

Tectonic Setting and Timing of Gold in the Superior Province

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Mineral Exploration Research Centre
AT THE HARQUAIL SCHOOL OF EARTH SCIENCES

**NEOMMS
Short Course
Oct. 03, 2019**



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Talk Outline

- **Superior Province Gold Endowment**
- **Controls on Abitibi Gold**
- **Controls on Hemlo Gold**
- **Controls on Red Lake Gold**
- **Conclusions & Recommendations**



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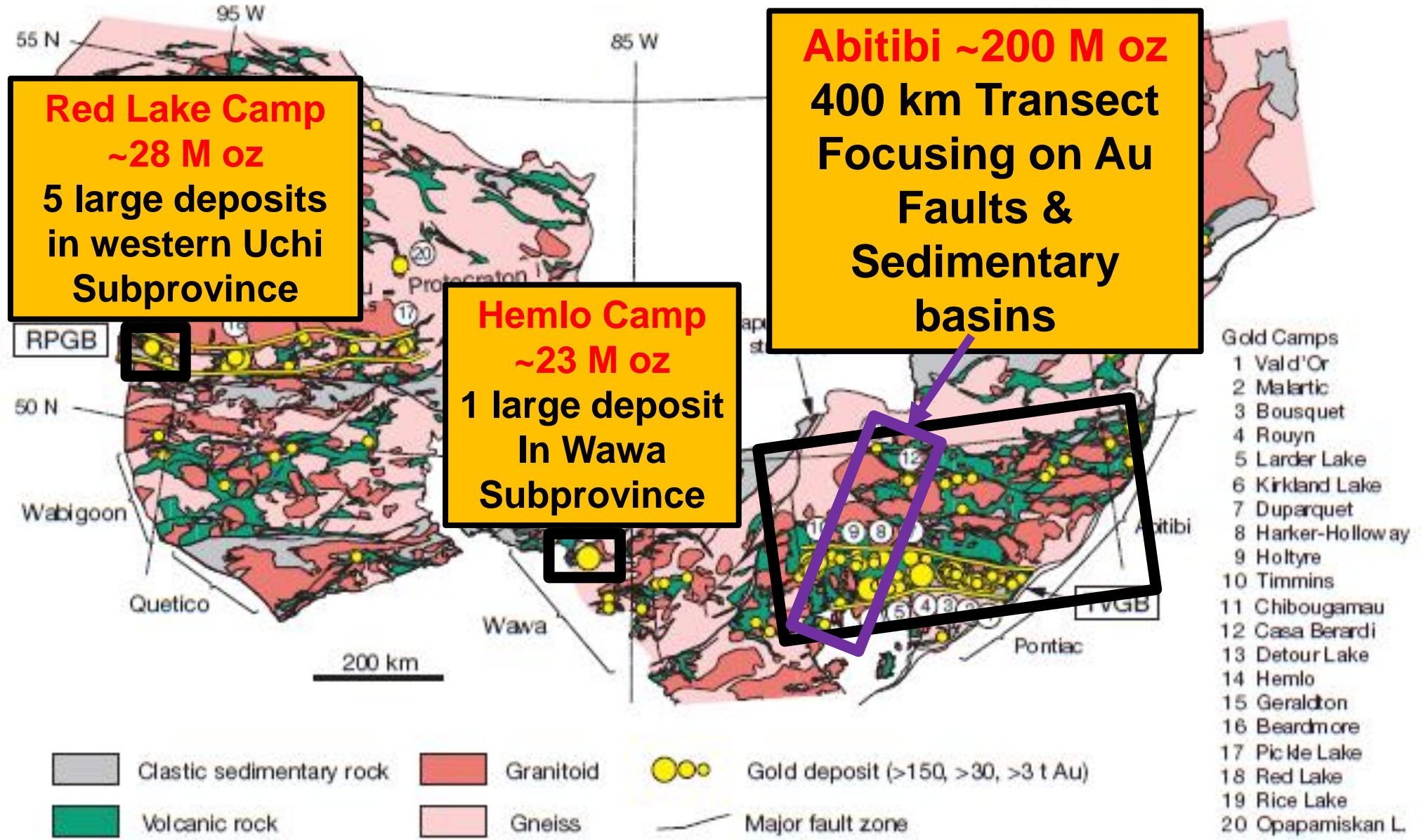
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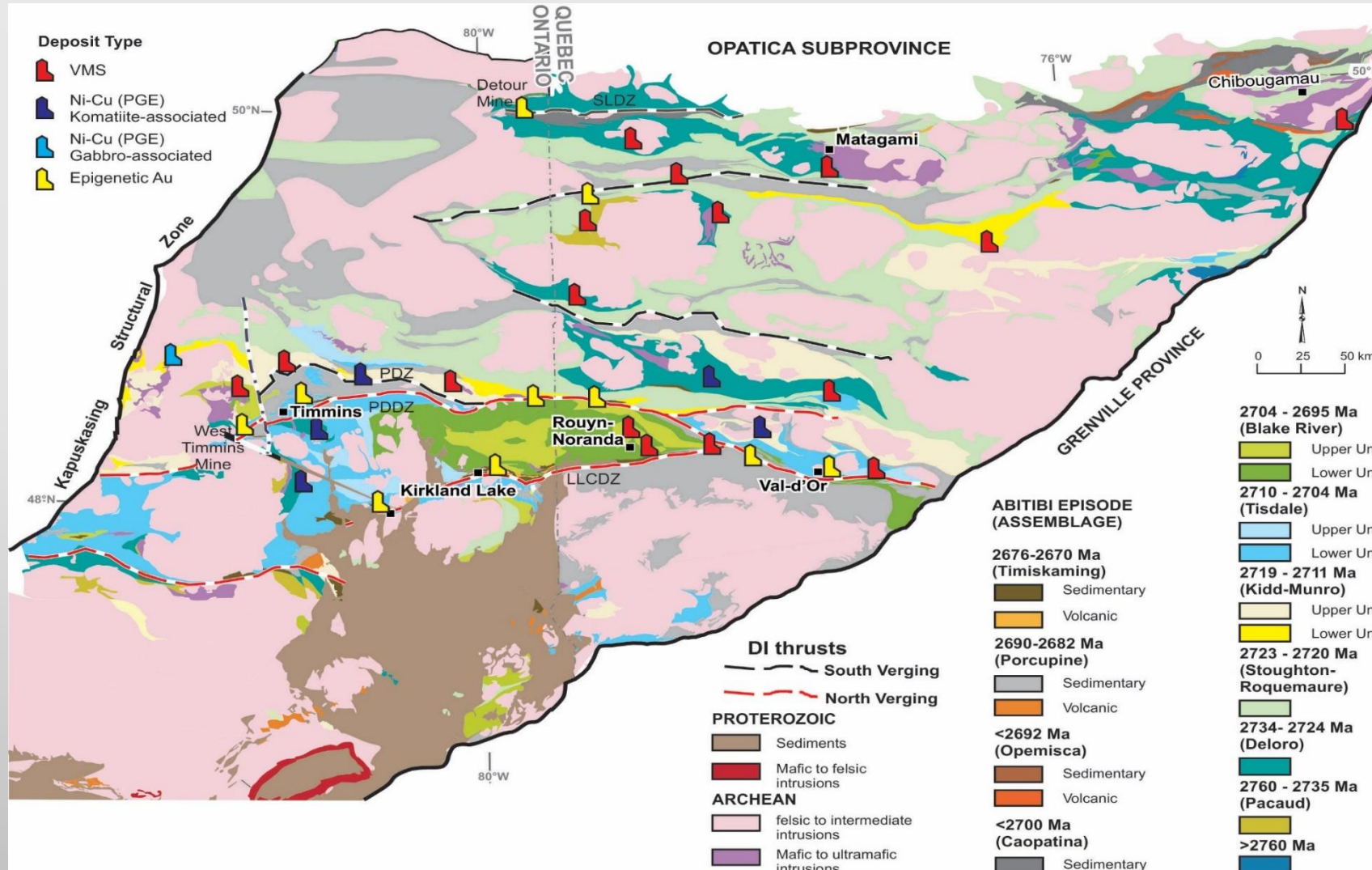
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Large Gold Camps



(Robert et al., 2005, Econ. Geol.)

Abitibi Greenstone Belt Stratigraphy



Abitibi Greenstone belt extends ~800 km E-W by ~400 km N-S

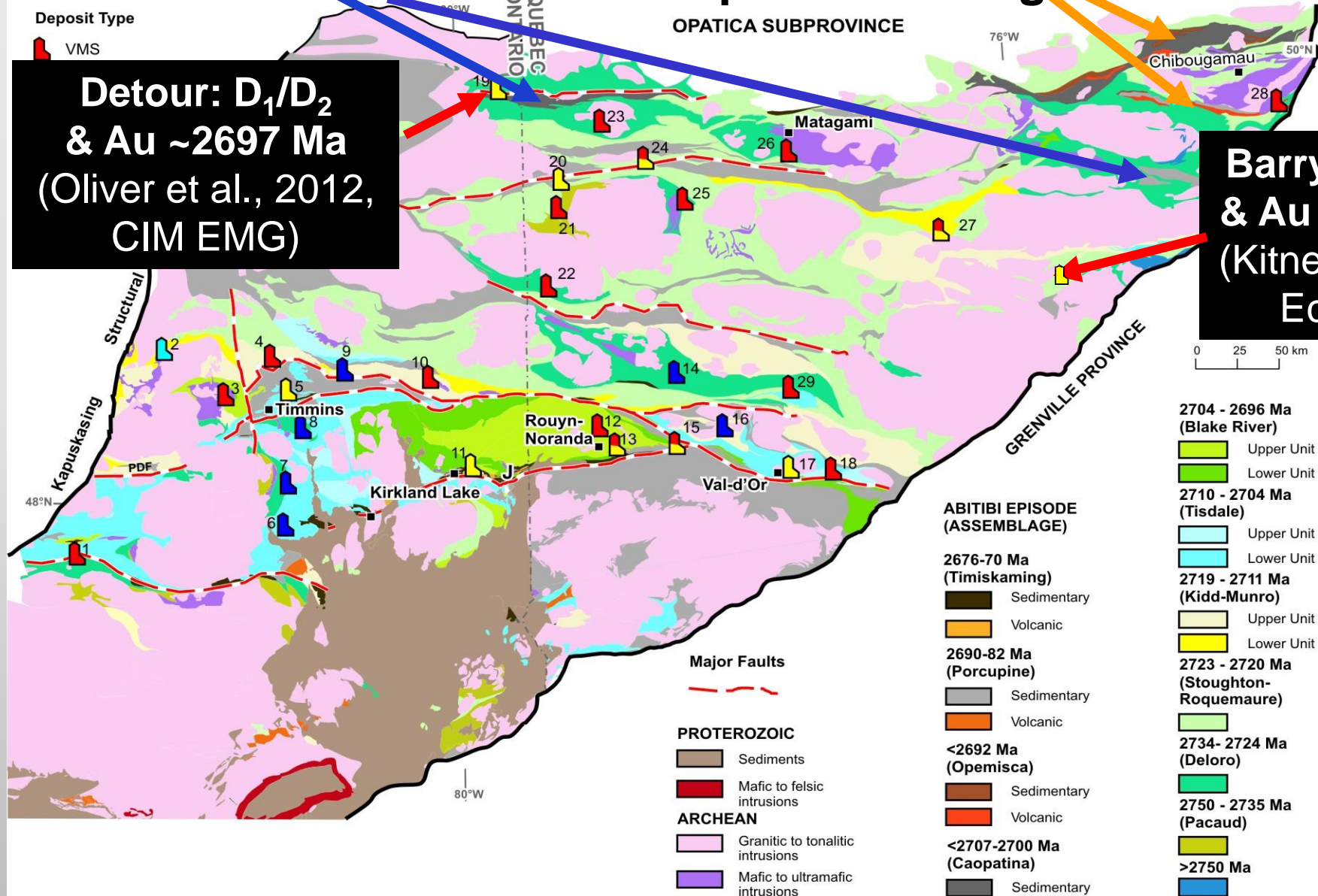
-7 older volcanic assemblages 2790-2700 Ma

-4 unconformably overlying sedimentary assemblages 2700-2670 Ma

Northern Abitibi: Timing of Sedts. & Gold

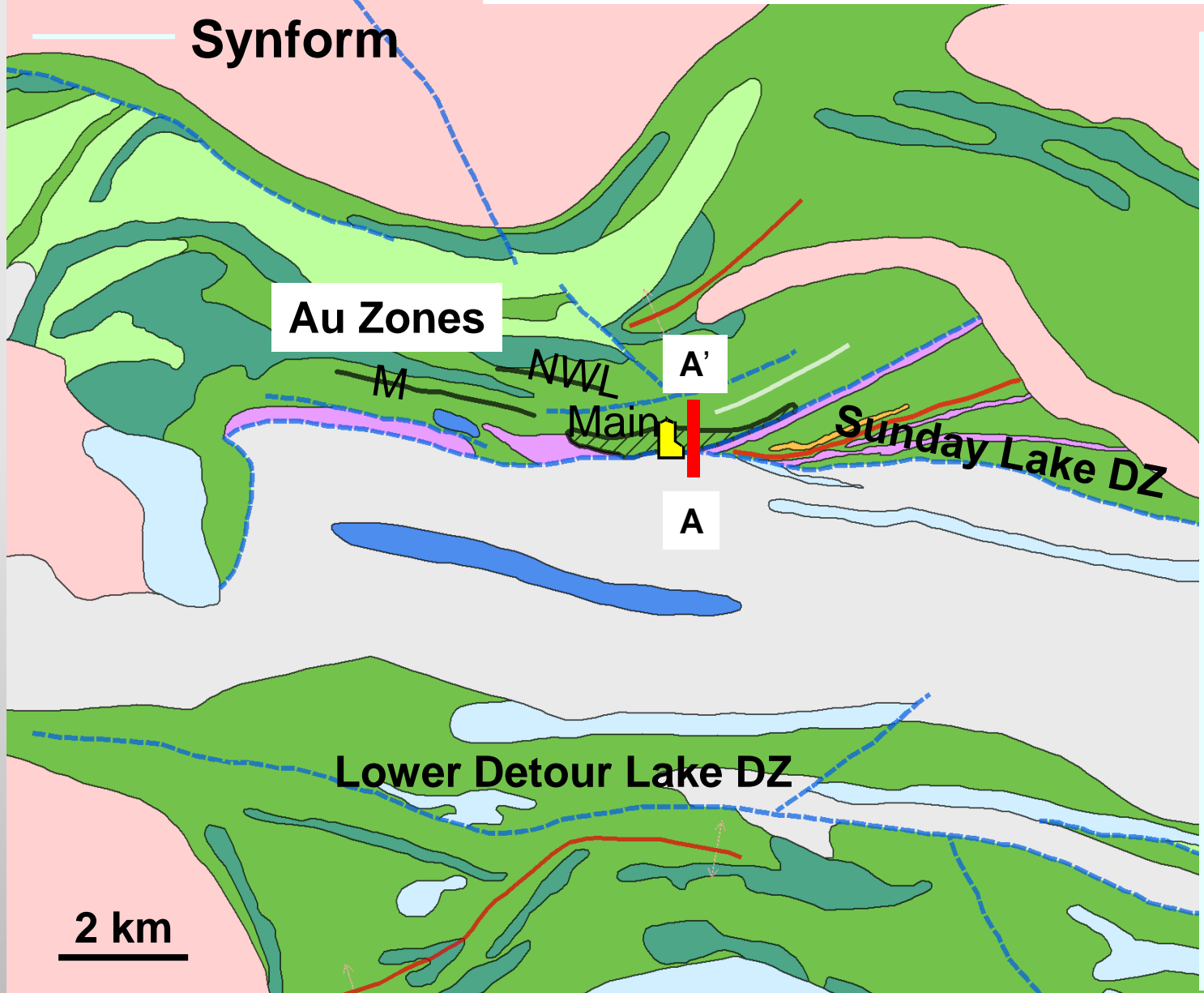
Caopatina Turbidites ~2700Ma

Opemisca Conglomerates ~2690 Ma



Detour Lake Area Geology

- Fault
- Antiform
- Synform



Detour Gold Mine
Au zones extend ~9 km
Reserves ~20 M oz @ 1g/t

Detour Structural Setting:

- Sunday Lake Deformation Zone
- south-verging D_1 thrust (extending ~150 km)
- D_2 sinistral overprint in Main & M zones
- D_3 dextral overprint evident in North Walter Lake zone

(Oliver et al, 2012, CIM)

A South SLDZ Main Zone X Section A' North

Caopatina seds
 $<2697 \pm 6 \text{ Ma}$

Cherty Marker Horizon = felsic volcs
between komatiitic & tholeiitic units
 $2725.1 \pm 1.4 \text{ Ma}$ (Deloro Assemblage)

Komatiites

Pillowed mafics
Massive mafics

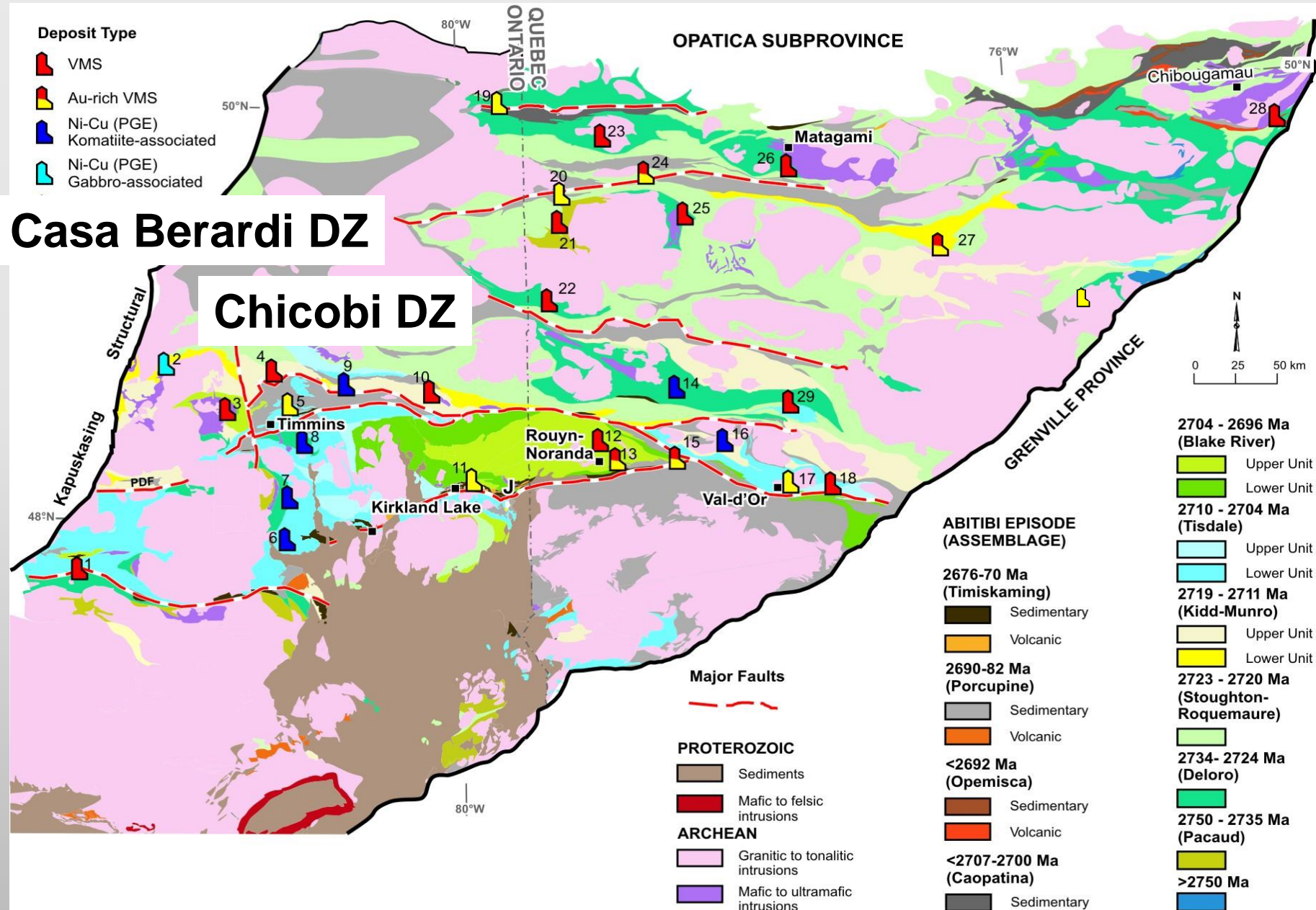
Gabbro dike cutting volcs.
 $\text{Age } 2720.1 \pm 1.3 \text{ Ma}$



