magmatic origin

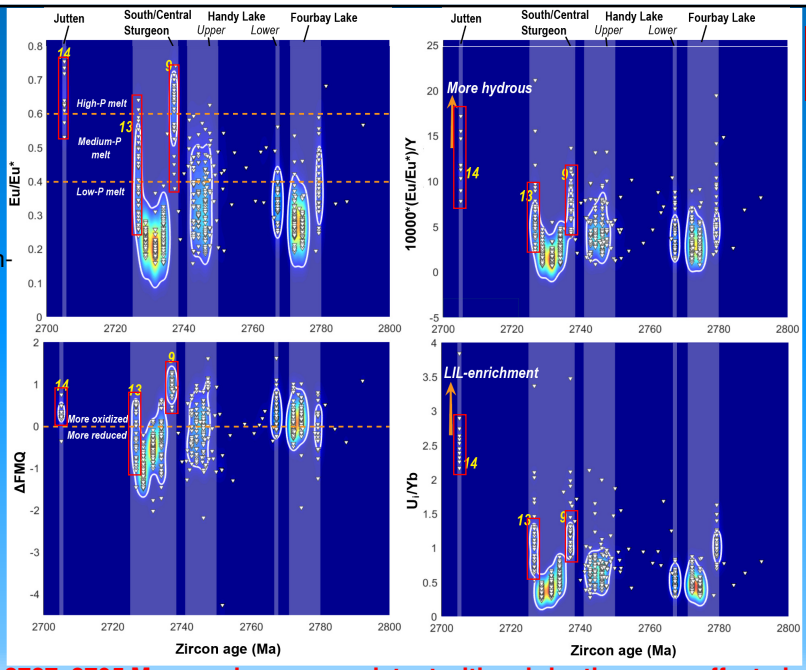
Cathodoluminescence image



Zircon trace element data over time

Dramatically higher Eu/Eu*, indicating more medium- to high-pressure magmas (e.g., Tang et al., 2021)

Distinctively higher ΔFMQ, suggesting more oxidized environments (e.g., Loucks et al., 2020)

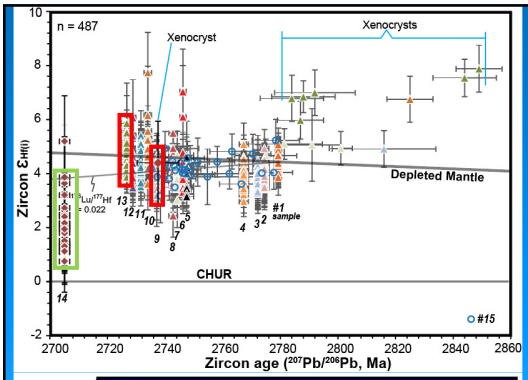


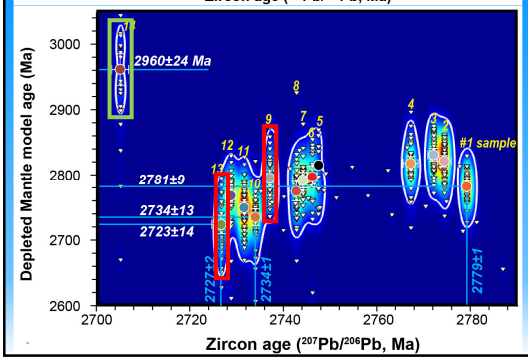
Zircon of 2737 Ma, 2727 Ma, 2705 Ma

Considerably higher 10000*(Eu/Eu*)/Y, indicating more hydrous melts (e.g., Mole et al., 2021)

Markedly higher Ui/Yb, suggesting enrichment of large-ion lithophile elements (Grimes et al., 2015)

The 2737, 2727, 2705 Ma samples are consistent with subduction zone-affected volcanism; others are consistent with ocean floor volcanism





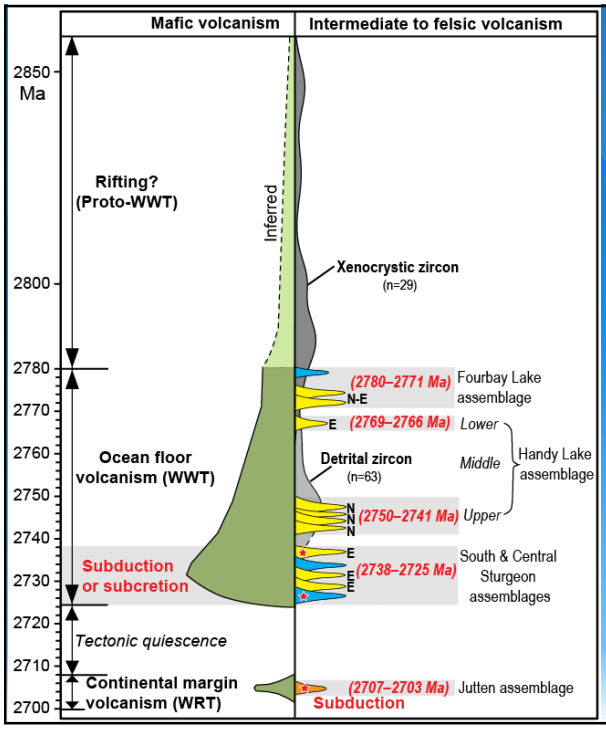
Zircon U-Pb & Lu-Hf data

ca. 2780 to 2727 Ma zircon:

- ❑ Initial epsilon Hf values range from +3 to +6 around DM line
- ❑ Broadly continuous Hf model ages from ca. 2830 - 2720 Ma
- ❑ Accompanying rocks: pillowed basalt of mid-ocean ridge affinities, chert, banded iron formation, carbonate minerals
- ❑ ***Intra-oceanic setting***

