Mapping fertile fault systems in the Superior Craton

Ross Sherlock

CONGRÈS AEMQ
QMEA CONVENTION
XPLOR 2024

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–

https://xplor.aemq.org/

Ensemble, faisons progresser l'exploration minière.
Together, let's take mineral exploration to the next level.

METAL EARTH

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

CANADA FIRST RESEARCH EXCELLENCE FUND

Canada

LaurentianUniversity
UniversitéLaurentienne
HARQUAIL SCHOOL OF EARTH SCIENCES
ÉCOLE DES SCIENCES DE LA TERRE

MERC
Mineral Exploration Research Centre

Mineral Exploration Research Center (MERC)

- **MERC is a collaborative center for mineral exploration research and education supported by industry, government and Laurentian University**

- Focused on field-based collaborative research on Exploration and Precambrian Ore Systems
- More than 100 faculty, research scientists, and graduate students working across the globe
- Lead organization on Metal Earth project
- Membership in MERC provides a seat at the advisory board.
  Matt Rees, Chair; François Robert, Science Advisor

MERC Foundation Members

BARRICK

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

125 ANNIVERSARY Est. 1891
ONTARIO GEOLOGICAL SURVEY

Newmont

O3 Mining

- Foundation: 5 members
- Tier 1: 4 members
- Tier 2: 17 members

MERC Tier 1 Members

ALAMOS GOLD INC.

eldorado gold

Evolution MINING

IAMGOLD

KINROSS

MERC Tier 2 Members

Agnico Eagle
Equinox Gold
Exiro
GFG Resources
Gold Fields
IEP, International Explorers and Prospectors
KGHM

McEwen Mining
Melkior
Noble Mineral Exploration
SRK Consulting
Sudbury Integrated Nickel Operation (Glencore)
Transition Metals
Vale
Wesdome

Metal Earth

- **METAL EARTH** is a **MERC** led collaborative research project focused on metal endowment in the Precambrian shield
- Partners with UQAC, U Laval, U Ottawa, U Toronto and U Alberta
- **THE GOAL** is to improve the science for targeting and finding new orebodies
- Fully-funded seven-year +$150M applied R&D initiative.
- **Canada FIRST** Research Excellence Fund (CFREF) $49M, $5M from NOHFC, $1M private donation and cash + in kind from 22 private sector and government survey partners
- Project started in summer 2017 and will end in August 2027

Metal Earth Components

- **FUNDAMENTAL SCIENCE:**

  Transform our understanding of Earth's early evolution and the processes that govern differential metal endowment