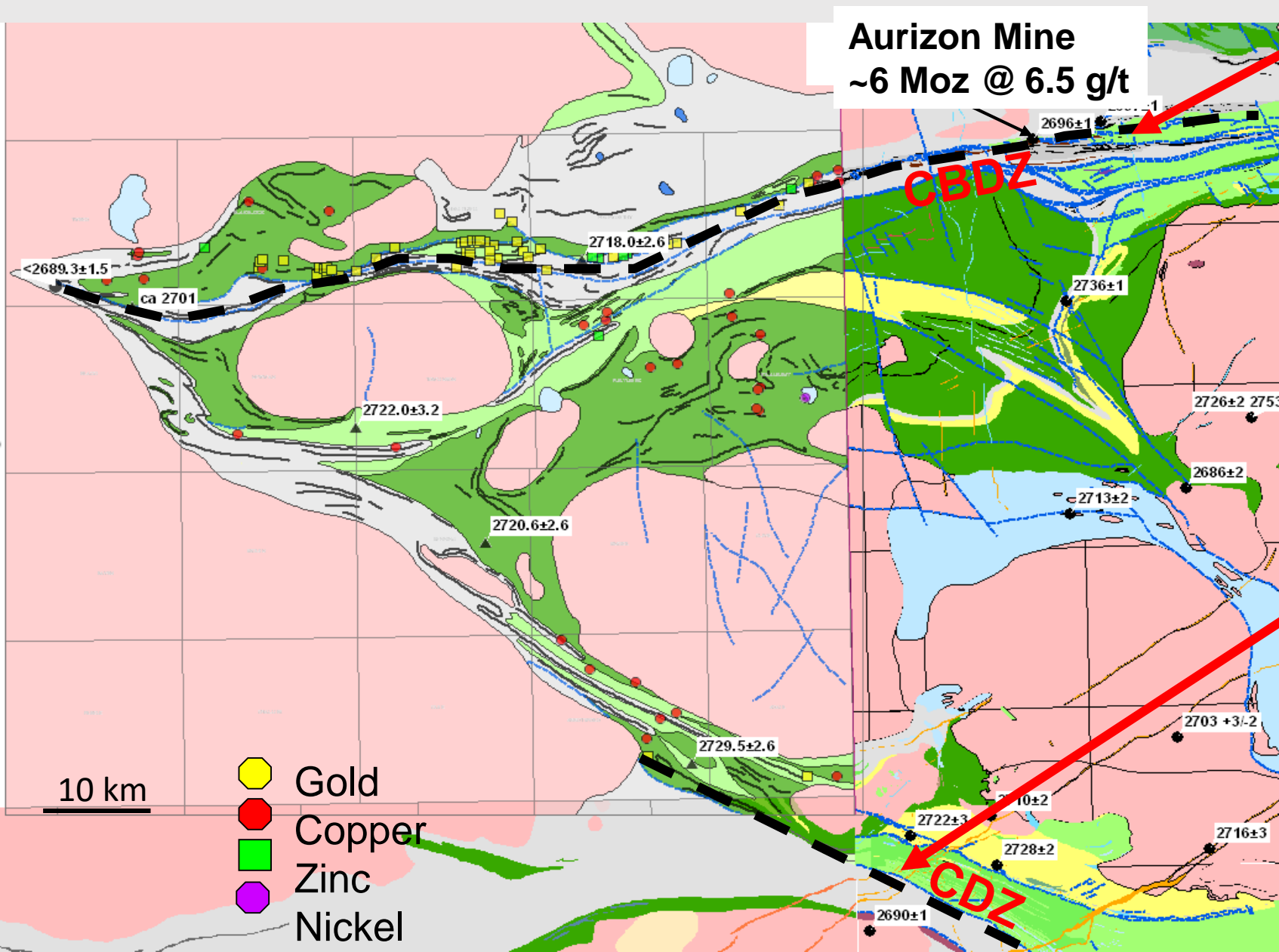
Max. Timing of Gold:
 $>2697 \text{ Ma}$ for barren
albitite dikes cutting Au
mineralization

(Oliver et al., 2012, CIM-EMG)

Northern Abitibi: Casa Berardi & Chicobi Deformation zones



Burntbush Belt Map



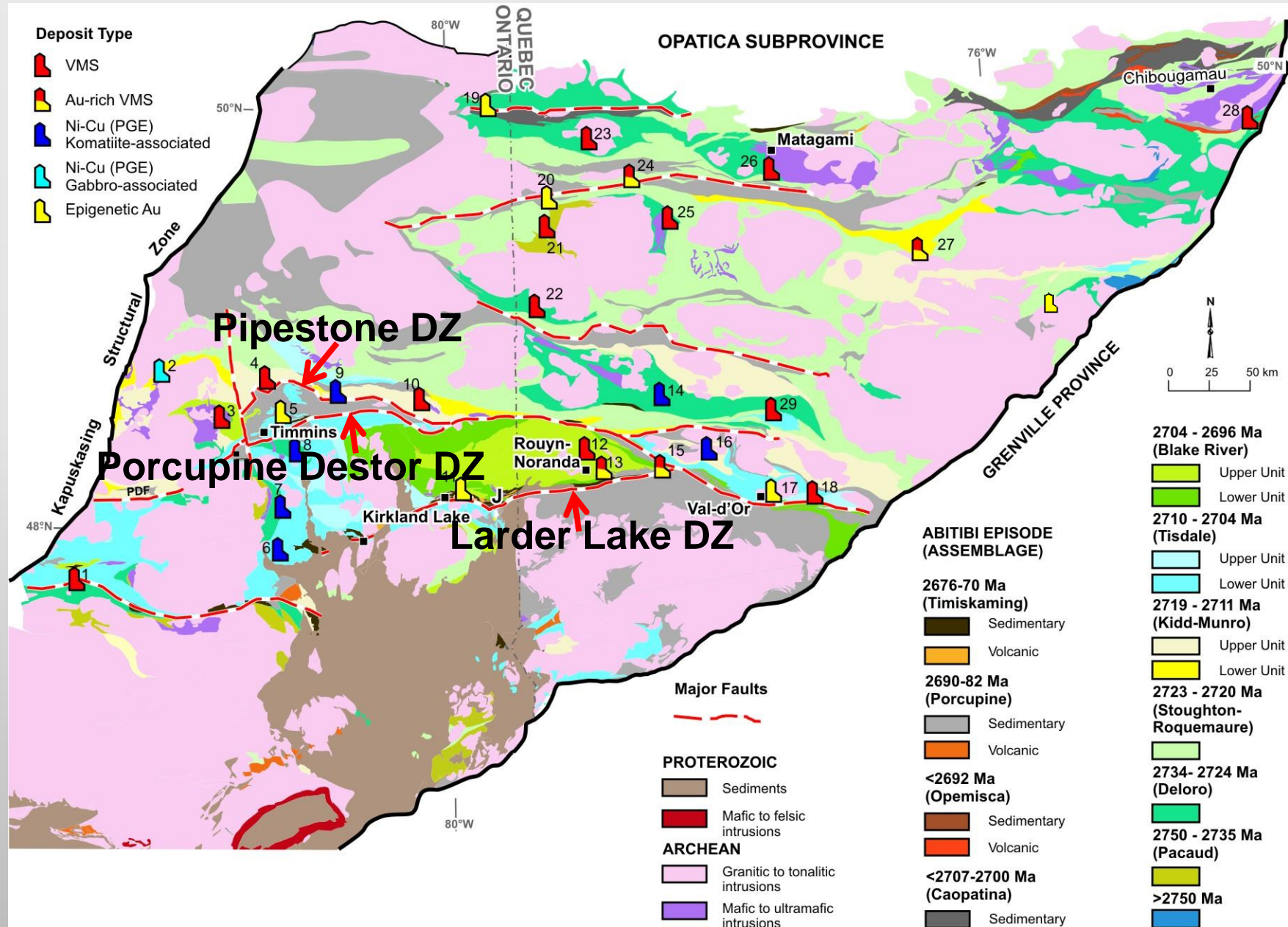
Casa Berardi DZ (CBDZ)

Extends ~ 300 km associated with 2696 Ma turbidites. Kinematics indicate early S-verging D_1 thrusting. Au veins at Casa Berardi mine associated with D_2 sinistral overprint within CBDZ (Pilote et al., 1990)

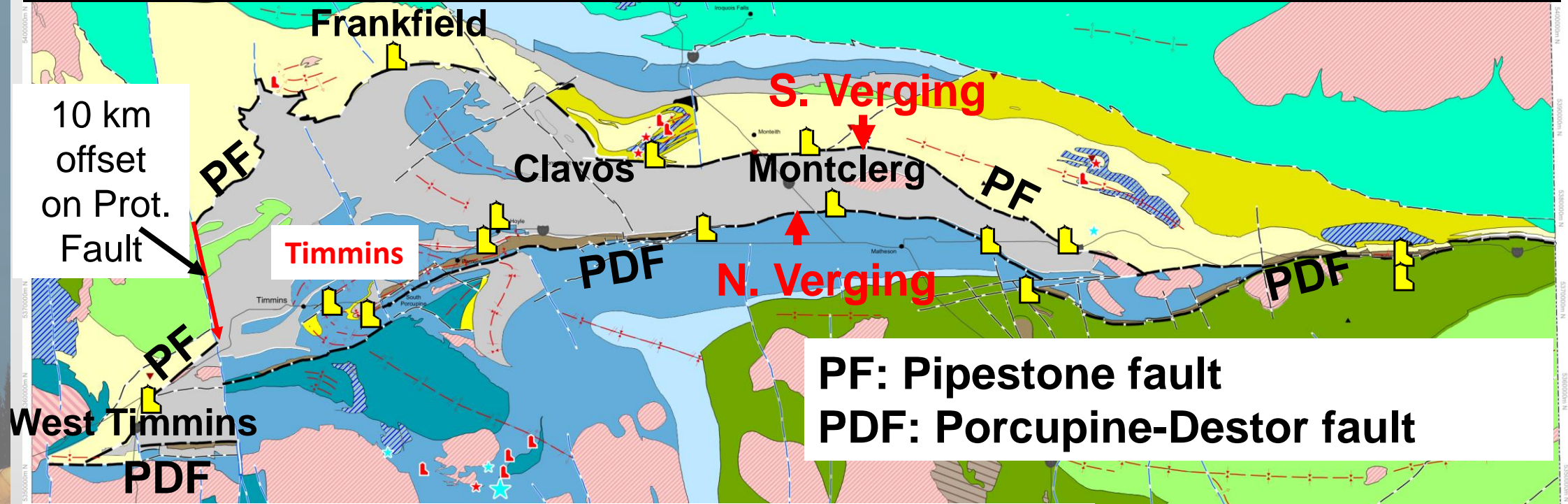
Chicobi DZ (CDZ)

Extends ~ 200 km. D_1 resulted in S-verging thrusting over 2693 Ma turbidities. Overprinted by sinistral D_2 & dextral D_3 (Barret et al., 2013)

Timmins-Auriferous Deformation Zones



Timmins Area Gold Deposits

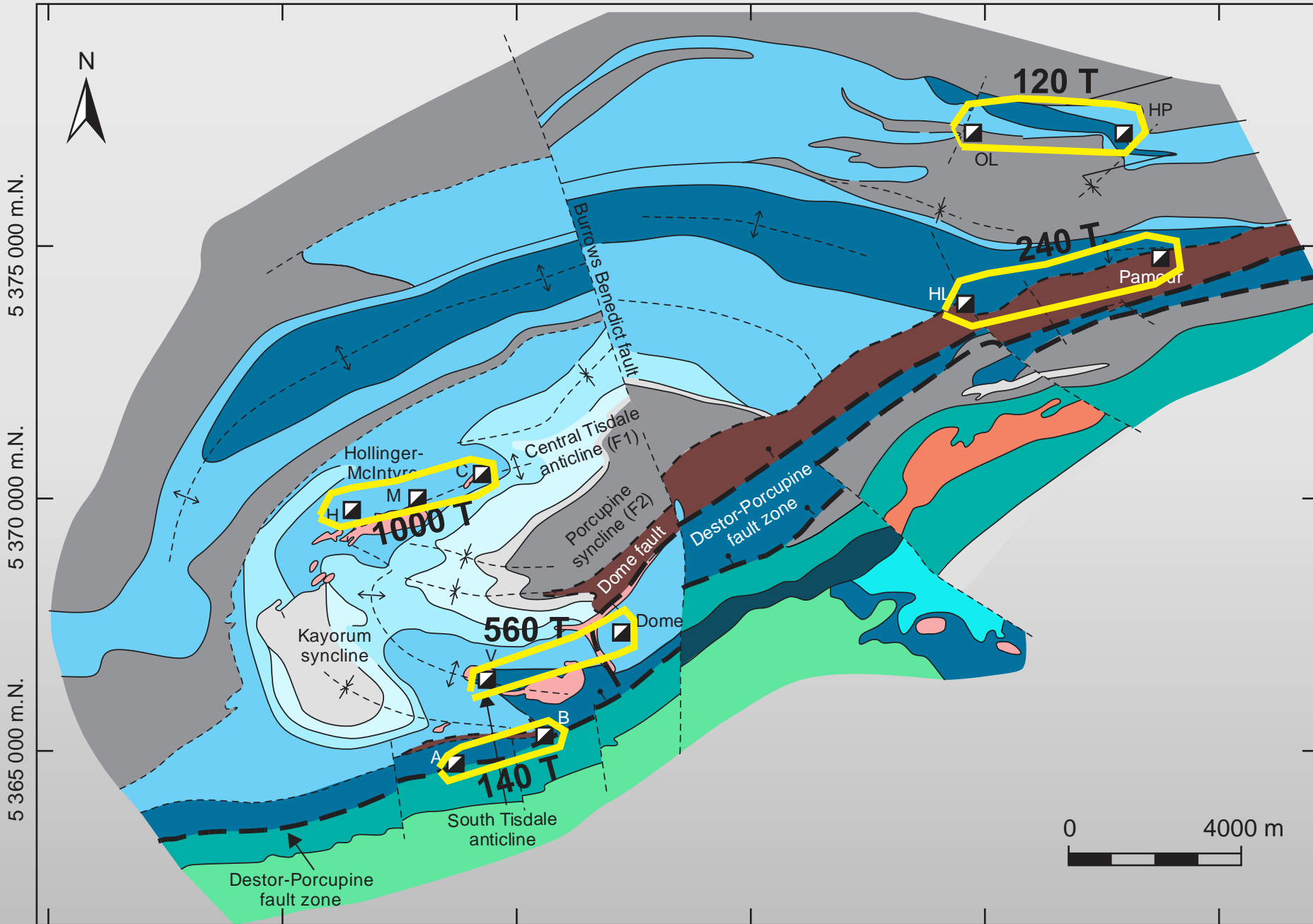


Timmins Au Deposits Occurs Along Two Major Faults

North: Pipestone Deformation Zone: D_1 thrust with Kidd-Munro volcs (2720-10 Ma) thrust south over Porcupine turbidites (2690-80 Ma); Au < 2680 Ma.

South: Porcupine Destor Deformation Zone: D_2 thrust associated with Timiskaming conglomerates & sandstones (2676-70 Ma); Au < 2670 Ma.

70 000 m.E. 475 000 m.E. 480 000 m.E. 485 000 m.E. 490 000 m.E. 495 000 m.E.