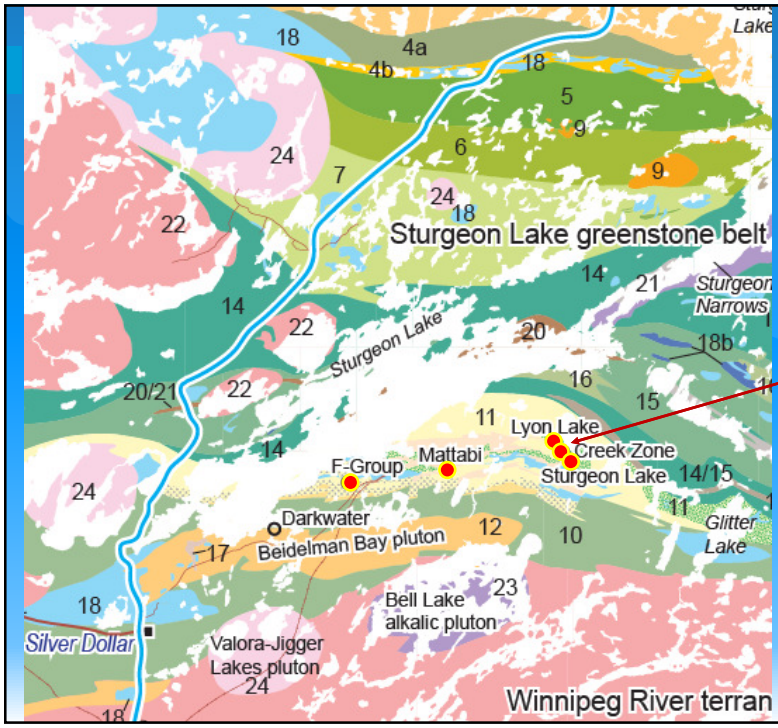
ca. 2705 Ma zircon:

- ❑ Initial epsilon Hf values are well below DM line
- ❑ Gave significantly older Hf model age: ca. 2960 Ma
- ❑ Located along the WRT continental margin
- ❑ Considerably enriched in large-ion lithophile elements
- ❑ ***Continental-margin setting***



Summary of volcanism

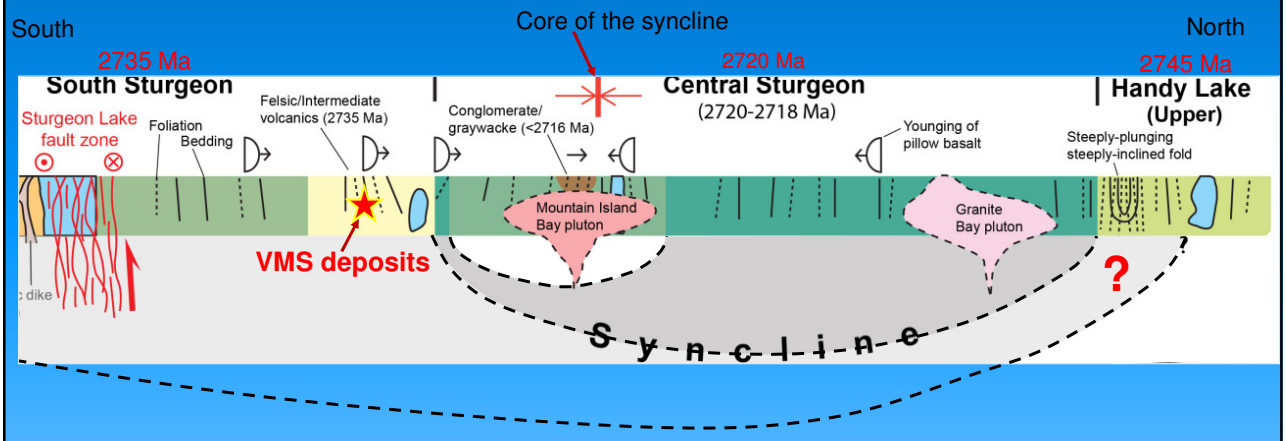
- Melting of mantle sources (range from those of N-MORB to those of E-MORB)
- Melting of mantle sources and assimilation of felsic crustal components
  - N-E: N- to E-MORB-like mantle source
  - E: E-MORB-like mantle source
  - N: N-MORB-like mantle source
- Melting of both juvenile & evolved sources with crust-derived fluids/melts
- Hydrous, oxidized, LILE-enriched, medium- to high-pressure magmas



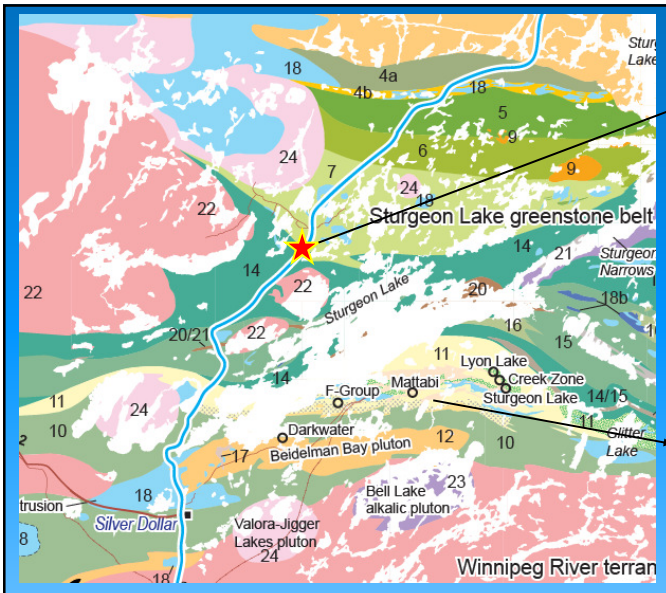
Distribution of past-producing VMS deposits