  Improve the science for targeting and finding new orebodies

- **APPLIED INNOVATION AND COMMERCIALIZATION COMPONENT:**

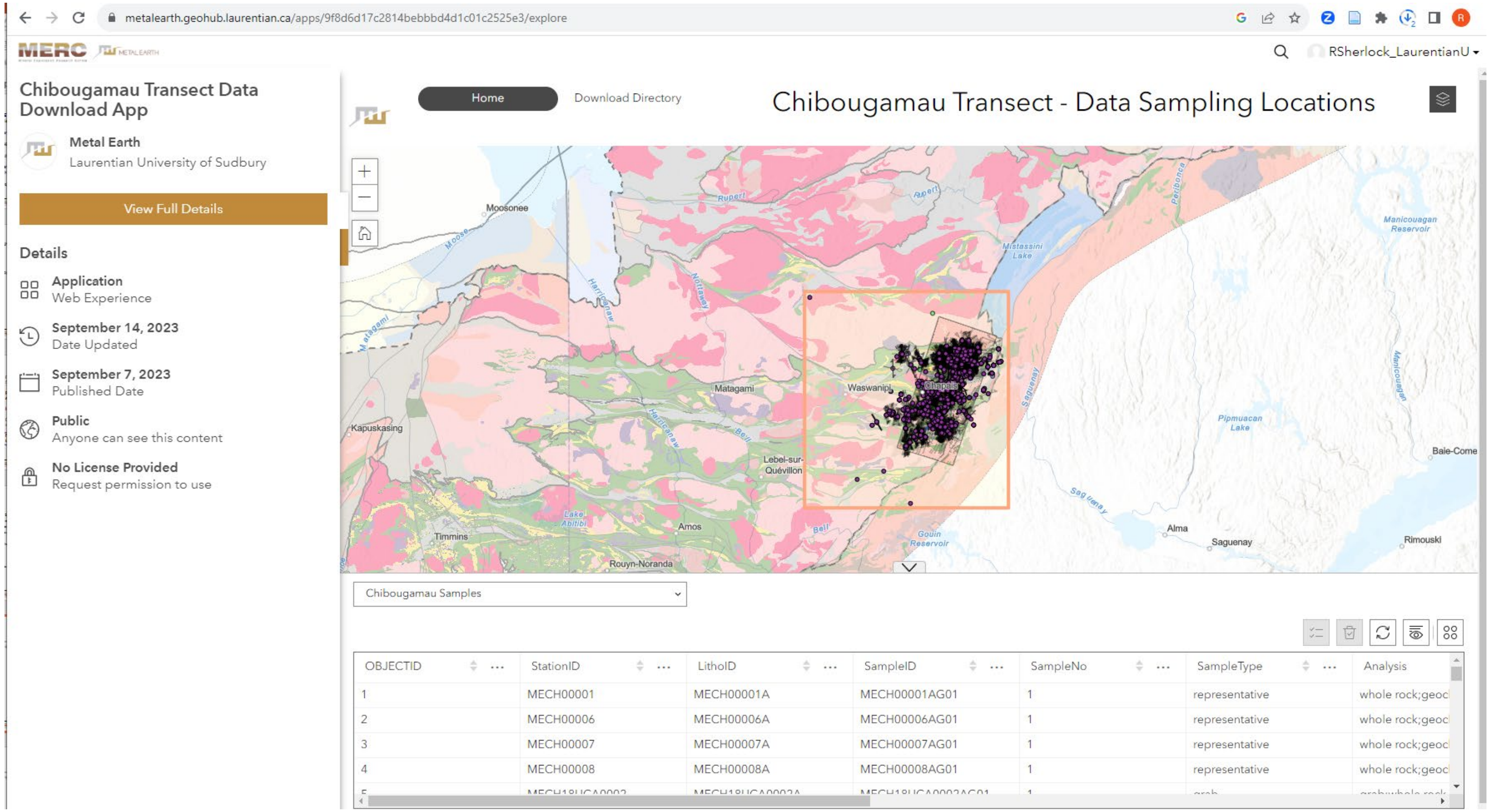
  Make Canada a global leader in mineral exploration research through open source delivery of new knowledge and the development of transformative technologies targeted at increasing exploration success

  Improve training of quality young geoscientists for the industry

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**
- Develop transformative 3D-4D data integration, analysis, and visualization tools that will aid discovery of new districts and new deposits
- **Focused on the Superior Craton as the level of framework geoscience is unprecedented, take this into other Precambrian terranes**

All Metal Earth Data online now



Geology
Geochemistry
Gravity
MT
Seismic

Geochron database (separate)

Open source

https://metalearth.geohub.laurentian.ca/

State of the Industry, why Metal Earth is needed

From Dan Wood's SEG newsletter

Value of discoveries less than the exploration investment

Unsustainable as an industry

Focus on Brownfields environments.