Timmins Camp

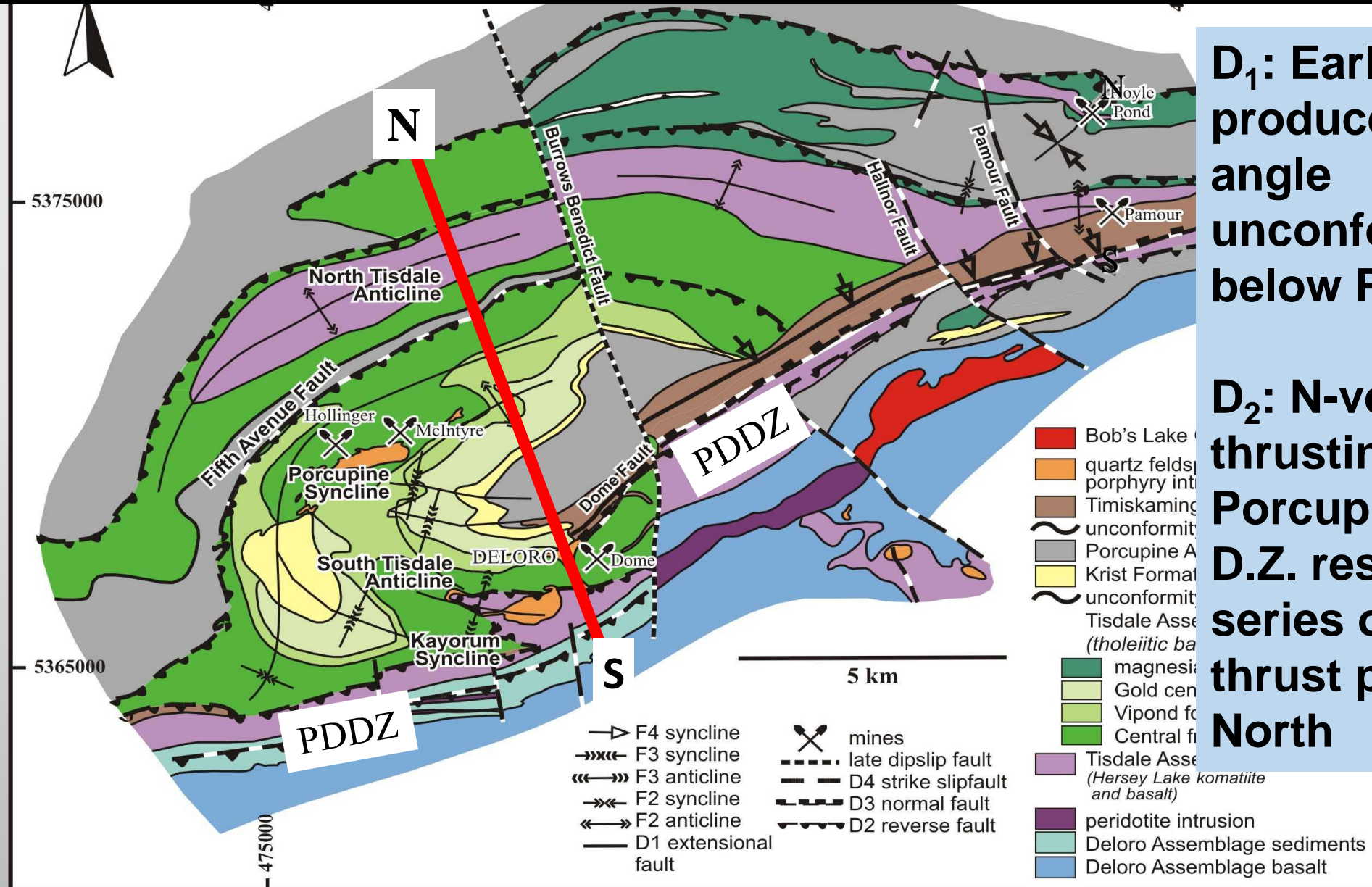
Worlds largest Archean orogenic gold camp

2125 T (75Moz) gold at an average grade of 6.5 g/t

- Five major clusters:
- 1000T Hollinger-McIntyre
 - 510T Dome-Paymaster
 - 240T Pamour-Halnor
 - 140T Aunor-Delinite
 - 120T Hoyle-Owl

Timmins Camp Structural Evolution

(Bateman et al., 2008. Econ. Geol.)

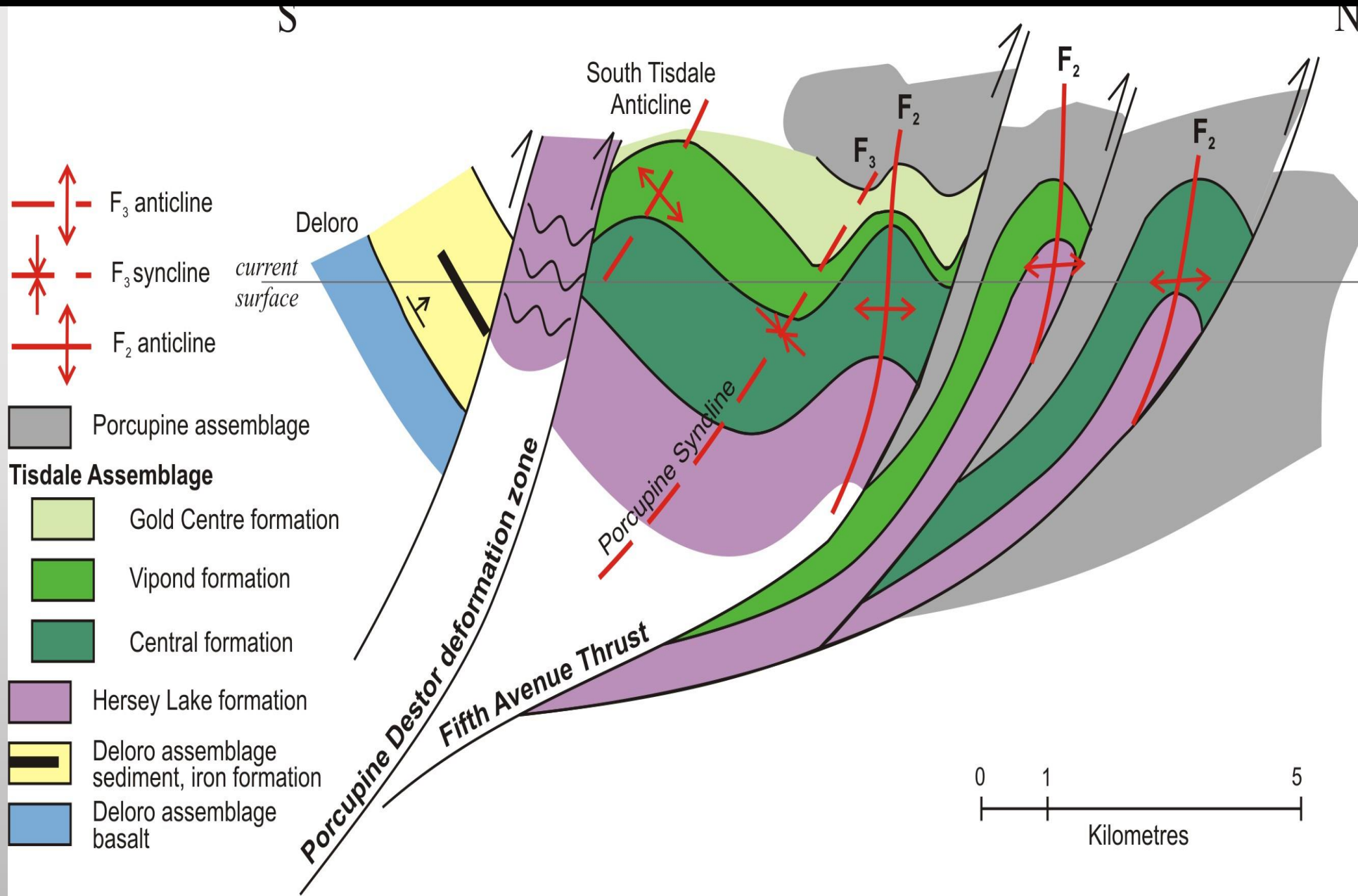


D₁: Early uplift produced a low angle unconformity below Porcupine.

D₂: N-verging thrusting on the Porcupine-Destor D.Z. resulted in a series of fold & thrust panels to North

N-S Schematic Cross Section showing D₂/D₃ Deformation

(Bateman et al., 2008. Econ. Geol.)



Timing of Deformation & Gold in Timmins

(Bateman et al., 2008, Econ. Geol.)

➤ Early Stage Au (D_1/D_2) (uneconomic):

Pre-Timiskaming (>2676 Ma): Au in ankerite vein clasts in conglomerates. Possibly related to Pipestone fault

➤ Main Stage Au (D_3/D_4) (~75 Moz):

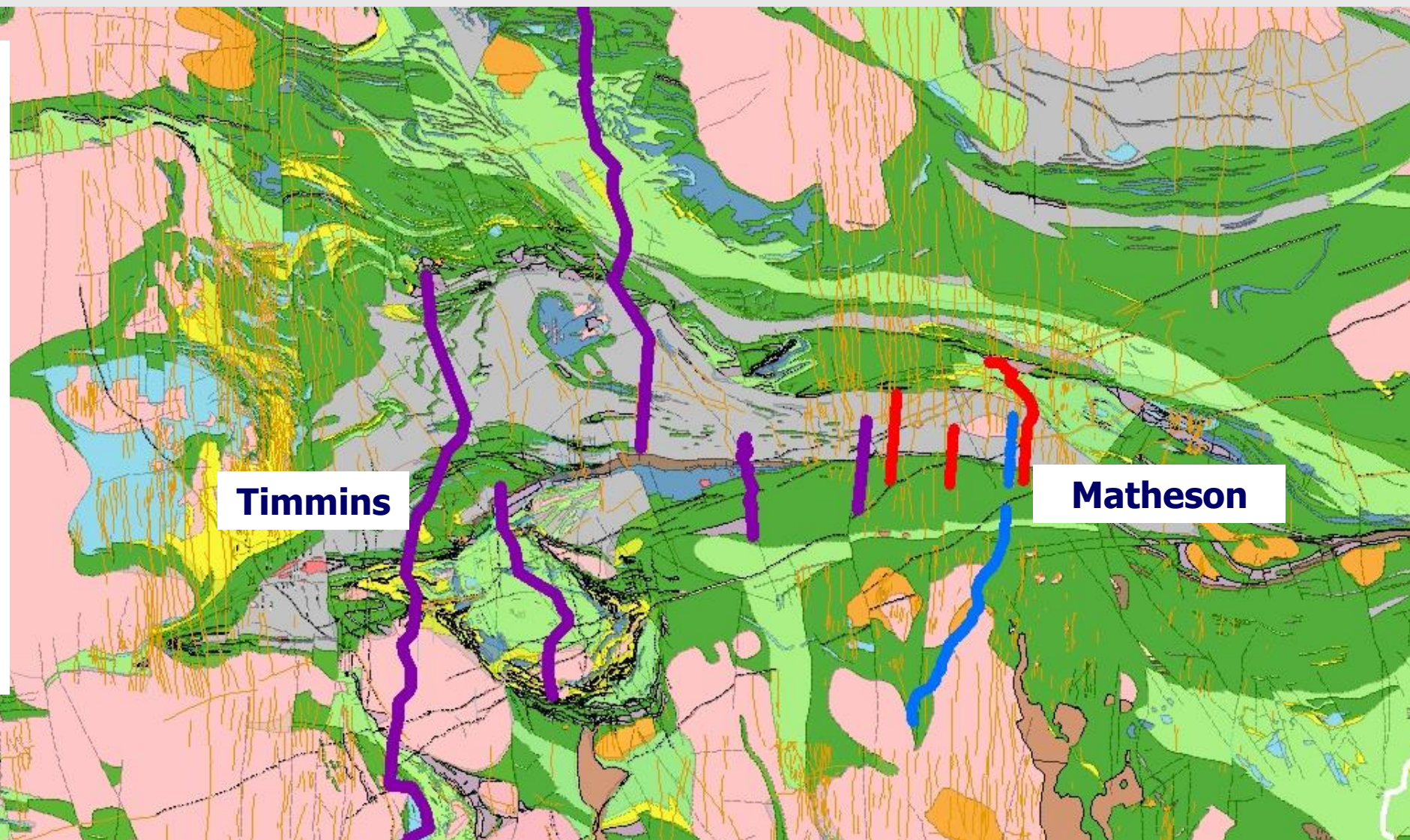
Post-Timiskaming (<2670 Ma)

- Cu-Mo-Au stockwork (eg. McIntyre Re-Os moly age of 2672 +/- 6 Ma)

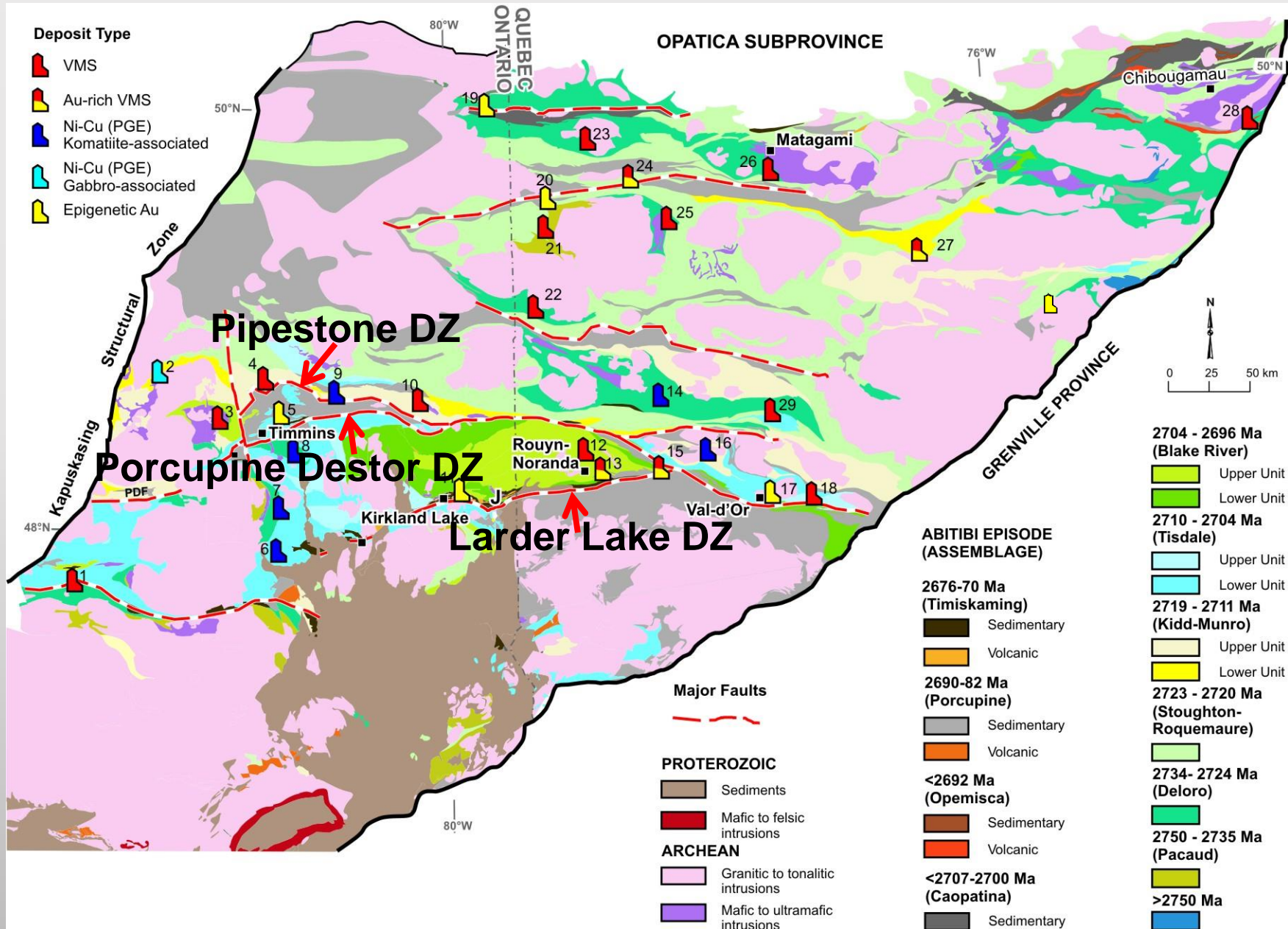
- Au veins in hanging wall anticlines (Hollinger-McIntyre, Dome – Re-Os moly age at Dome of 2670 +/- 10 Ma).

**Map showing
seismic
reflection
profiles:**

- Discover
Abitibi 2004
(purple)
- Metal Earth
2017
 - Blue R1
 - Red R2



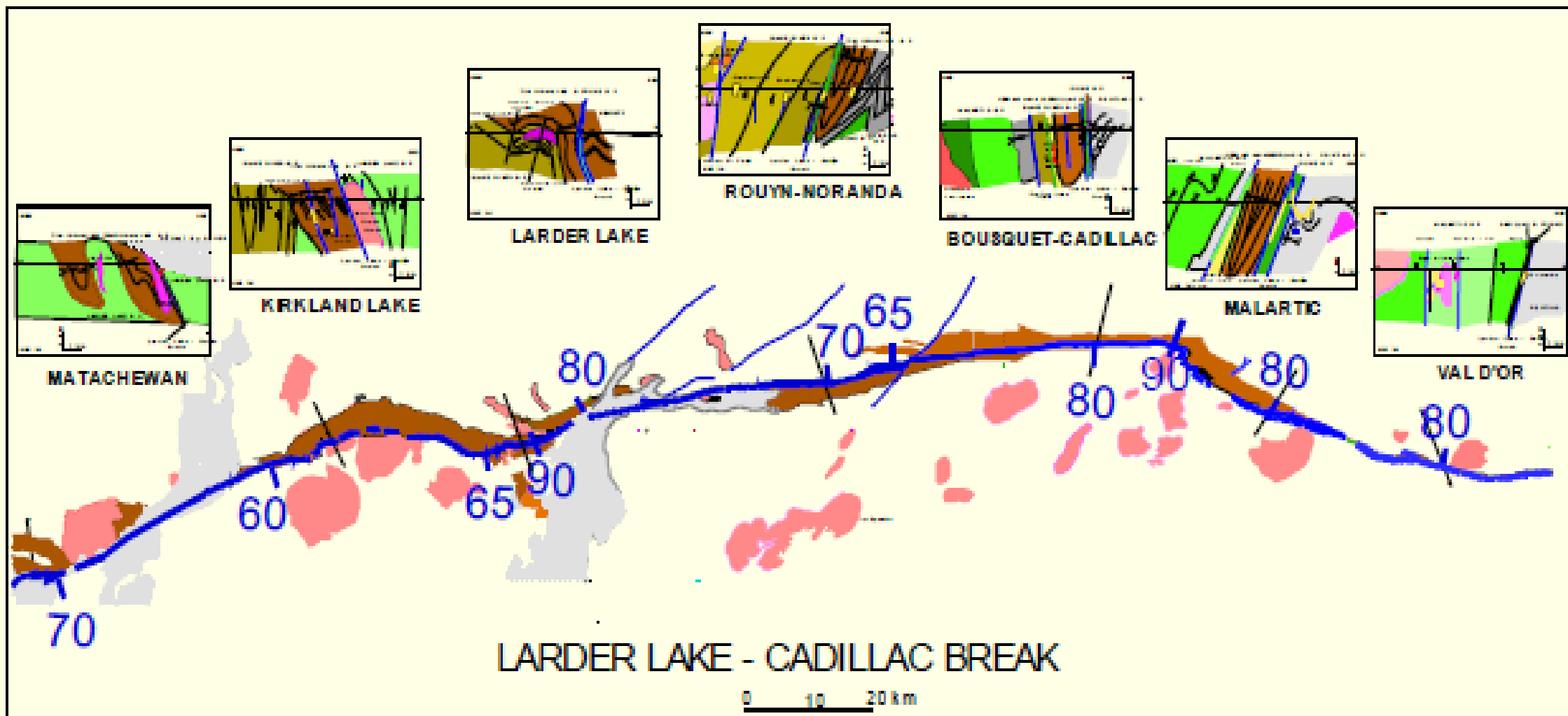
Kirkland-Larder Lake Gold Deposits



Larder-Cadillac Break:

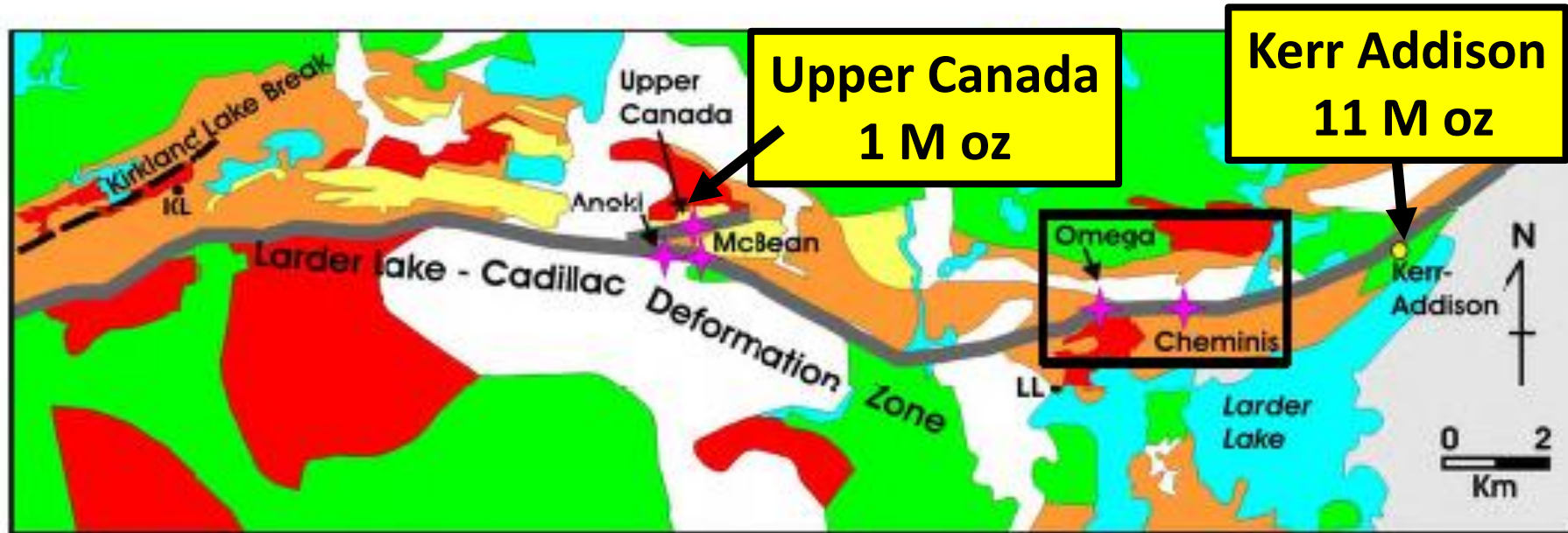
250 km D2 thrust - host to 7 mining camps (~100 Moz Au)

Thrust dips south from Matachewan to Kirkland, changes to N dip, east of Larder

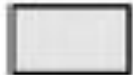


Poulsen (2017)

Structural Controls on Au in Larder Area



Huronian Supergroup



Timiskaming assemblage (2677-2669 Ma)



Syenitic intrusions



Sandstone and conglomerate



Alkalic pyroclastics and flows

Tisdale, Kinojevis, Blake River assemblages (2710-2696 Ma)



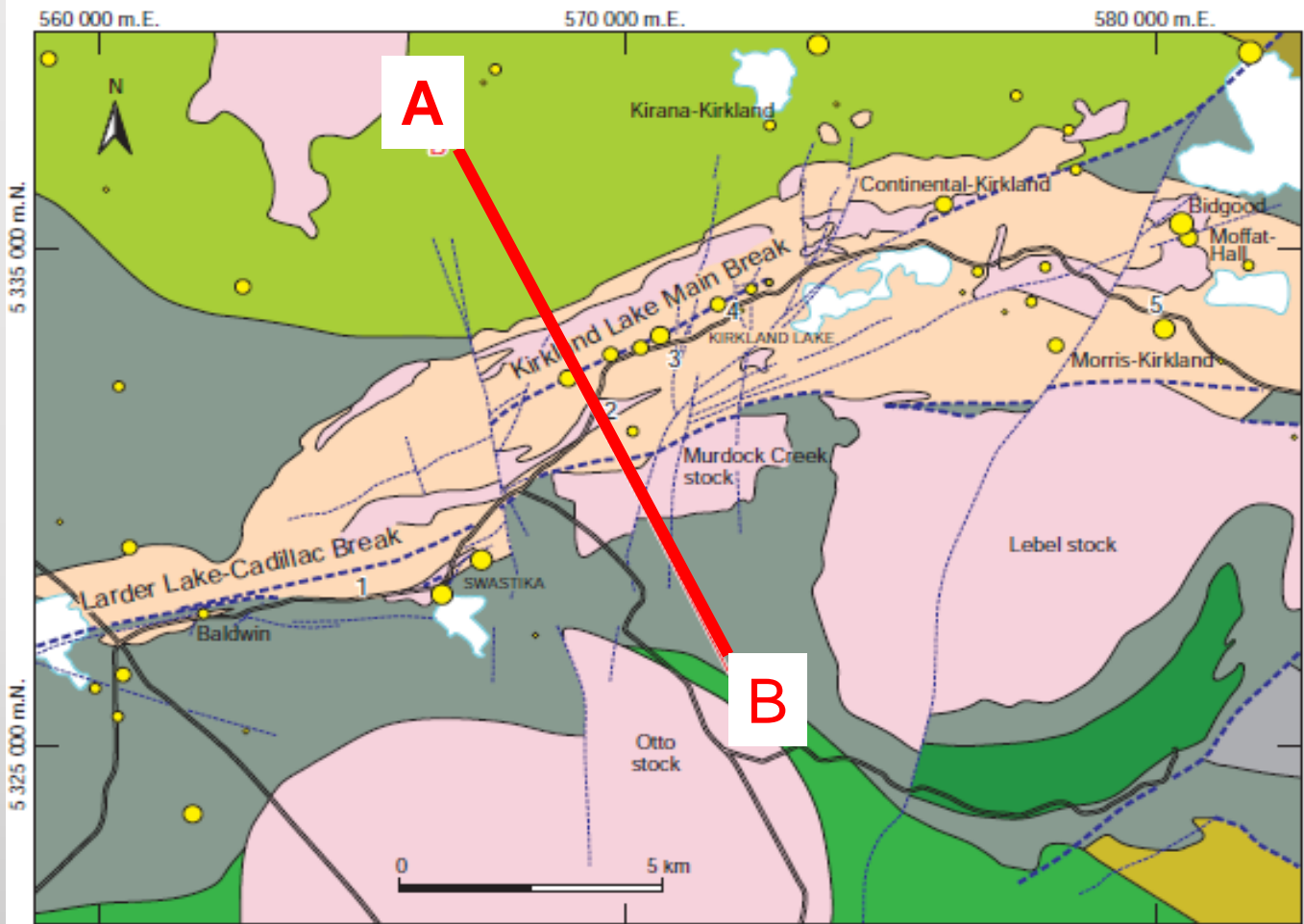
Mafic volcanic rocks

-Deposits formed during D_2 associated with the Larder Lake-Cadillac deformation zone.

-Associated with qz-cb veining, disseminated sulfides & extensive carbonate alteration

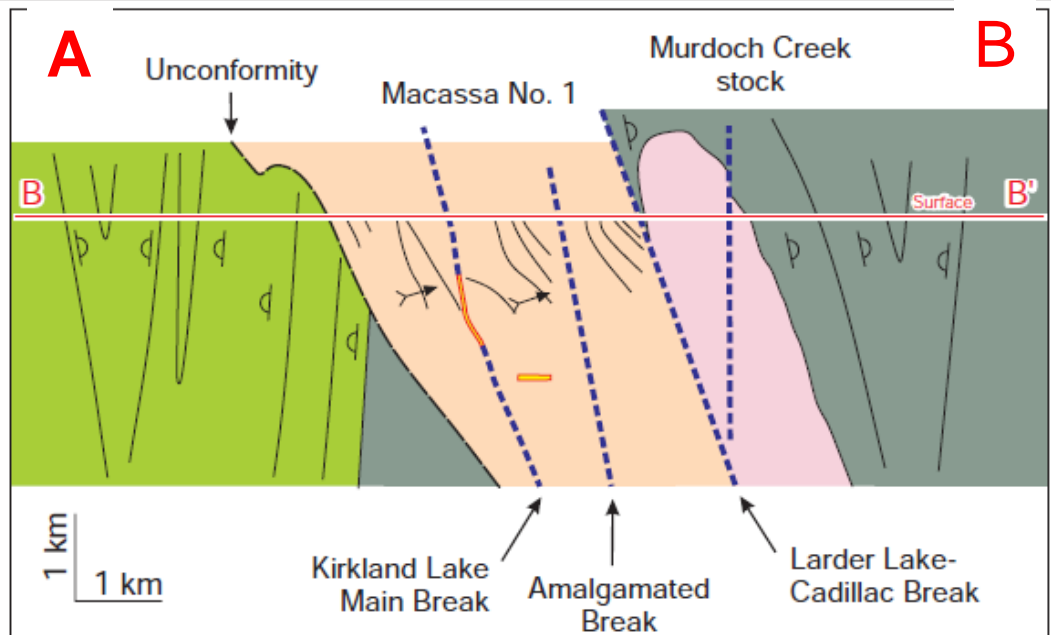
Lafrance (2015)

Kirkland Lake 26 Moz Au in 6 km long deposit along “Main Break”



- | | | | |
|---|---------------------------------------|------------------------------------|---------------------|
| Archean intrusive rocks | Blake River Group | Larder Lake Group | Gold deposit |
| Syenite, feldspar porphyry | Intermediate to felsic volcanic rocks | Ultramafic to mafic volcanic rocks | Gold deposit |
| Timiskaming Group | Mafic to intermediate volcanic rocks | Unassigned | Fault |
| Conglomerate, sandstone, alkalic volcanic rocks | Mafic volcanic rocks | Mafic to ultramafic volcanic rocks | |
| | | Mainly iron formation | |
| | | Mainly graywacke | |

“Main Break” Fault lies 2 km NE of LLCDZ. It strikes NE & dips steeply S. Au occurs in narrow qz-cb veins within brittle fault breccias along with Au- & Ag-tellurides, Mo, & Pb (Ispolatov et al., 2008)

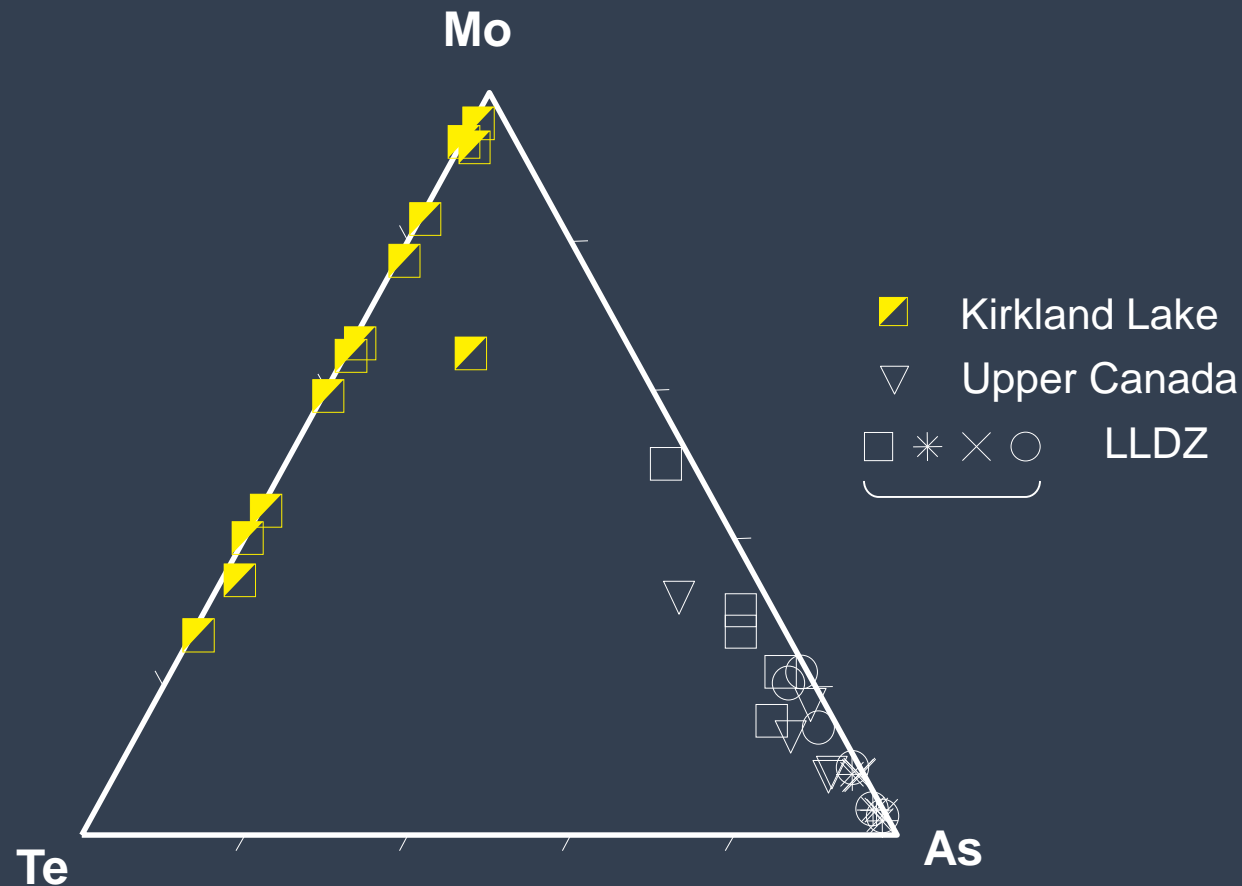


(Poulsen, 2017)

Kirkland / Larder Au geochemistry:

- Main Break Au associated with telluridies and molybdenite; high Te (Te>Au), Mo & low As
- Main Break is distinct from Upper Canada & LLDZ deposits

(Ispolatov et al., 2008)



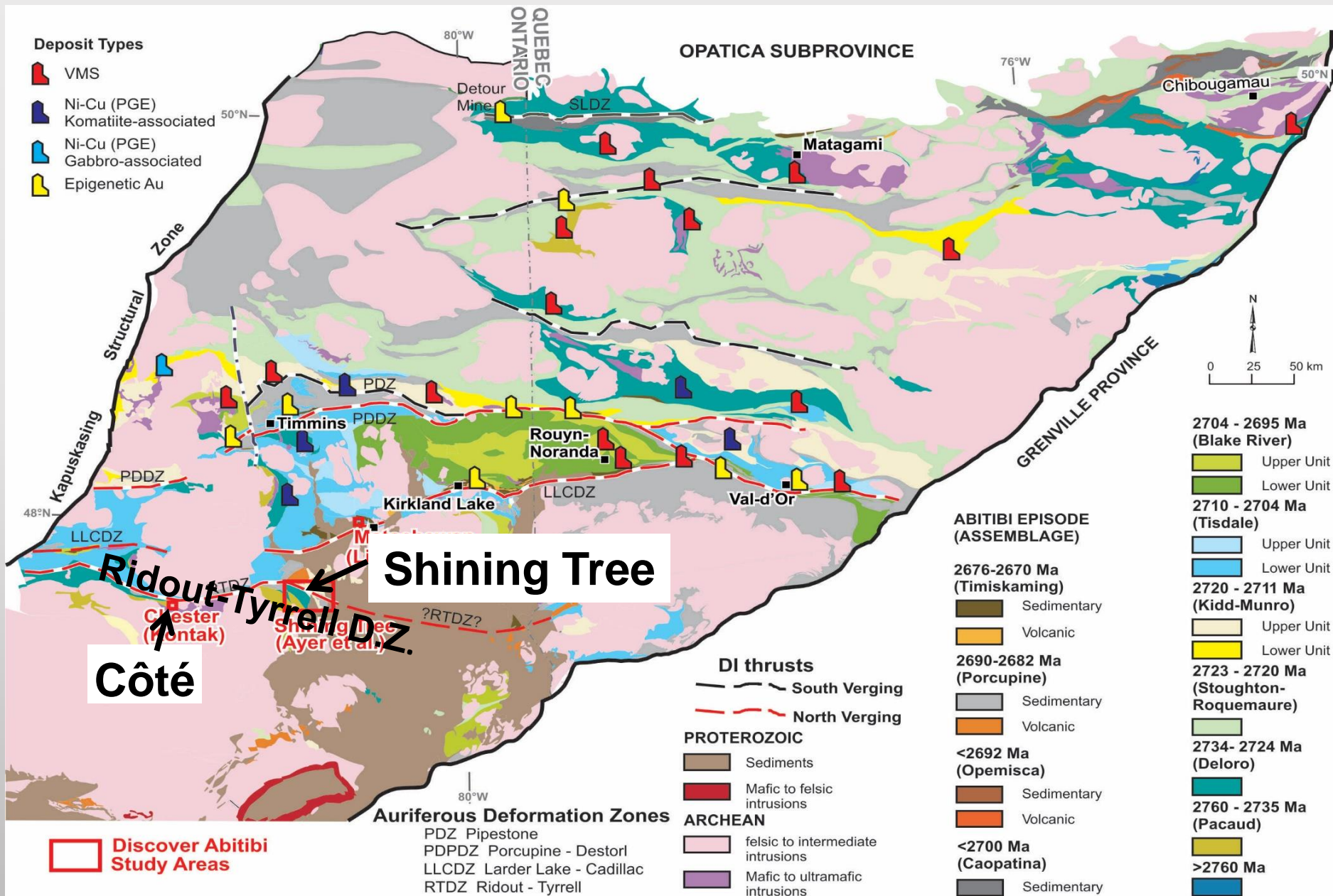
Larder-Kirkland Timing of Deformation & Gold

Conclusions

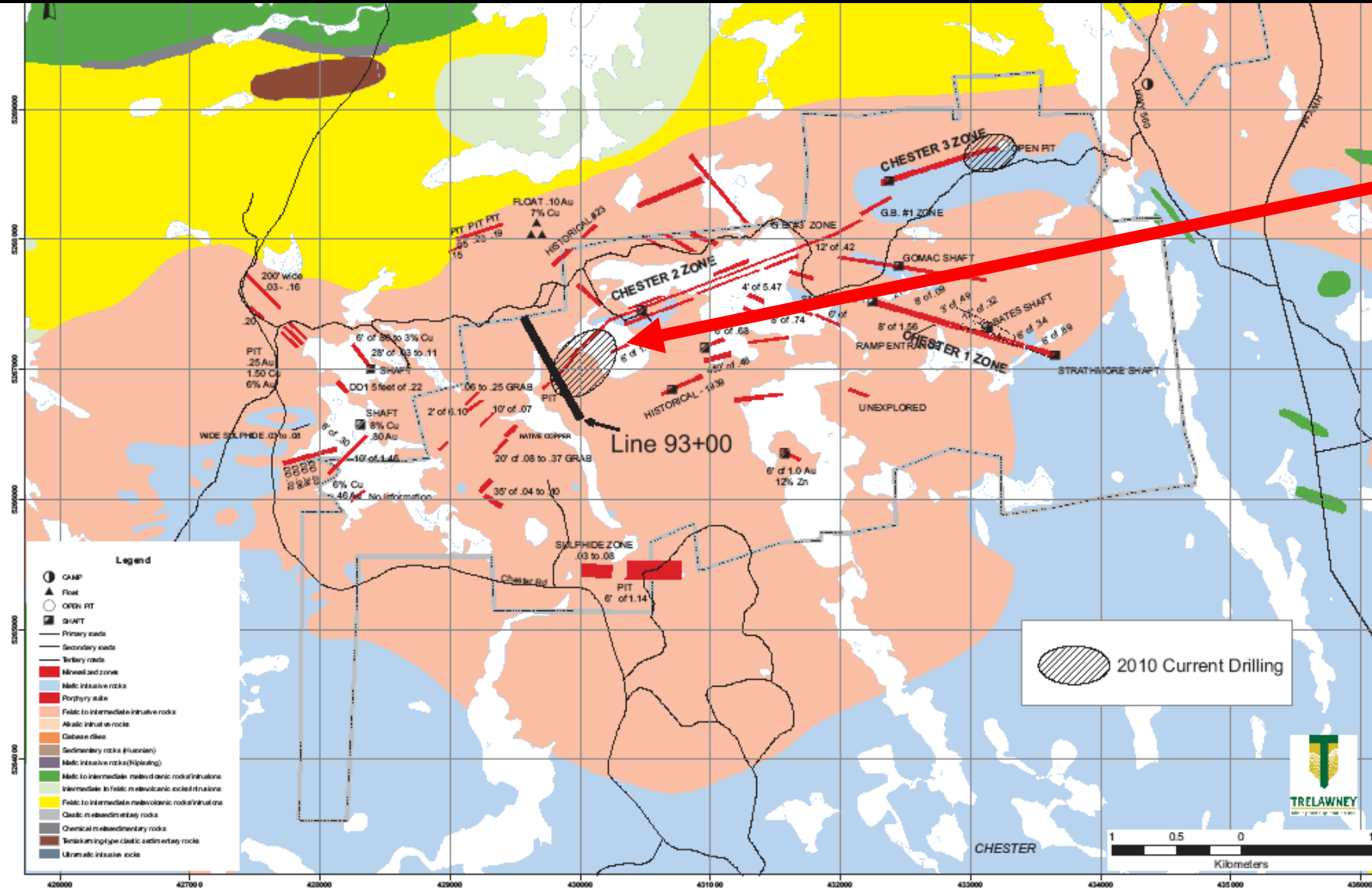
- ❖ Gold mineralization along the Larder Lake deformation zone was emplaced syn-D2 in a wide ductile corridor of deformation with strong ankerite alteration.
- ❖ Gold at Kirkland Lake is associated with Te & Mo in brecciated quartz veins emplaced in syn-D4, sericitized, brittle faults.
- ❖ Mineralization is coeval with a long-lived alkalic magmatic system.