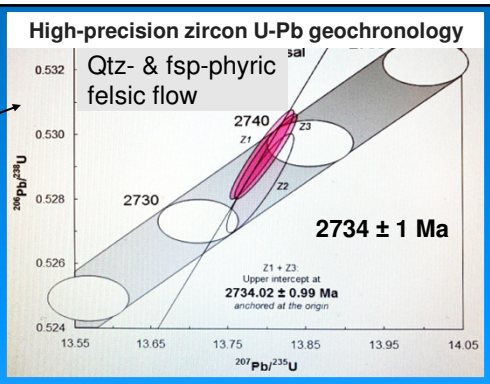
All (red dots) are within South Sturgeon assemblage

The regional syncline implies a missing South Sturgeon assemblage



- ❑ The greenstone belt is folded as a regional syncline
- ❑ VMS deposits occur in the southern limb of the syncline (South Sturgeon assemblage)
- ❑ Rocks of ca. 2735 Ma are apparently missing in the current geologic map
- ❑ **Where are the ca. 2735 Ma rocks in the northern limb of the syncline?**





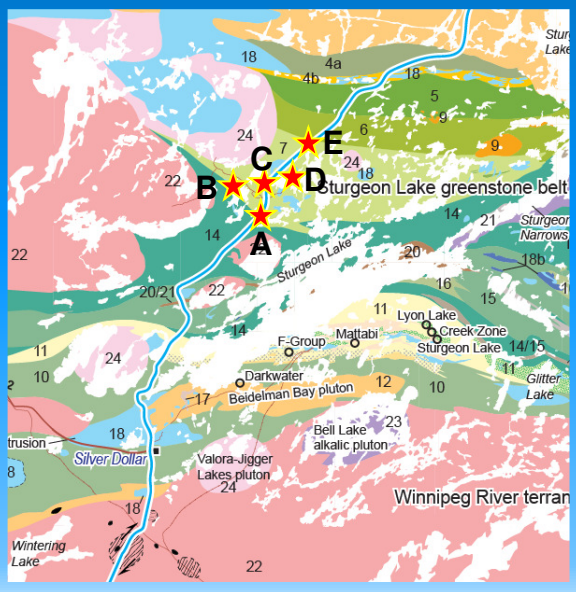
Mattabi rhyolite	> 2734.7 ± 1.6
NBU rhyolite	2735 ± 1.7
NBU rhyolite	2735.5 +3/-1.9
NBU rhyolite	2736.3 +9.3/-3.9
Lyon Lake rhyolite	2735.2 +6.9/-3.2
Lyon Lake rhyolite	2734.8 +2.8/-2.5
Lyon Lake rhyolite	2736 ± 1.8

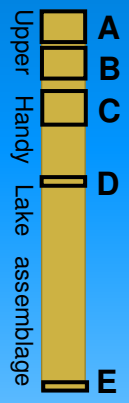
Published zircon ages from the South Sturgeon assemblage

Davis et al. (1985)

- ❑ Felsic volcanic flow of the uppermost Handy Lake assemblage, similar in age to the South Sturgeon assemblage
- ❑ **Stratigraphy of the upper part of the Handy Lake assemblage?**

Stratigraphy of Upper Handy Lake assemblage





Volcanic composition
- Felsic
- Intermediate
- Mafic

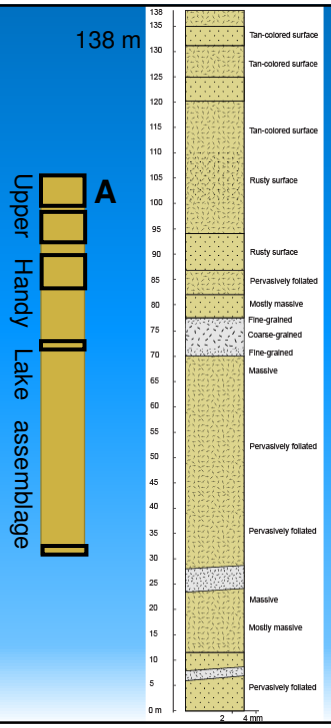
Volcanic texture

Volcaniclastic texture
- Tuff
- Crystal lapilli tuff
- Lithic lapilli tuff
- Pyroclastic breccia