Greenfields discoveries are rare

Requires new search space to change

Deep

Covered

Remote

Needs new tools to be effective in these spaces

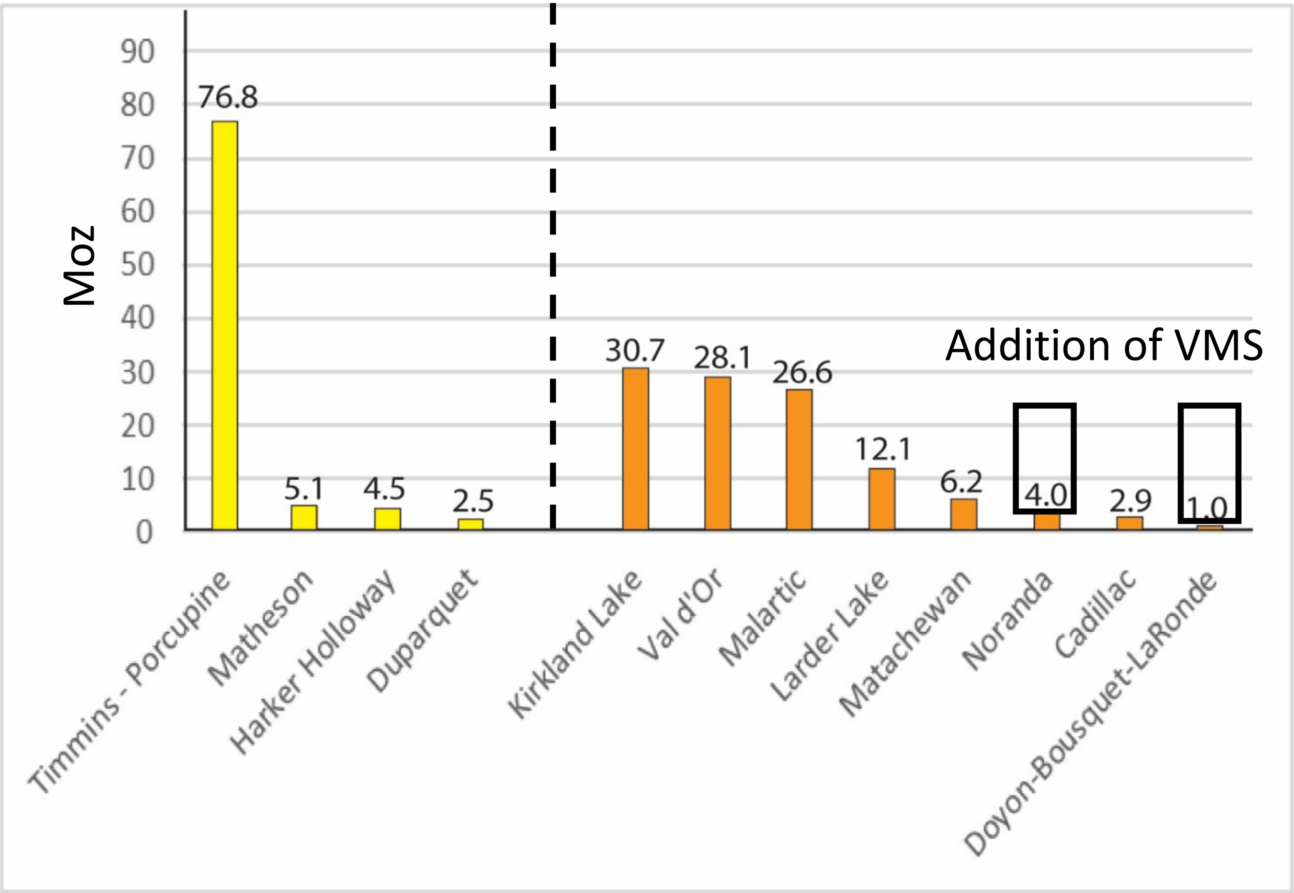
. . . from page 1 Transforming the Business of Gold Exploration: Adapting to Deeper Exploration (c