(Ispolatov et al., 2008)

Southern Abitibi: Ridout-Tyrrell Deformation Zone



Côte Gold Deposit ~3 km South of Ridout-Tyrrell Deformation Zone in SE Swayze Belt



-Large tonnage, low grade deposit with reserves of ~ 8 M oz @ 1 g/t

-Intrusion-related Au+Cu porphyry-style deposit formed @ ~2740 Ma

(Kontak et al., 2013)



Côte Deposit:

U-Pb zircon ages of intrusion and Re-Os ages of magmatic-hydrothermal gold-copper mineralization

**Tonalite
U-Pb
Zircon
age 2741
 \pm 1 Ma**



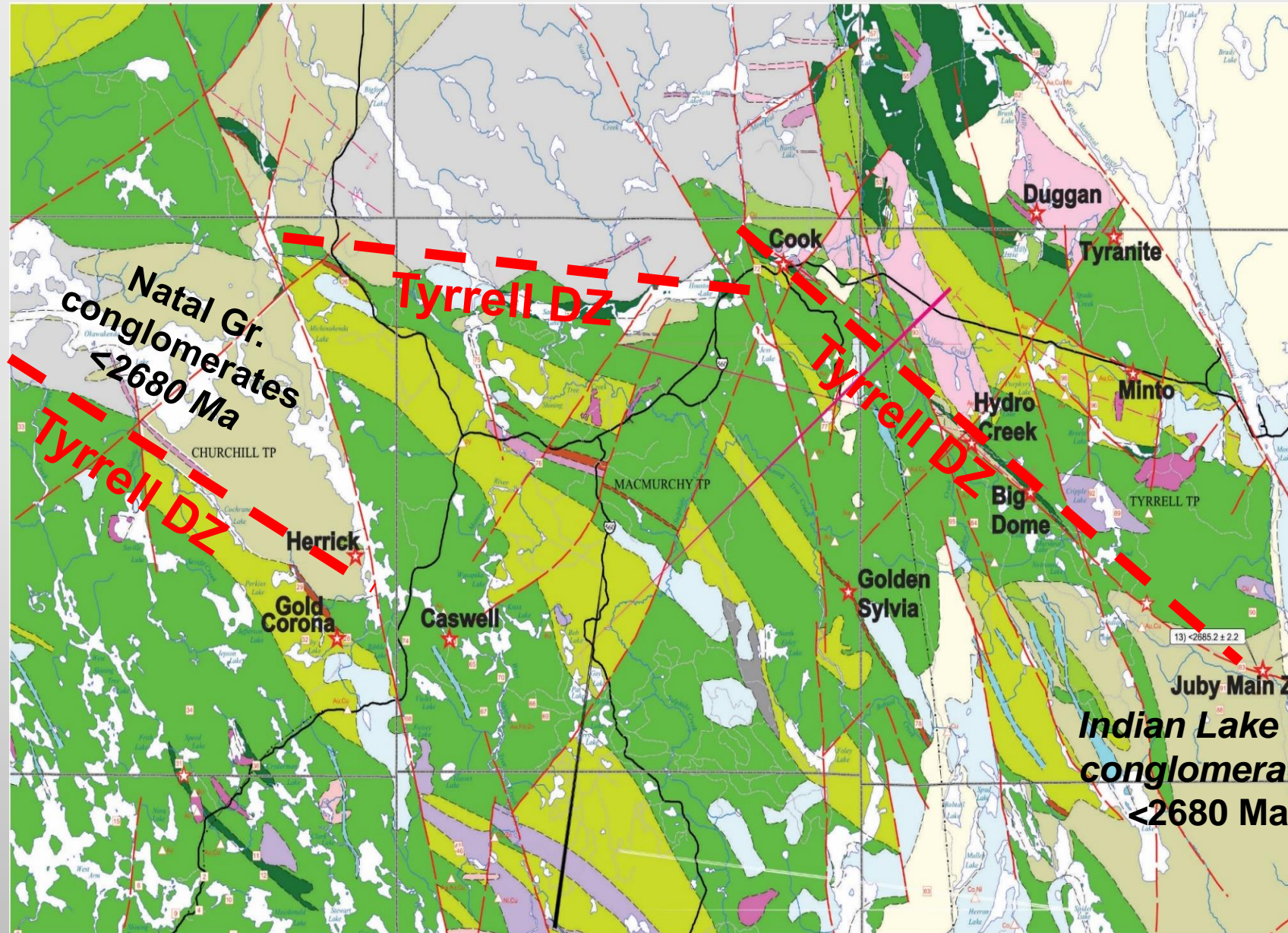
**Re-Os
Moly age
2737 \pm 7
Ma**



**Moly with Au in diorite; Re-Os age
= 2741 \pm 7 Ma (DDH E-09-01)**

(Kontak et al., 2013)

Southern Abitibi: Shining Tree Belt

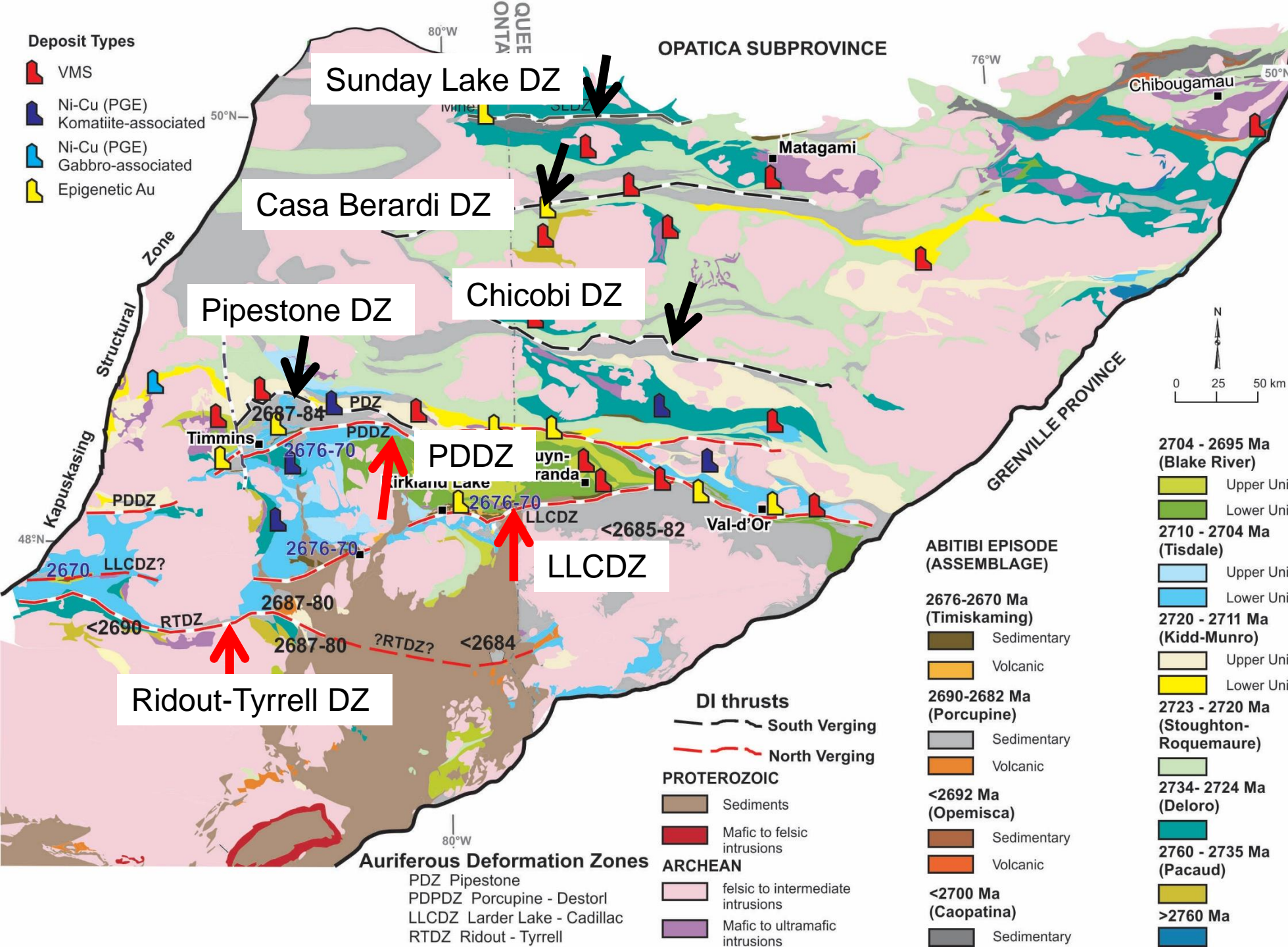


~2 Moz along the Tyrrell DZ, a north-verging D_2 thrust overprinted by D_3 dextral shearing

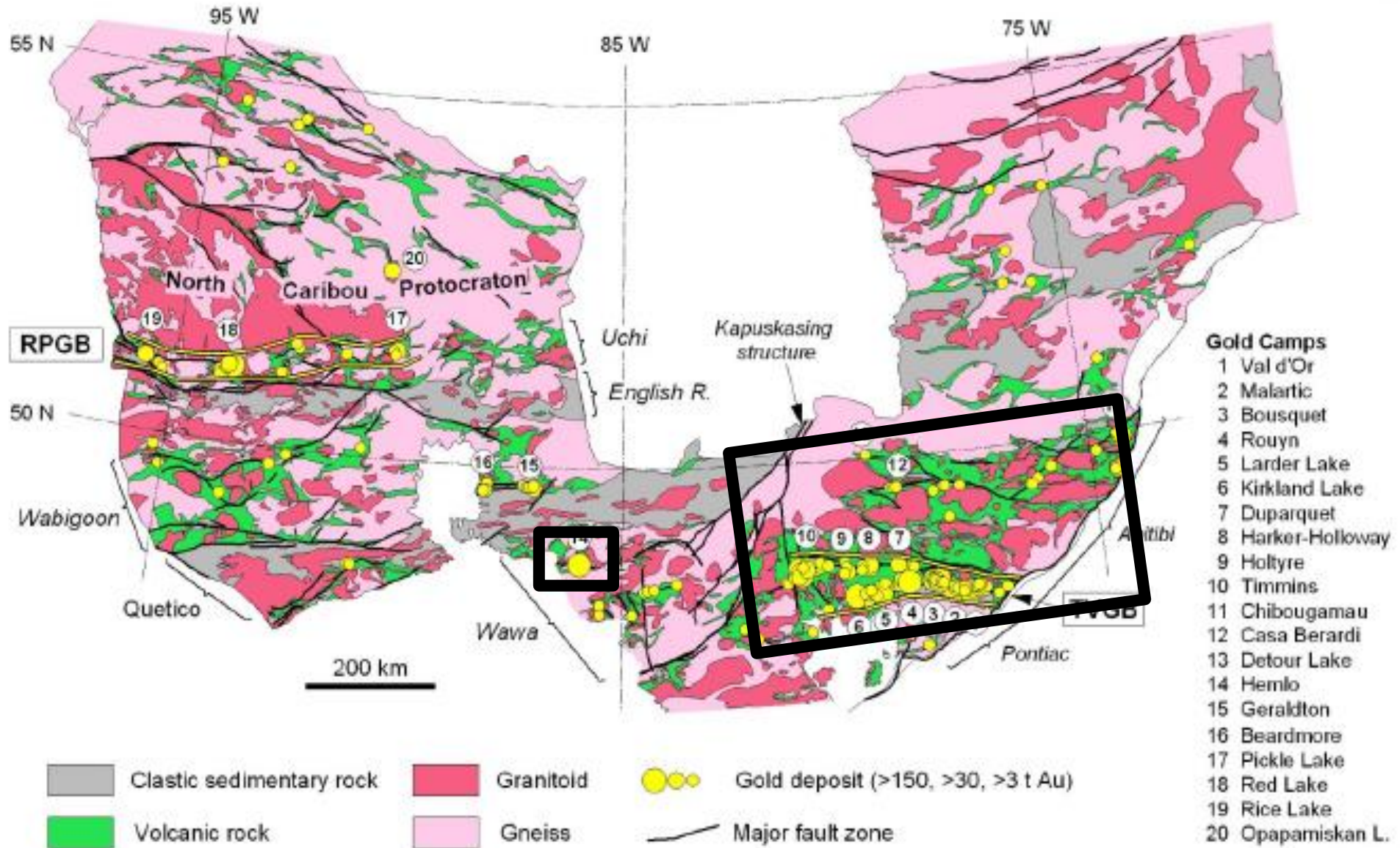
- Au is syn- D_3 , (@2676 ± 2Ma age of mineralized dike)
- D_4 deformation N-trending brittle faults with Au in brecciated qz-cb veins @ 2640+/-11 Ma Re-Os moly age (Ayer et al., 2013)