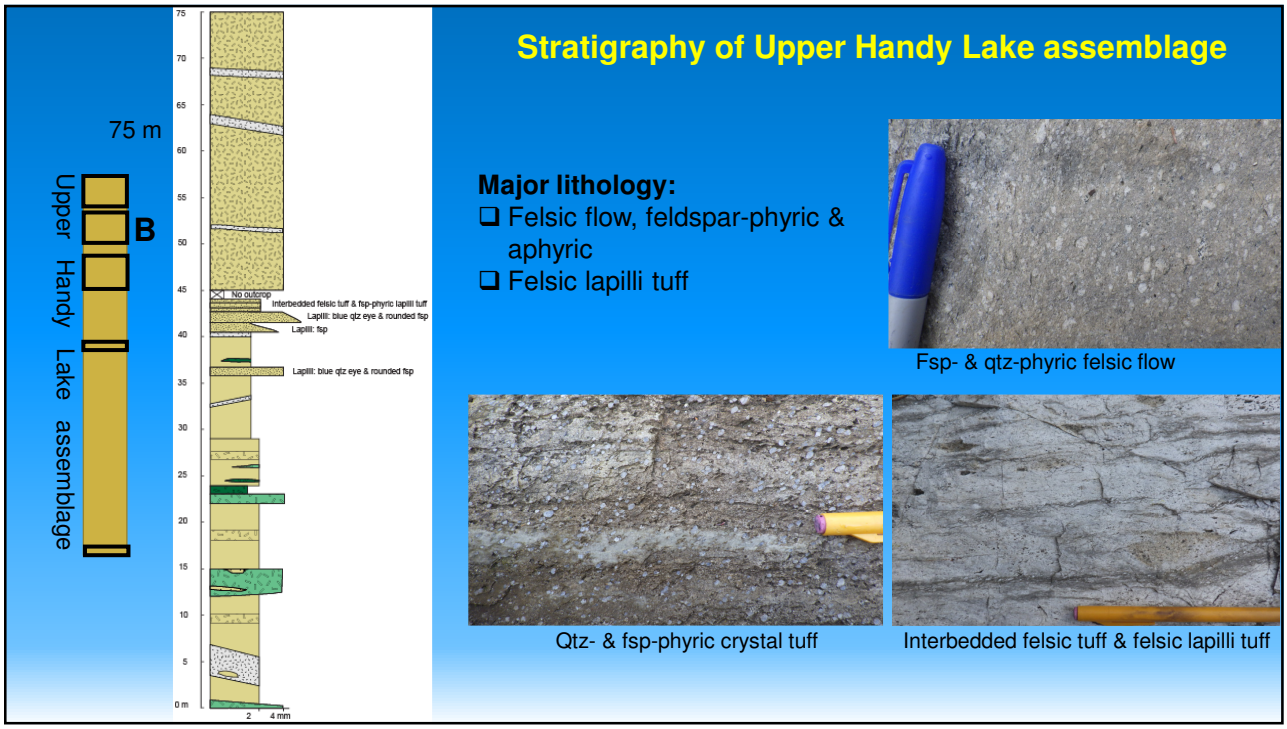
Coherent texture
- Aphyric flow
- Feldspar-phyric flow
- Quartz-phyric flow
- Quartz- and feldspar-phyric flow