Summary of Abitibi Auriferous Faults

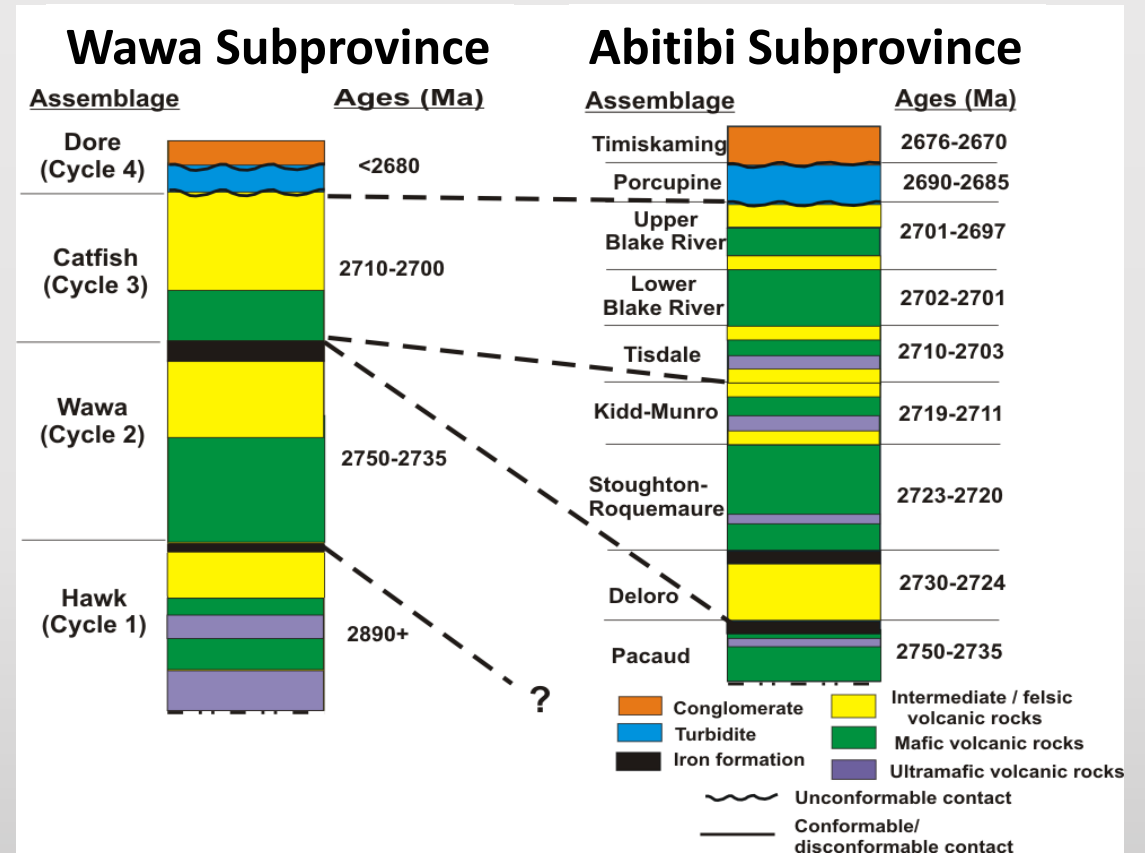
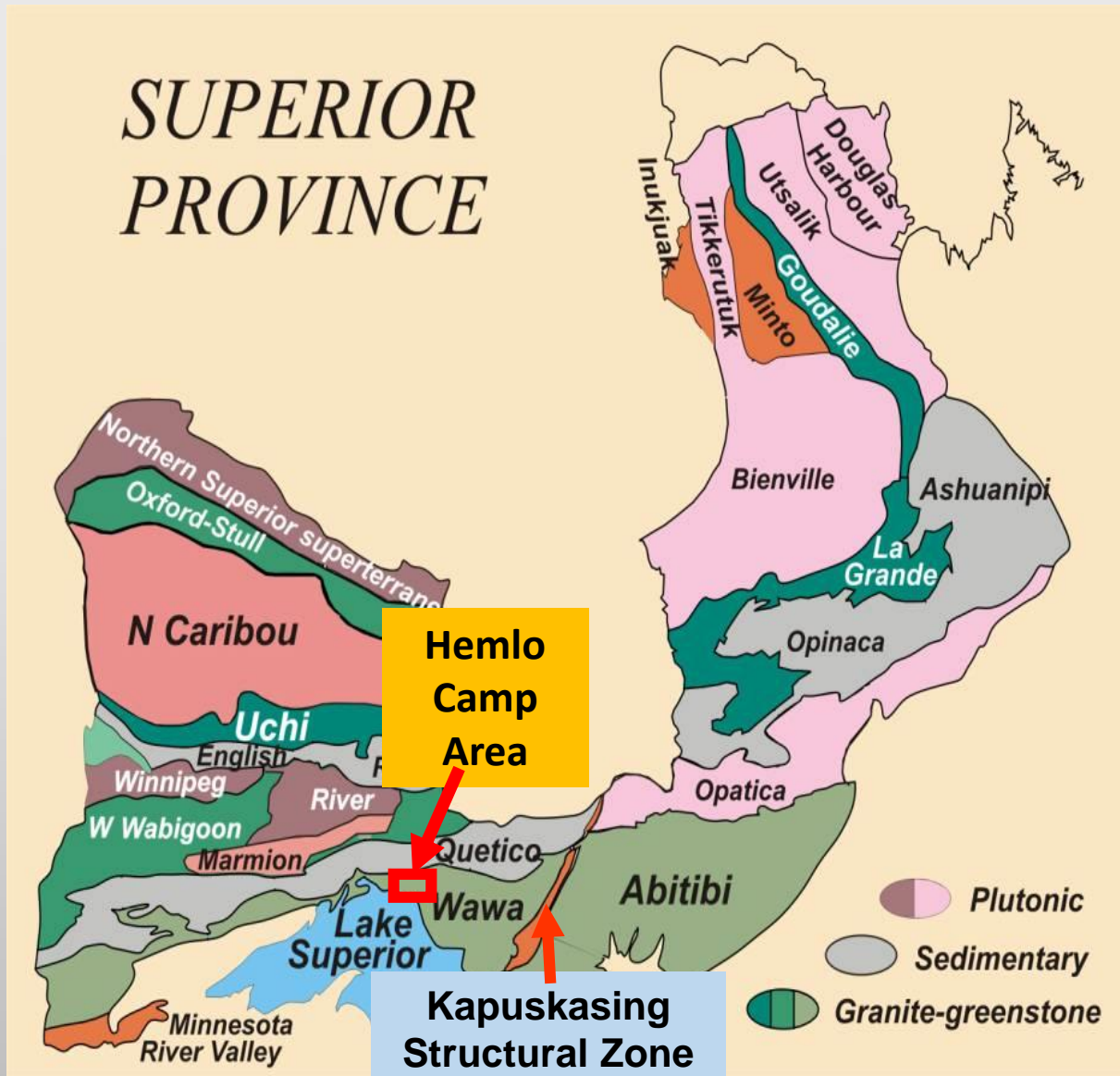
- Northern Abitibi Successor Basins:**
- Coapatina ~2700 Ma
 - Opemisca ~2690 Ma
 - ✓ Early thrusts S-verging
 - ✓ Au 2700-2690 Ma
- Southern Abitibi Successor Basins:**
- Porcupine 2690-80 Ma
 - Timiskaming 2676-70 Ma
 - ✓ Early thrusts N-verging
 - ✓ Au 2670-2665 Ma



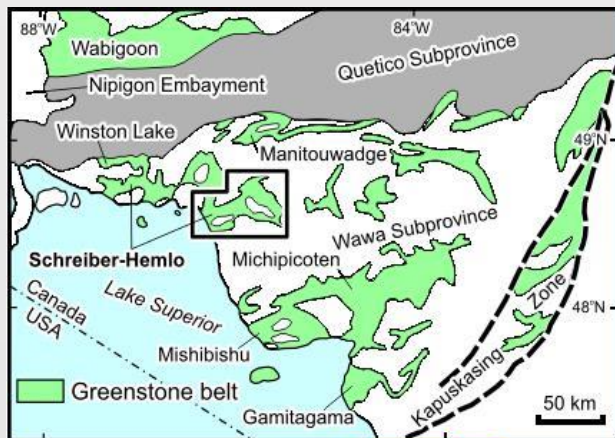
Comparison of Abitibi and Hemlo Gold Camps



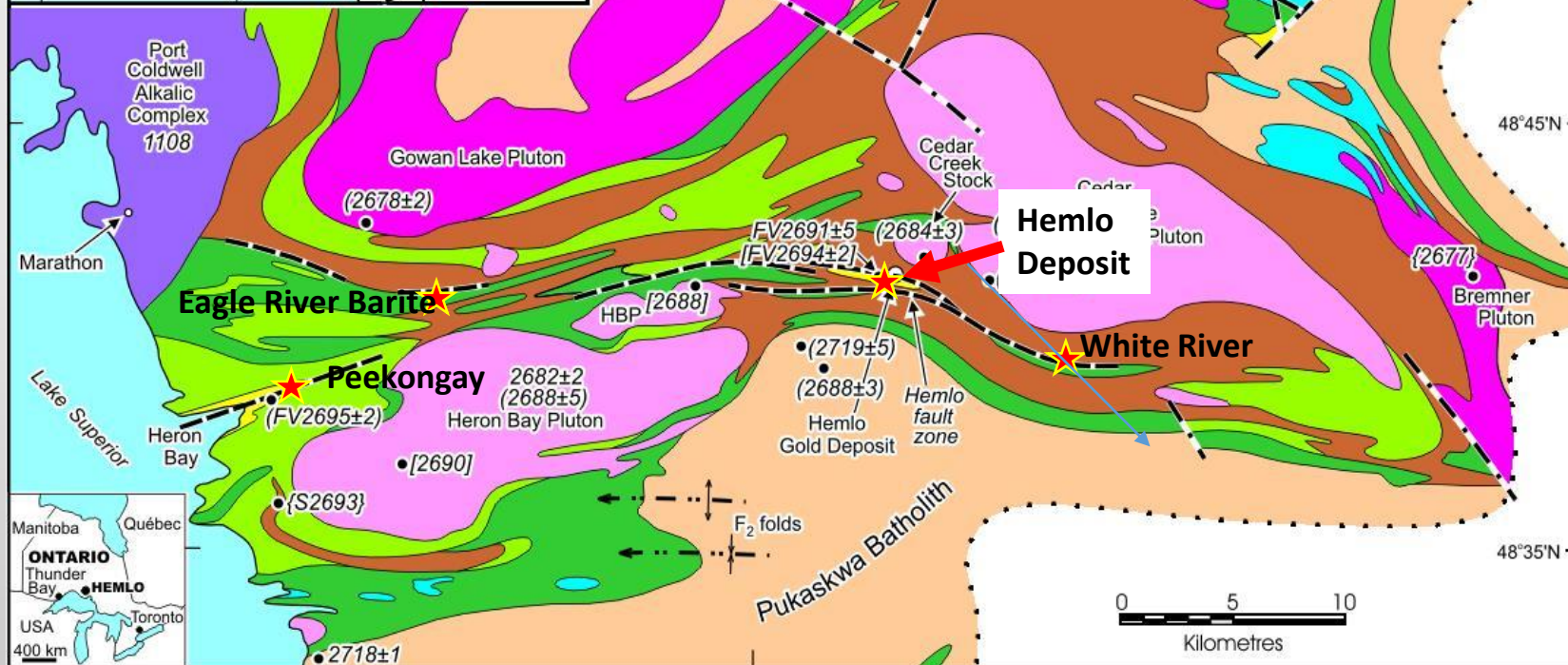
Comparison of Abitibi and Hemlo Gold Camps



- Upper stratigraphic units in Abitibi & Wawa have similar lithologies & ages (i.e. 2.76-2.68 Ga).
- One difference in the Wawa terrane is the presence of a ~2.9 Ga lowermost unit representing a stratigraphic gap (unconformity ?) of >100 Ma.



Geology of Hemlo Belt (Muir, 2003)



Proterozoic		Archean		Structural Features	
	Gabbro, syenite		Metasedimentary rocks		Trace of fold axial plane
Archean			Felsic metavolcanic rocks and subvolcanic intrusions		Brittle fault
	Granitoids: batholiths		Intermediate metavolcanic and related metasedimentary rocks		Ductile high-strain zone
	Granitoids: plutons & stocks (early, middle, late)		Mafic, rare ultramafic metavolcanic rocks		Compiled mapping limits
	Mafic/Ultramafic intrusions				U-Pb age sample site

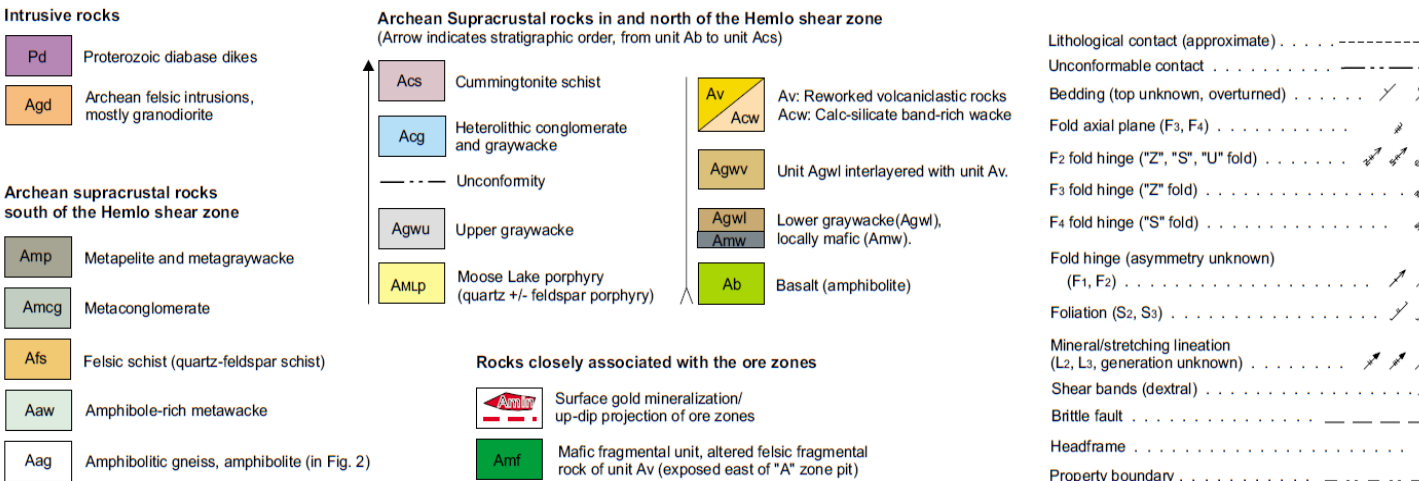
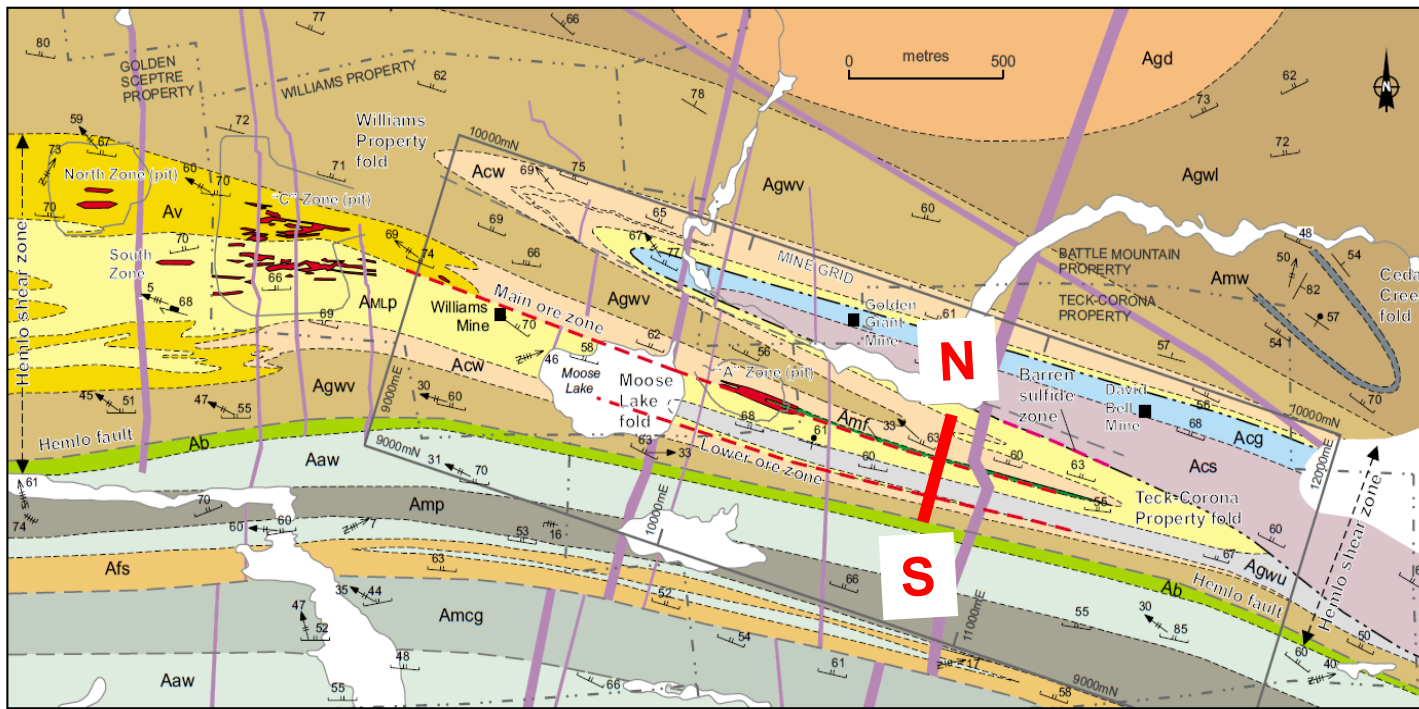
Hemlo Deposit Setting

Occurs within 2693-2685 Ma clastic sed. & felsic volcs (i.e. Porcupine age), underlain by mafic volcs, metamorphosed to amphibolite facies, and intruded by 2720 Ma tonalite batholiths to N & S

Deposit occurs at a jog in the ~50 km Lake Superior deformation zone

Au associated with disseminated sulfides in broad replacement zones

Hemlo Deposit Area Map and Cross Section (Davis and Lin, 2003)

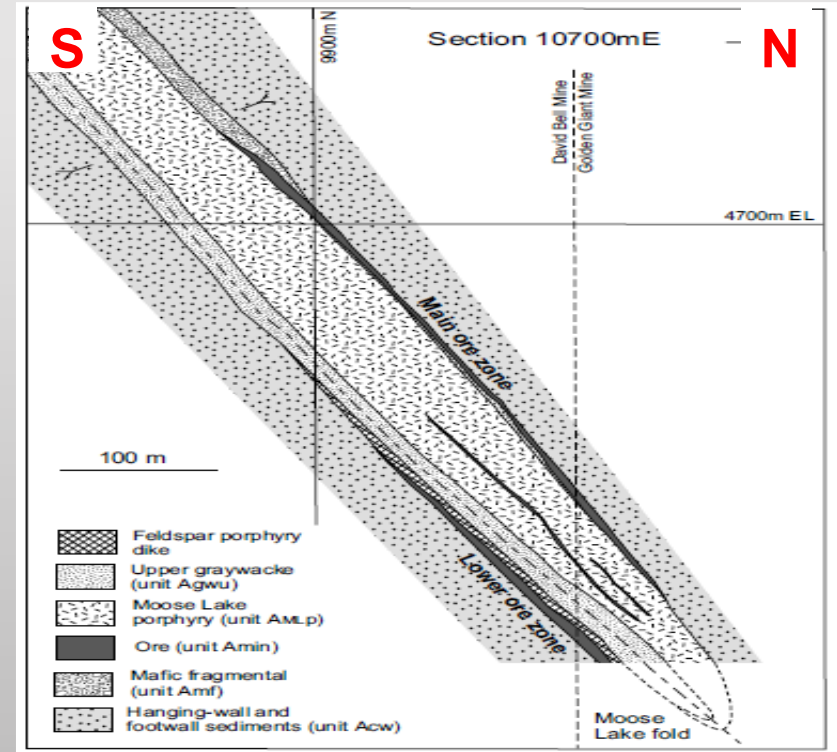


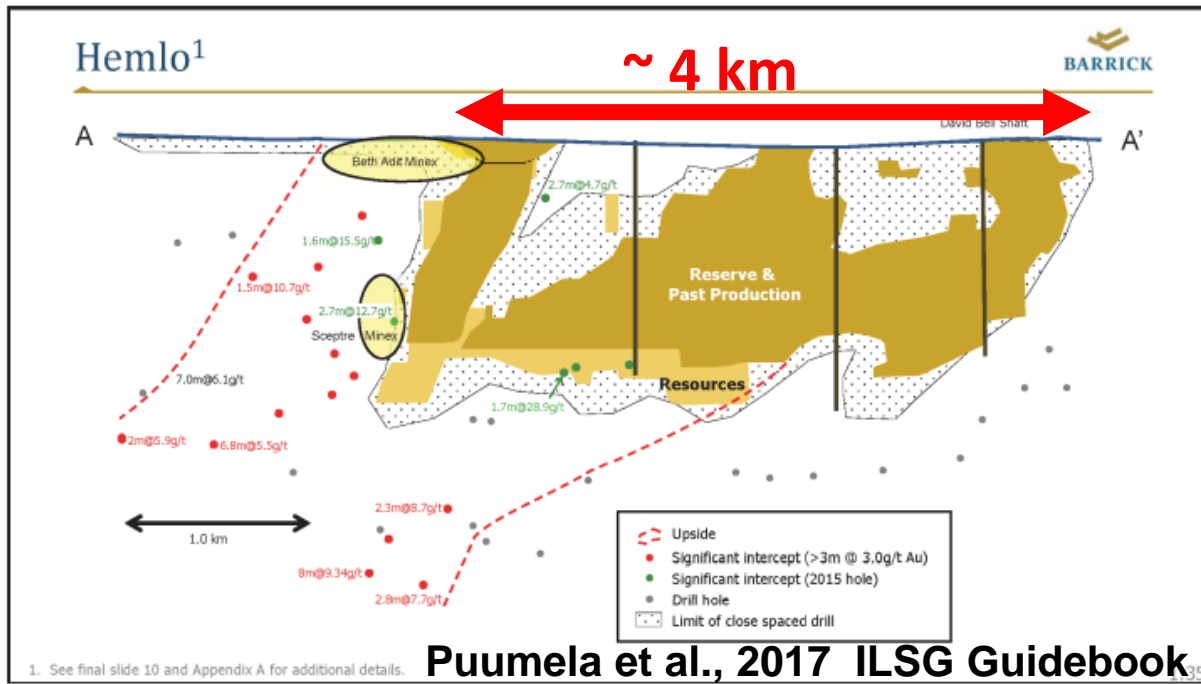
Structural History:

-D₁ early thrusting, fabric only locally preserved

-D₂ sinistral kinematics with tight folds & shearing parallel to stratigraphy

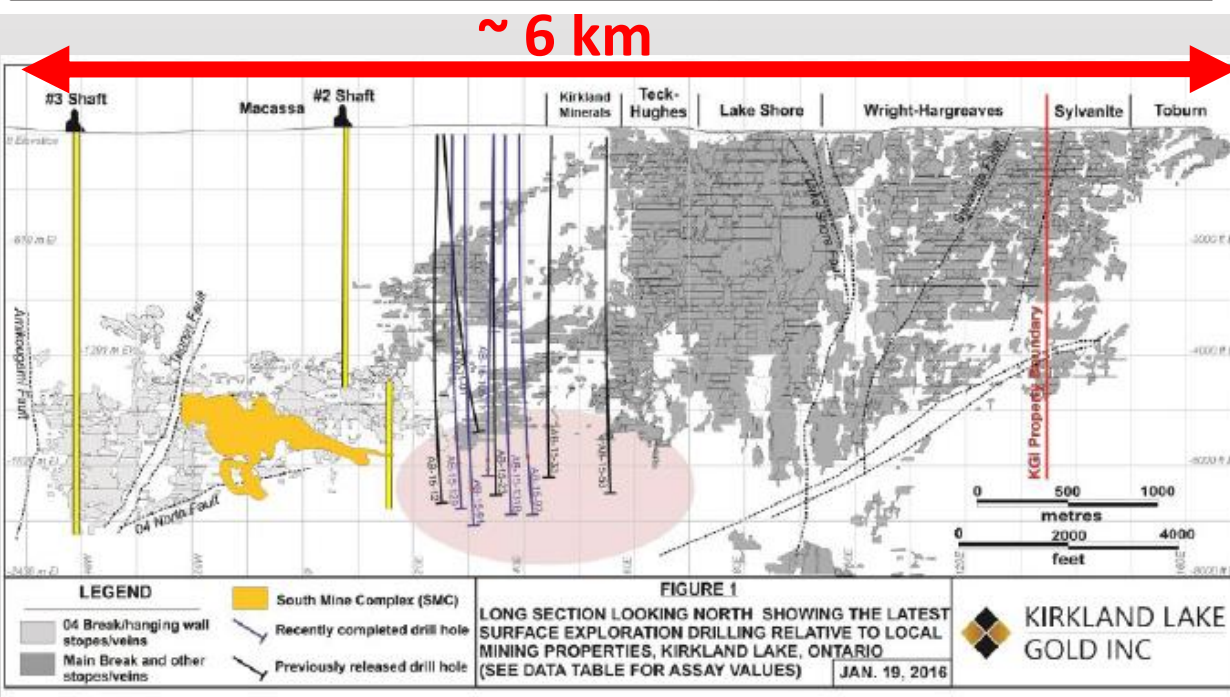
-D₃ crenulation folding overprints Au





Comparison of Hemlo and Kirkland Lake deposits

Hemlo ~23 M oz Au over 4 km strike length. The ore zone strikes W & plunges steeply W, changes to a WNW strike with a shallow western plunge in the east. Au occurs in broad shear zones associated with Mo, As, Sb, Hg, Ba & V (magmatic affinity?).



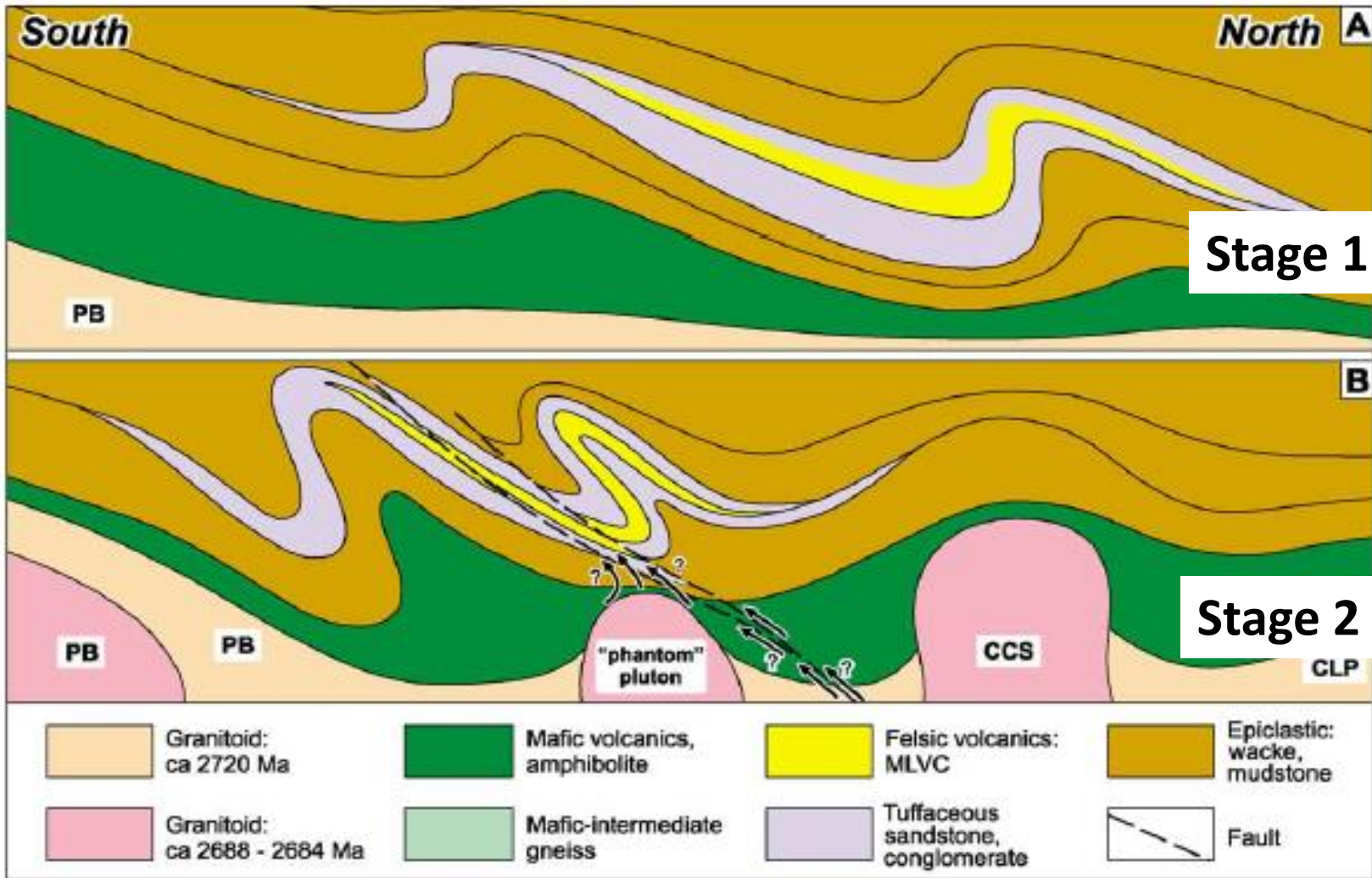
Kirkland Lake ~26 M oz Au over 6 km strike length. The ore zone strikes NE with shallow plunge to SW. Au occurs as narrow qz-cb veins in brittle D4 faults. Au is associated with Te, Mo, & Pb, (magmatic affinity?)

Model for formation of the Hemlo Gold Deposit (Muir, 2002)

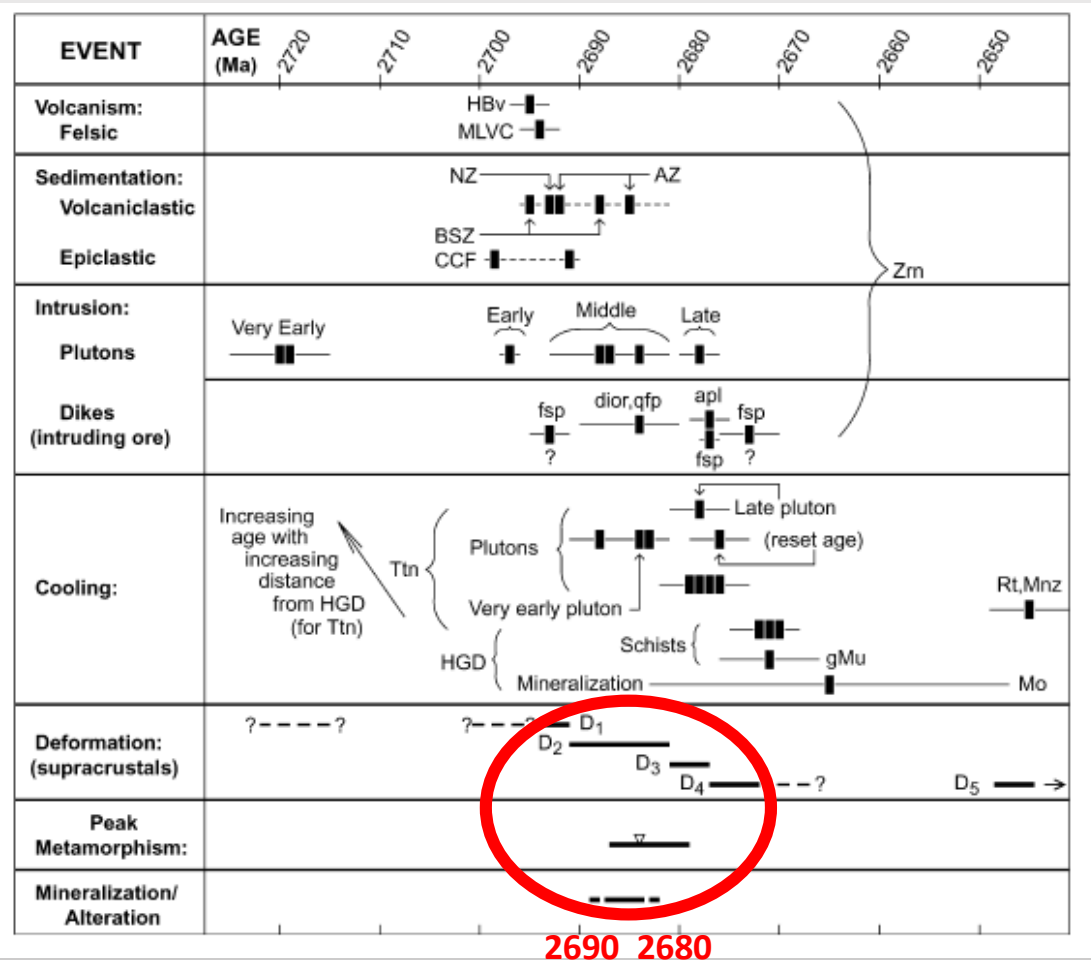
- D₁: N-S compression & south verging thrusting resulting in deposition of 2695-2685 Ma clastics & felsic volcs.
- D₂: NE-SW transpression & sinistral deformation resulted in NE-NW jog & pathway for hydrothermal fluids & Au @ ~2680 Ma

Similarities of Hemlo Deposit to Northern Abitibi faults

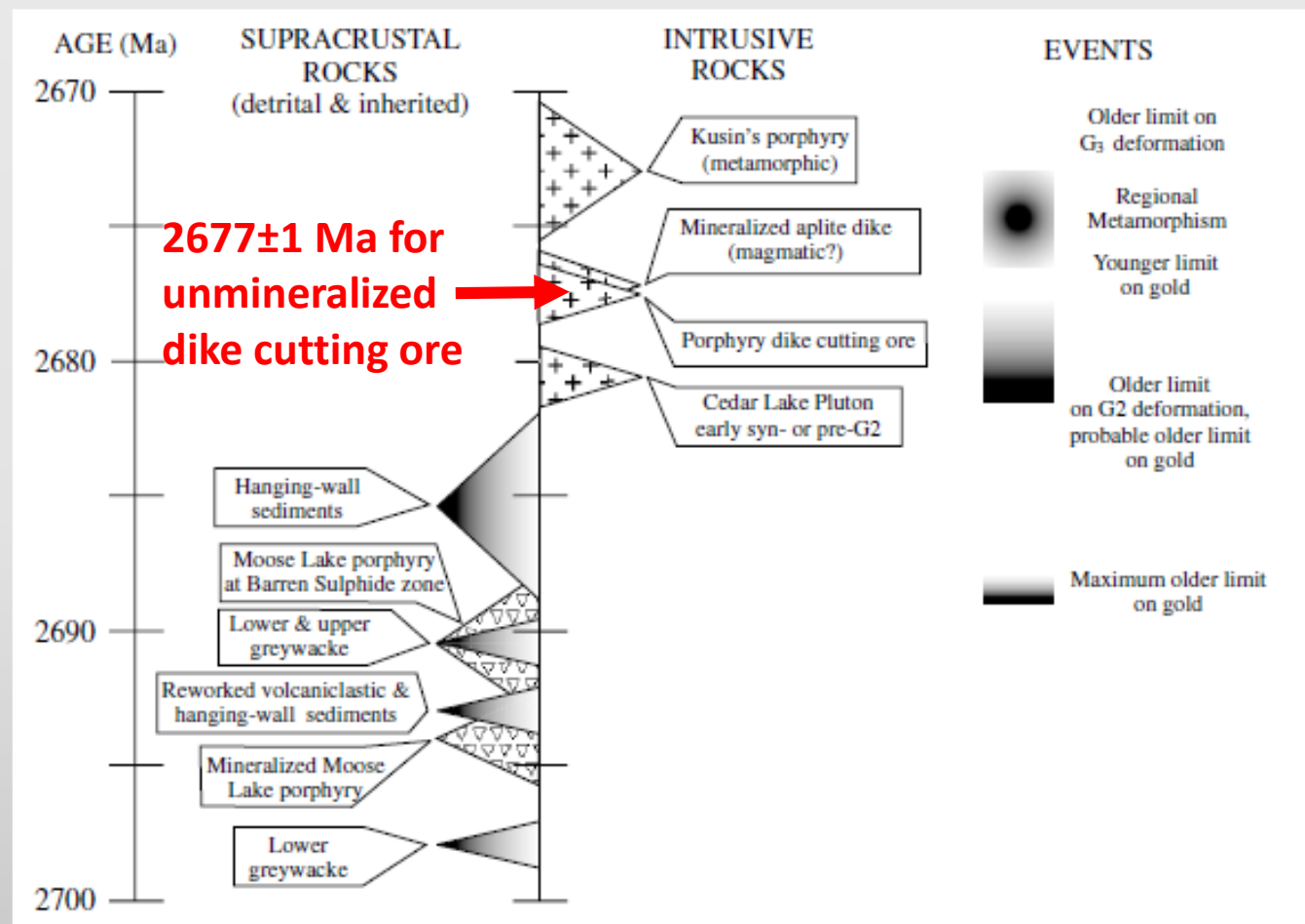
- South-verging thrusting
- Deposit associated with 2695-2685 Ma clastics & volcanics
- No evidence for Timiskaming assemblage rocks @2676-2670 Ma
- Age of main stage Au @ 2680 Ma is older than 2670-2665 Ma in S. Abitibi



Timing of Hemlo Deformation and Gold

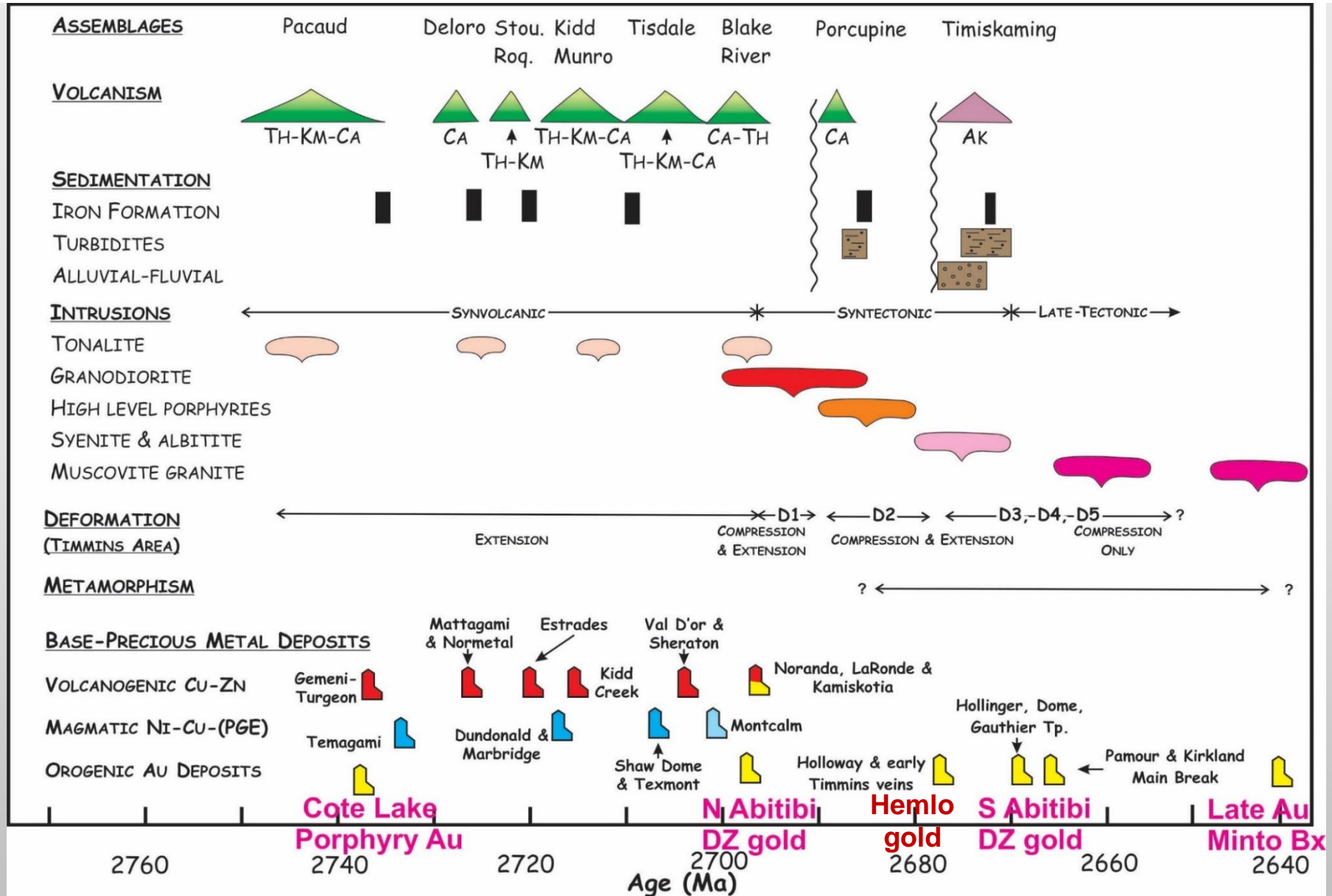


Gold is syn-D₂ & pre-D₃ @ 2690-2680 Ma & peak metamorphism is post-ore @ 2678-76 Ma. (Muir, 2002)