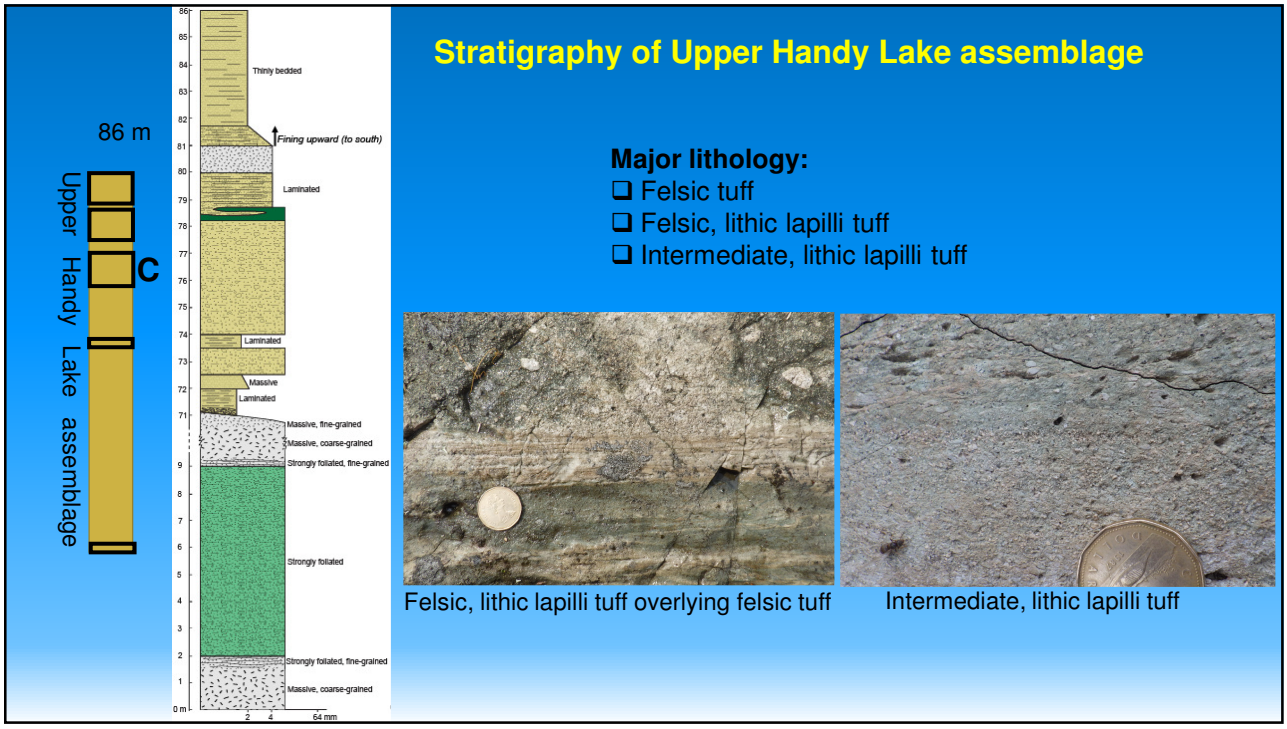
Intrusion
- Gabbro dike

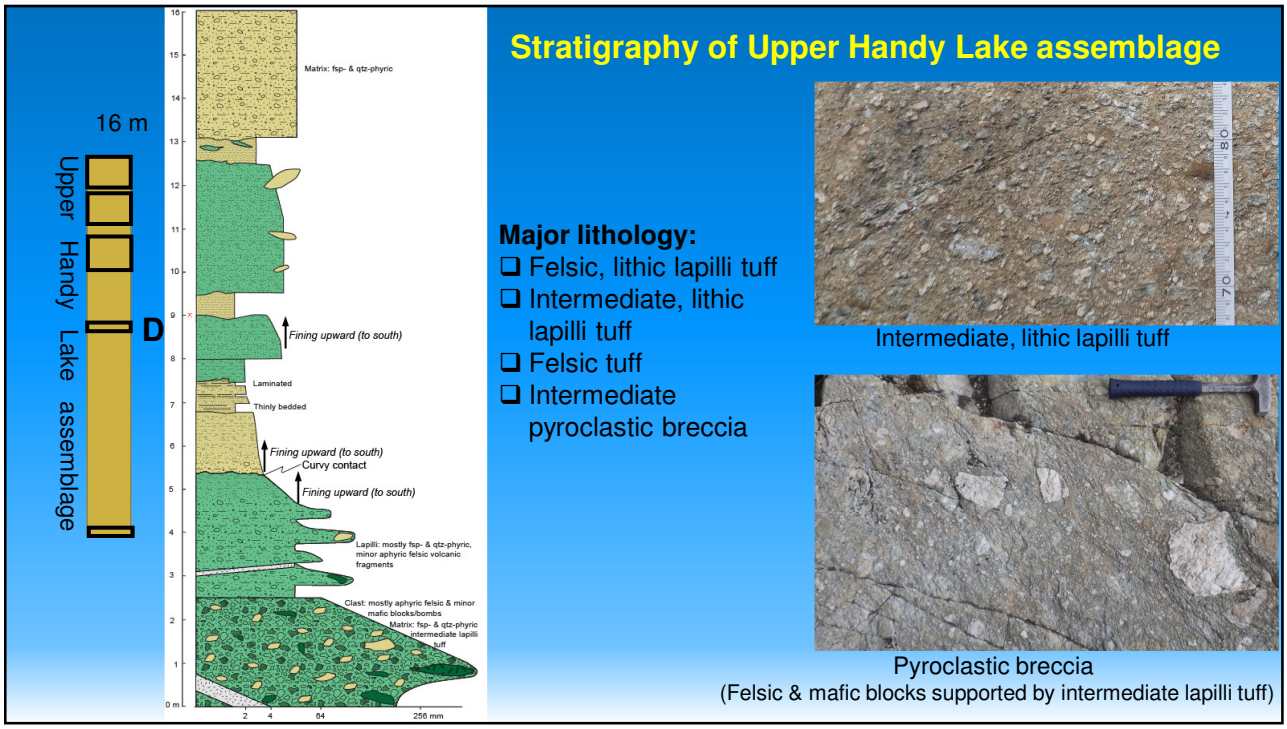
Stratigraphy of Upper Handy Lake assemblage