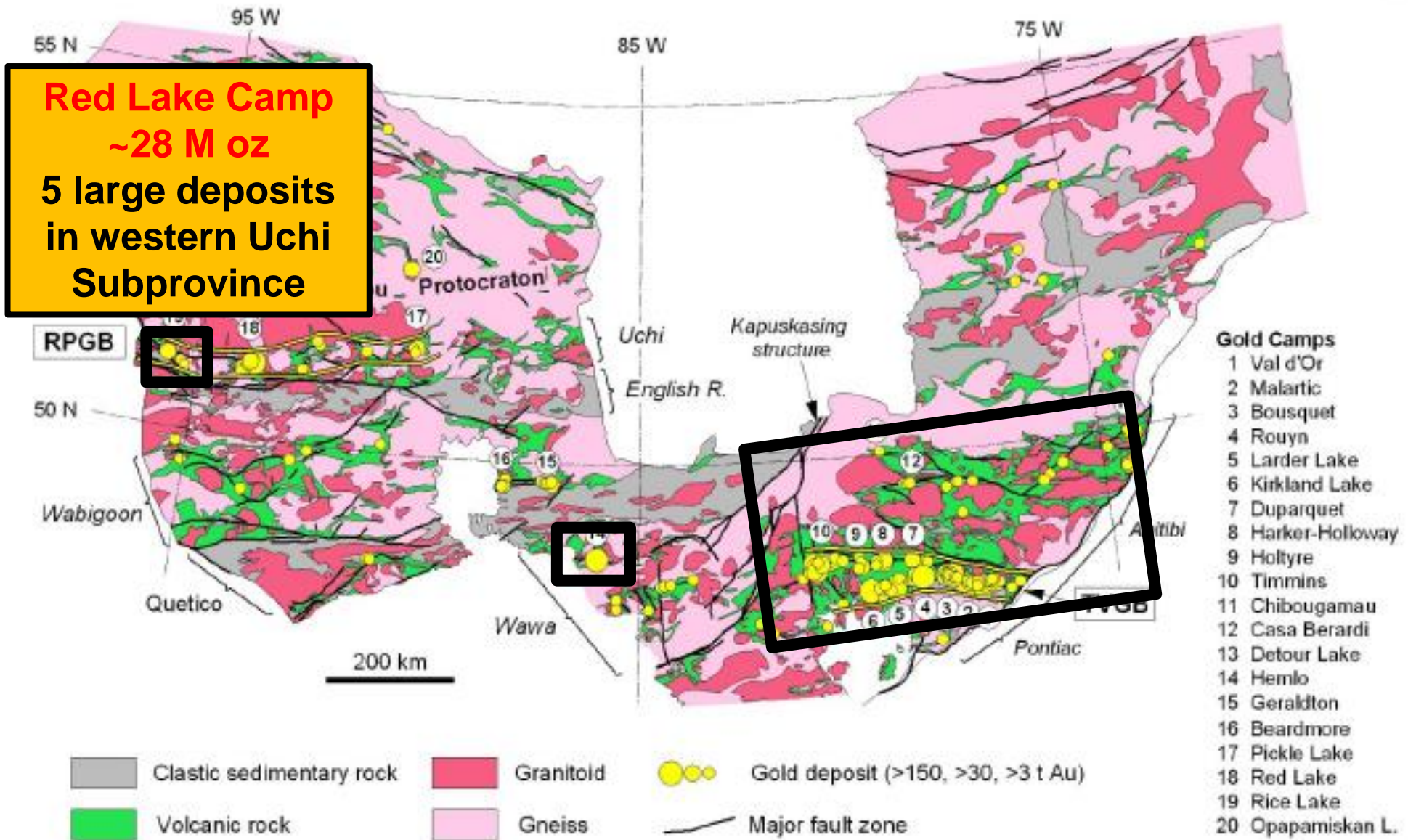


Gold is pre-D₂ & D₃ @ 2680-2677 Ma. Maximum age of Au @ 2677±1 Ma for barren dike cutting ore. (Davis and Lin, 2003)

The Timing of Abitibi-Wawa Events

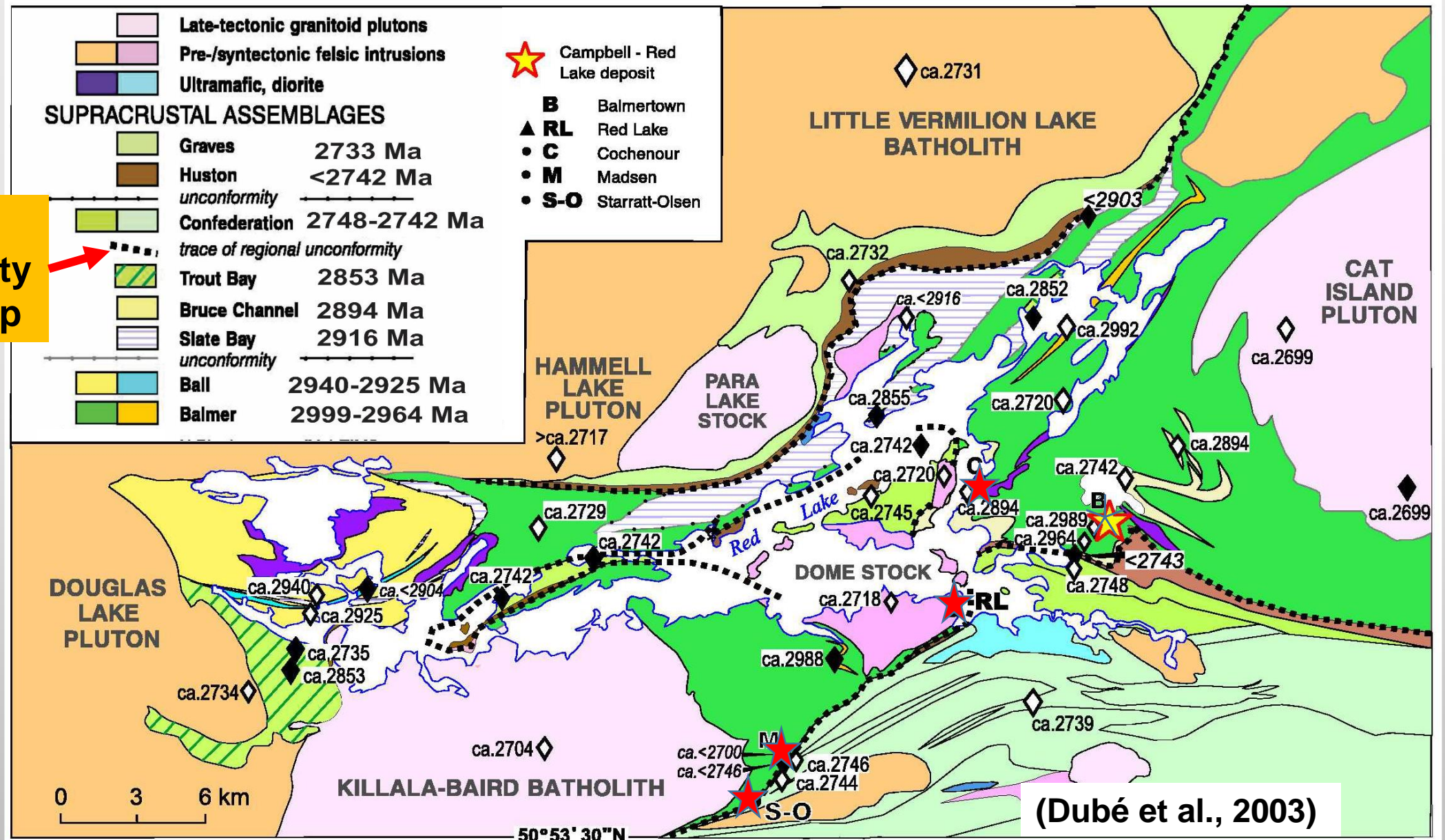


Superior Craton Gold Deposits

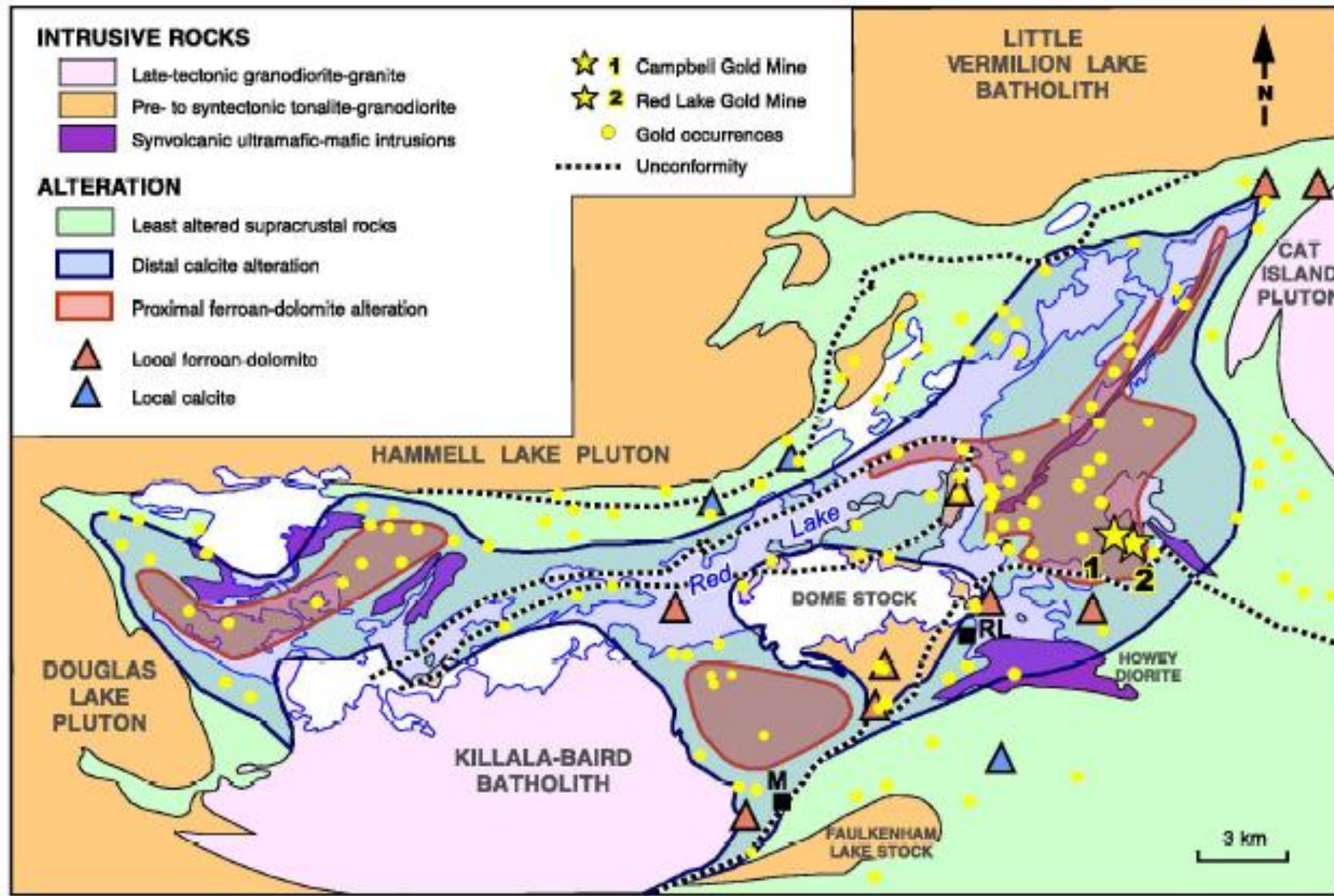


Geology and Stratigraphy of Red Lake Belt

Regional Unconformity
~100 Ma gap



Red Lake Alteration & Gold Deposits Map

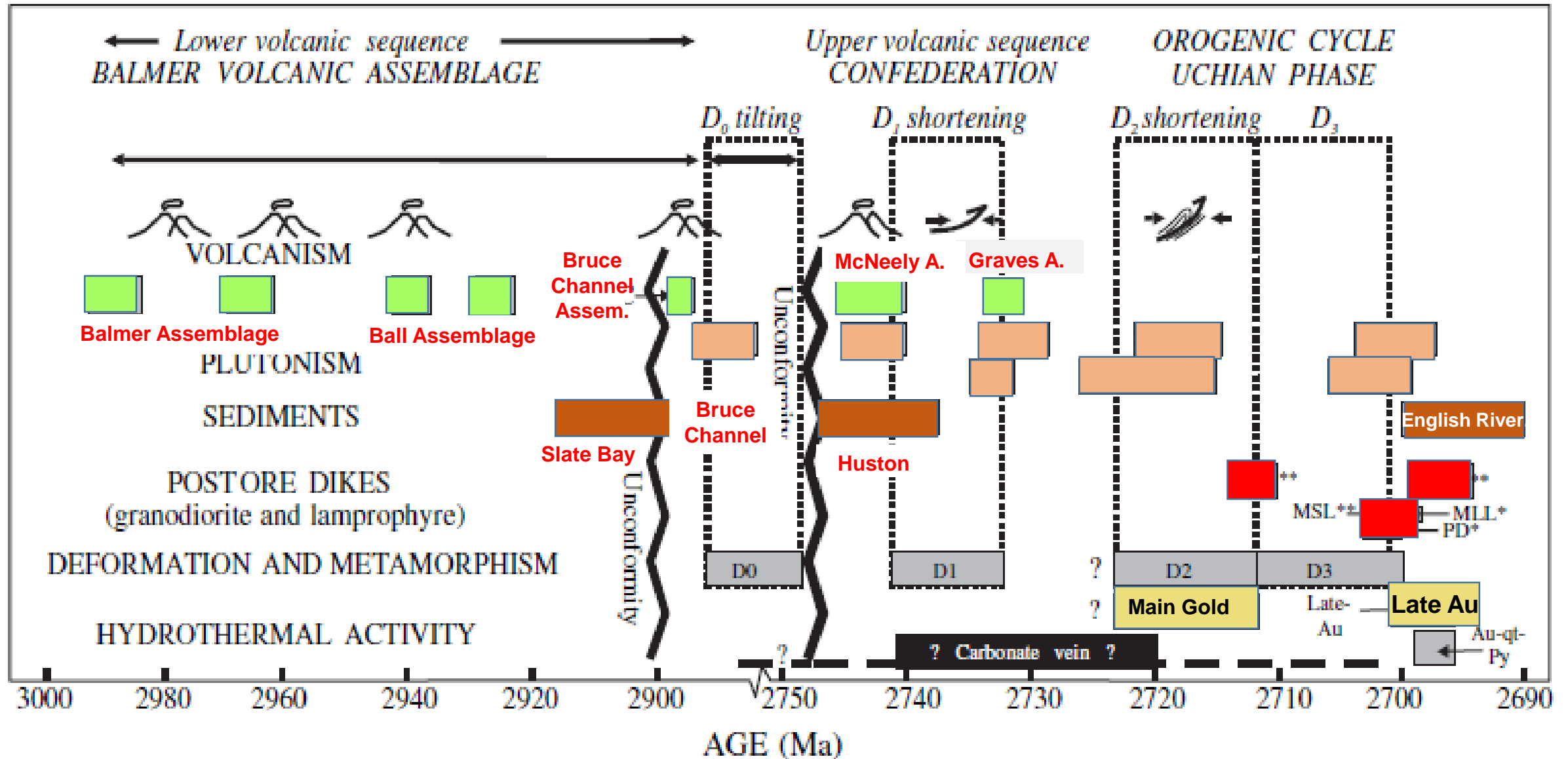


Hydrothermal alteration envelopes with spatial relationship to Au:

- 1) Distal alteration of widespread calcite, weak potassic & chloritization
- 2) Proximal alteration of ferroan-dolomite, strong potassic alteration

95% of the Au deposits are within ½ km of the regional Mesoarchean-Neoproterozoic unconformity, within the proximal alteration envelopes

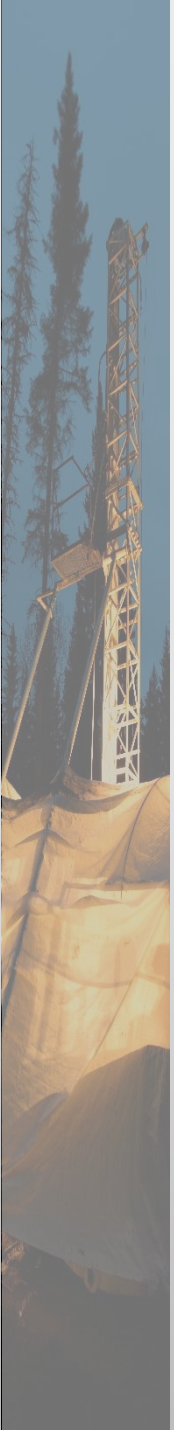
Timing of Events and Gold in the Red Lake Greenstone Belt (Dube et al., 2003)



Summary & Recommendations

Southern Superior, (Abitibi-Wawa)

- Orogenic Au deposited from hydrothermal fluids, localized within the regional faults (eg. Detour, Kerr, Hemlo) & 2nd order splay faults (eg. Dome, Hollinger, Hoyle Pond, Kirkland)
- Faults in proximity to late, unconformable successor basins with turbidites, conglomerates, ± calc alkaline/alkaline volcanics & mantle-derived intrusions
- Focus on contacts between brittle, ductile & Fe-rich lithologies (seds/mafic/ultramafics/felsics, etc.) flexures in regional faults; (eg. Timmins, Hemlo, Larder Lake), proximal alteration facies (ankeritic & potassic)



Northern Superior (Red Lake Area)

- Regional faults are less important. Focus on unconformities, conglomerates, proximal alteration facies (ankeritic & potassic) and transitions between greenschist & amphibolite metamorphic facies

Porphyry Au-Cu-Mo

- Archean Porphyry Au-Cu-Mo in upper crustal intrusions (e.g. Côté, Triolus, Chibougamau) represent an underexplored target. Focus on high level diorite & tonalite intrusive complexes, breccias & sheeted veins.
- Synvolcanic upper crustal intrusions (e.g. Côté & Triolus ~2740 Ma; Chibougamau ~2715 Ma). They represent an underexplored target. Focus on high level diorite-tonalite complexes, breccias & sheeted veins.

Thank You



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