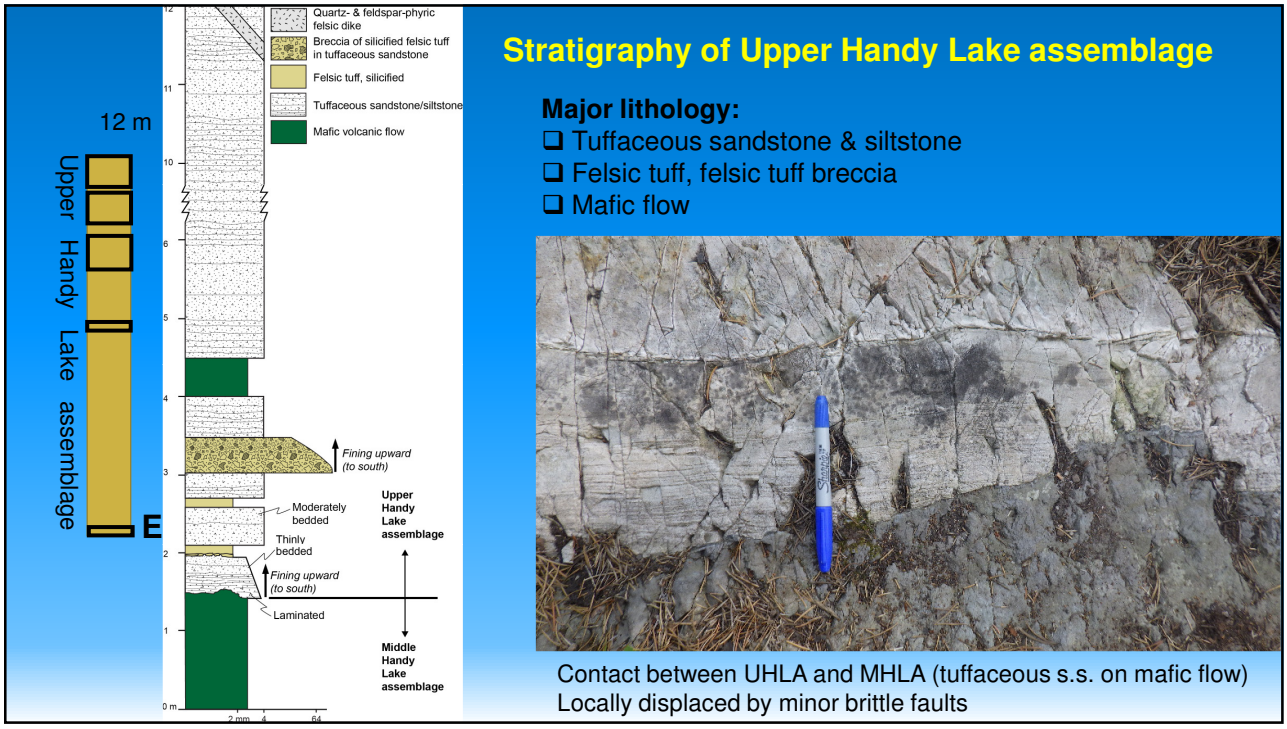


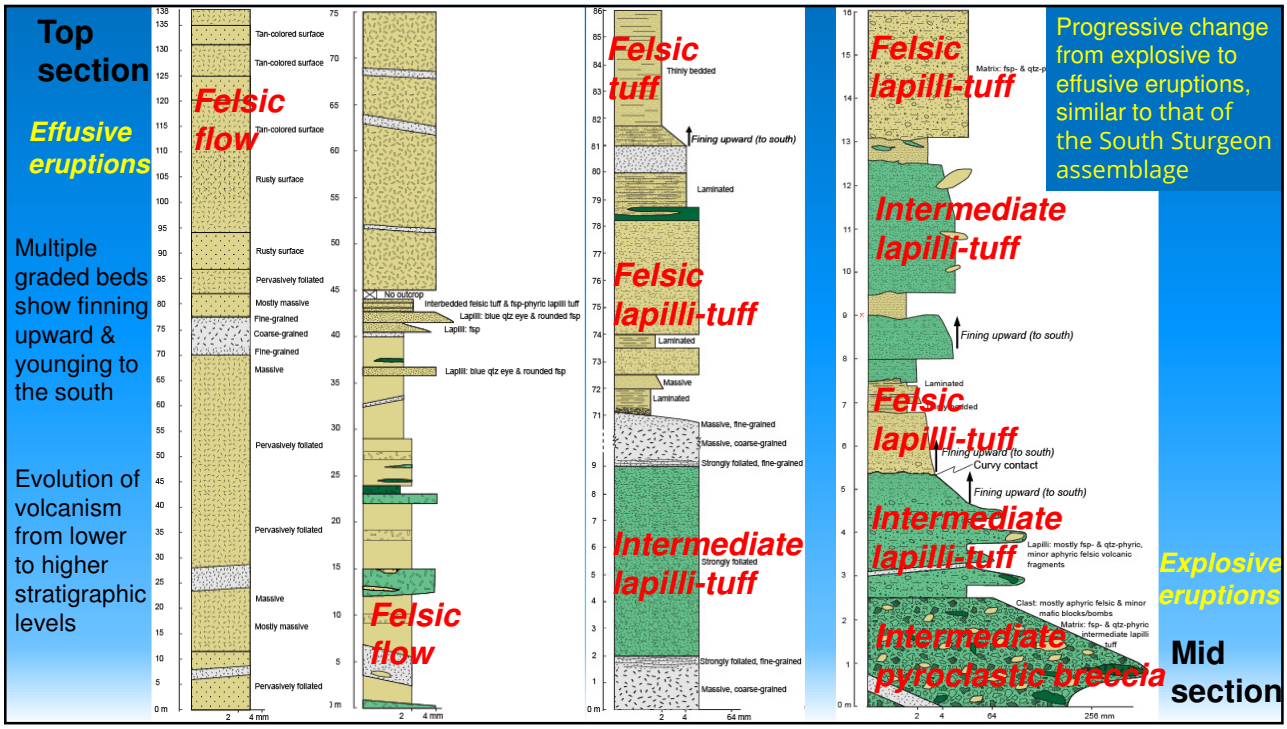
Major lithology:
- ❑ Felsic flow
- ❑ Texture:
  - Quartz- & feldspar-phyric
  - Quartz-phyric


75 m
Upper Handy Lake assemblage
B
No outcrop
Interbedded felsic tuff & fsp-phyric lapilli tuff
Lapilli: blue qtz eye & rounded fsp
Lapilli: fsp
Lapilli: blue qtz eye & rounded fsp
0 m
2
4 mm
Stratigraphy of Upper Handy Lake assemblage
Major lithology:
❑ Felsic flow, feldspar-phyric & aphyric
❑ Felsic lapilli tuff
Fsp- & qtz-phyric felsic flow
Qtz- & fsp-phyric crystal tuff
Interbedded felsic tuff & felsic lapilli tuff


86 m
Upper Handy Lake assemblage
C
Thinly bedded
Fining upward (to south)
Laminated
Laminated
Massive
Laminated
Massive, fine-grained
Massive, coarse-grained
Strongly foliated, fine-grained
Strongly foliated
Strongly foliated, fine-grained
Massive, coarse-grained
0 m
2
4
64 mm
Stratigraphy of Upper Handy Lake assemblage
Major lithology:
❑ Felsic tuff
❑ Felsic, lithic lapilli tuff
❑ Intermediate, lithic lapilli tuff
Felsic, lithic lapilli tuff overlying felsic tuff
Intermediate, lithic lapilli tuff

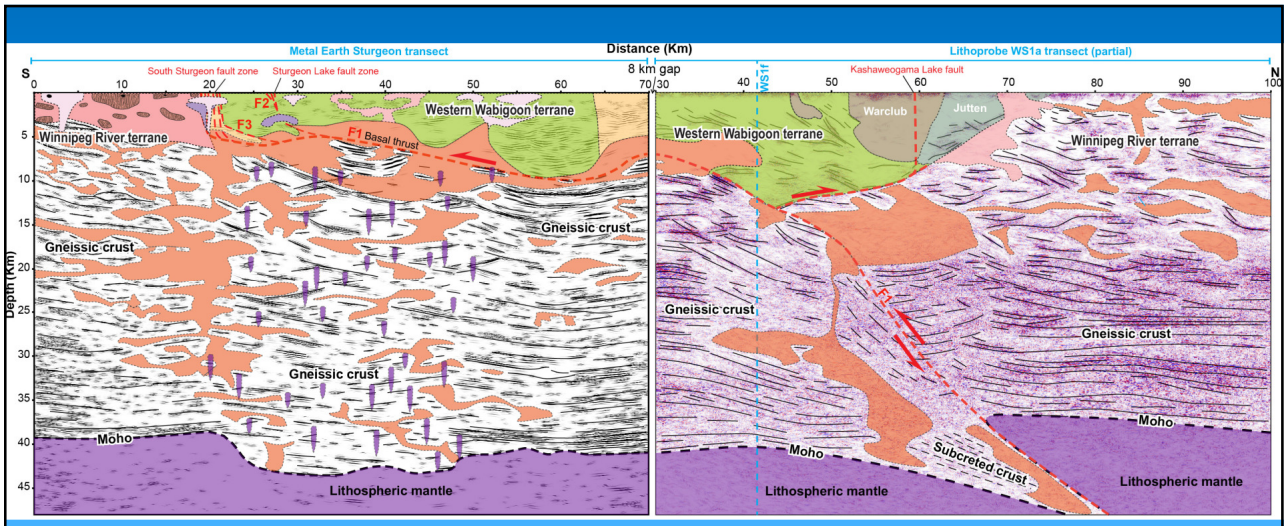

16 m
Upper Handy Lake assemblage
D
Matrix: fsp- & qtz-phyric
Fining upward (to south)
Laminated
Thinly bedded
Fining upward (to south)
Curvy contact
Fining upward (to south)
Lapilli: mostly fsp- & qtz-phyric, minor aphyric felsic volcanic fragments
Clast: mostly aphyric felsic & minor mafic blocks/bombs
Matrix: fsp- & qtz-phyric intermediate lapilli tuff
0 m
2
4
64
256 mm
Stratigraphy of Upper Handy Lake assemblage
Major lithology:
❑ Felsic, lithic lapilli tuff
❑ Intermediate, lithic lapilli tuff
❑ Felsic tuff
❑ Intermediate pyroclastic breccia
Intermediate, lithic lapilli tuff
Pyroclastic breccia
(Felsic & mafic blocks supported by intermediate lapilli tuff)


12 m
Upper Handy Lake assemblage
E
Quartz- & feldspar-phyric felsic dike
Breccia of silicified felsic tuff in tuffaceous sandstone
Felsic tuff, silicified
Tuffaceous sandstone/siltstone
Mafic volcanic flow
Fining upward (to south)
Moderately bedded
Thinly bedded
Fining upward (to south)
Laminated
Upper Handy Lake assemblage
Middle Handy Lake assemblage
0 m
2 mm
4
64
Stratigraphy of Upper Handy Lake assemblage
Major lithology:
❑ Tuffaceous sandstone & siltstone
❑ Felsic tuff, felsic tuff breccia
❑ Mafic flow
Contact between UHLA and MHLA (tuffaceous s.s. on mafic flow)
Locally displaced by minor brittle faults



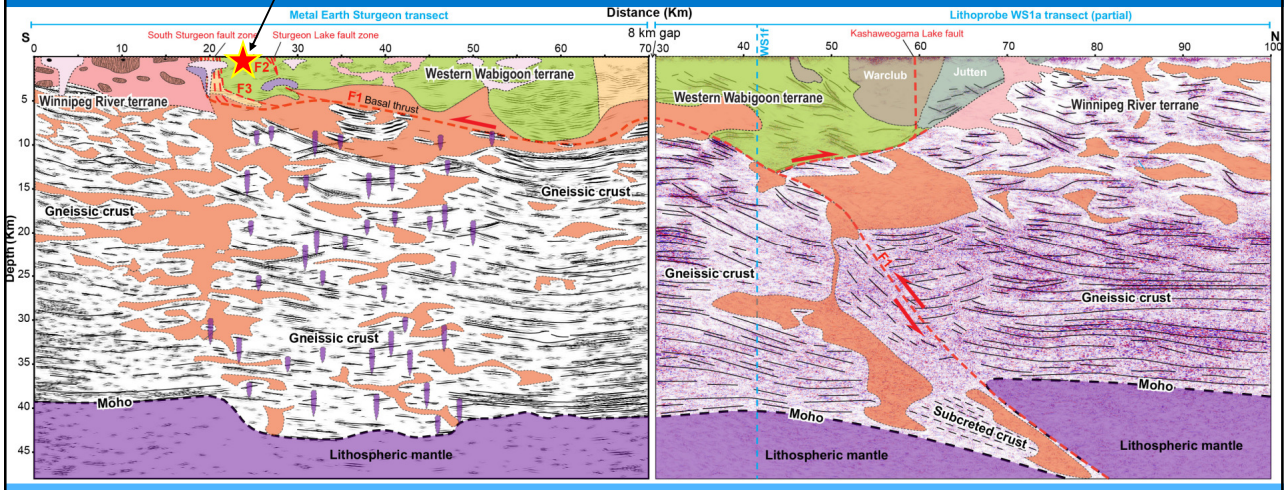
PART III

Implications for VMS endowment in the region



- The combined geologic-geophysical data revealed a Neoarchean convergent belt between the main WRT to the north and a probable continental margin promontory of the WRT to the south, of which the WWT tectonically emplaced onto the WRT. This convergence occurred between ca. 2700 & 2696 Ma.

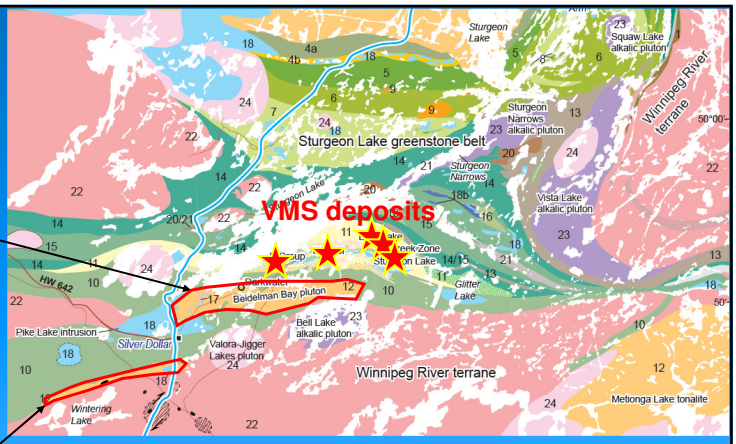
VMS deposits in South Sturgeon assemblage

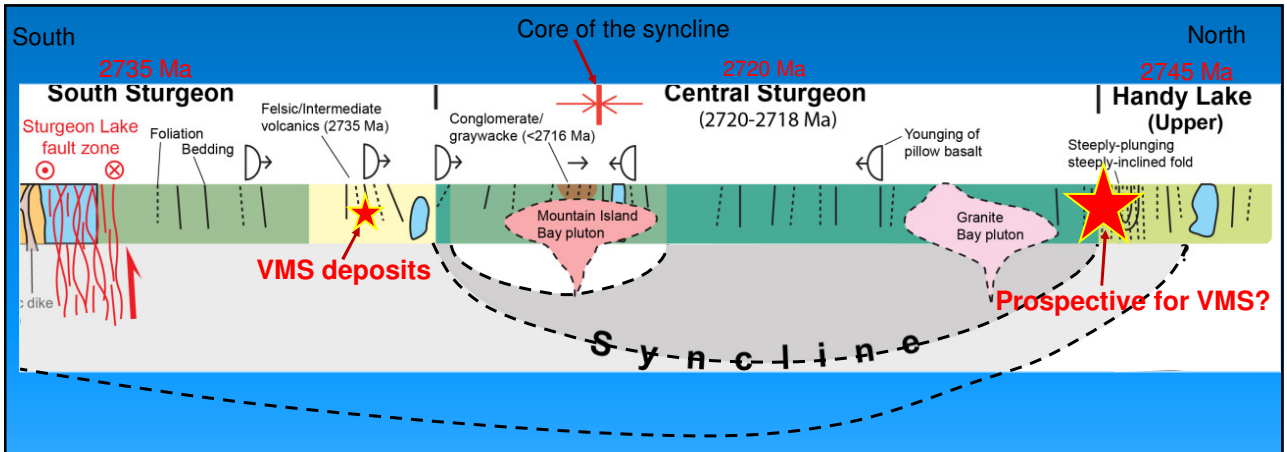


- The South Sturgeon assemblage & VMS deposits were tectonically emplaced to the current position
- The original VMS mineralization had no impact from the current crustal architecture
- The VMS deposits likely formed in an oceanic crust setting near the end of the greenstone volcanism from 2780-2725 Ma that generated various N-MORB and E-MORB along with genetically related silica-rich volcanic rocks

Formation of the South Sturgeon VMS deposits is interpreted to be caused by heat and fluid from the coeval Beidelman Bay pluton (e.g., Galley et al., 2000).

Newly discovered 2738.6 ± 1.3 Ma felsic intrusion at the base of the South Sturgeon assemblage may have jointly facilitated the formation of the VMS deposits.





- ❑ The new 2734±1 Ma volcanic rocks in the Handy Lake assemblage confirms age-equivalent rocks to the South Sturgeon assemblage in the northern limb of the regional syncline
- ❑ The Handy Lake volcanic rocks in the northern limb of the regional syncline evolved from ***intermediate pyroclastic breccia → interbedded intermediate and felsic lapilli-tuff → felsic tuff → felsic flow*** at 2734 ± 1 Ma, suggesting a progressive change ***from explosive to effusive*** eruptions, which is similar to the history of the VMS-bearing volcanic rocks in the southern limb of the syncline

Sulfide vein

VMS alteration and mineralization in ca. 2734 Ma Handy Lake volcanic rocks

Disseminated sulfide

Chlorite-carbonate-pyrite alteration

Prospective for VMS deposit in the ca. 2734 Ma succession of the Handy Lake assemblage

Project Research & Funding Partners

Academic	Industry	Government
Laurentian University / Université Laurentienne HARQUAIL School of Earth Sciences / École des sciences de la Terre	RedPine exploration inc	
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University of Wisconsin Eau Claire	WESDOME	
METAL EARTH	Canada CANADA FIRST RESEARCH EXCELLENCE FUND APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE	MERC Mineral Exploration Research Centre at the HARQUAIL School of Earth Sciences

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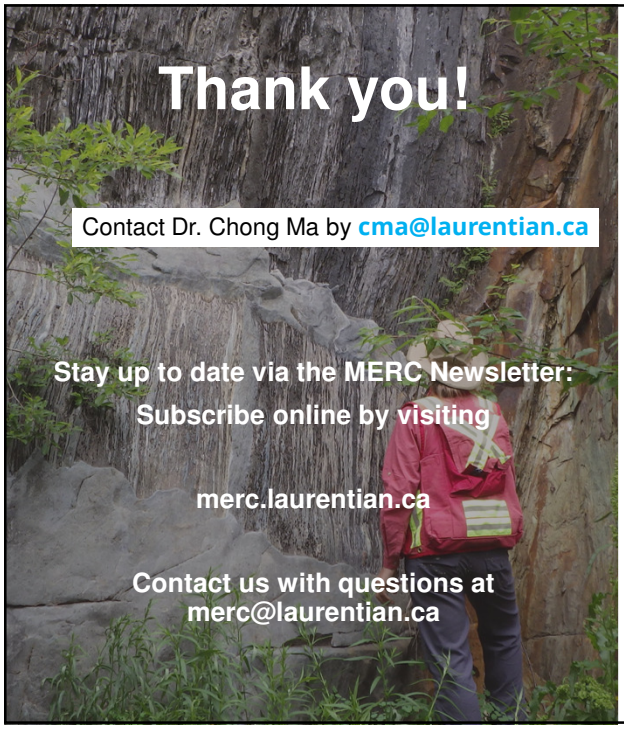

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