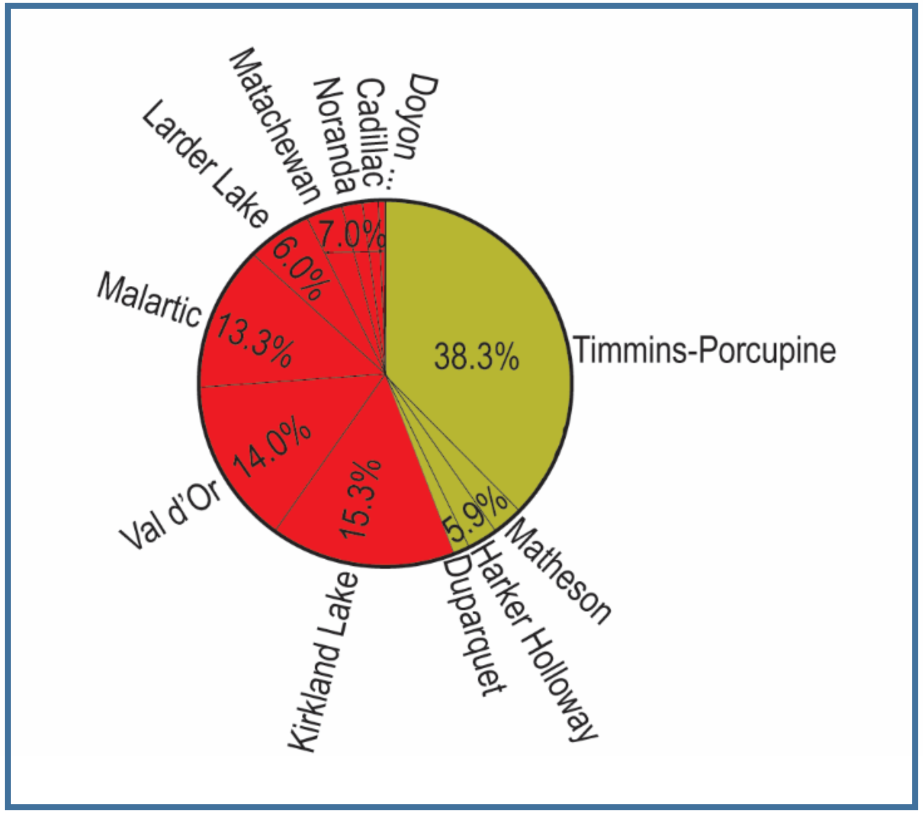
Commodity	Exploration Spend (2016 $b)		No of Discoveries #		Tier 1+2 Discoveries		Estimated Value (2016 $b)		Value / Spend
Gold	$65	33%	320	37%	4 + 17	26%	$30	32%	0.46
Copper	$35	18%	102	12%	3 + 15	22%	$17	18%	0.47
Nickel	$7	4%	34	4%	0 + 4	5%	$3	4%	0.47
Zinc + Lead	$11	5%	30	3%	1 + 4	6%	$5	6%	0.50
Uranium	$10	5%	28	3%	1 + 7	10%	$6	7%	0.61
Diamonds	$6	3%	11	1%	0 + 1	1%	$1	1%	0.19
Iron Ore	$20	10%	143	16%	0 + 3	4%	$6	7%	0.33
Coal	$24	12%	64	7%	1 + 6	9%	$8	8%	0.33
Other	$21	11%	135	16%	2 + 12	17%	$16	17%	0.75
	-----	------	------	-------	------	-------	-------	-------	-------
TOTAL	$197	100%	867	100%	12 + 69	100%	$92	100%	0.47

FIGURE 2. Discovery performance by commodity, 2007 to 2016. Value of discoveries (US$ 2016) estimated as $2 billion, $500 million, $80 million, and $10 million for tiers 1, 2, and 3 and unassigned, respectively (excludes unreported discoveries). Value/Spend is the ratio of the value of all discoveries to the total cost of exploration (break even = 1.0). From Schodde (2017), used with

Gold Endowment

Destor Porcupine +89 Moz Cadillac-Larder Lake +112 Moz Au





Monecke et al., 2017 Reviews in Economic Geology, v. 19 pp 7-49

Gold Endowment

CLLdz

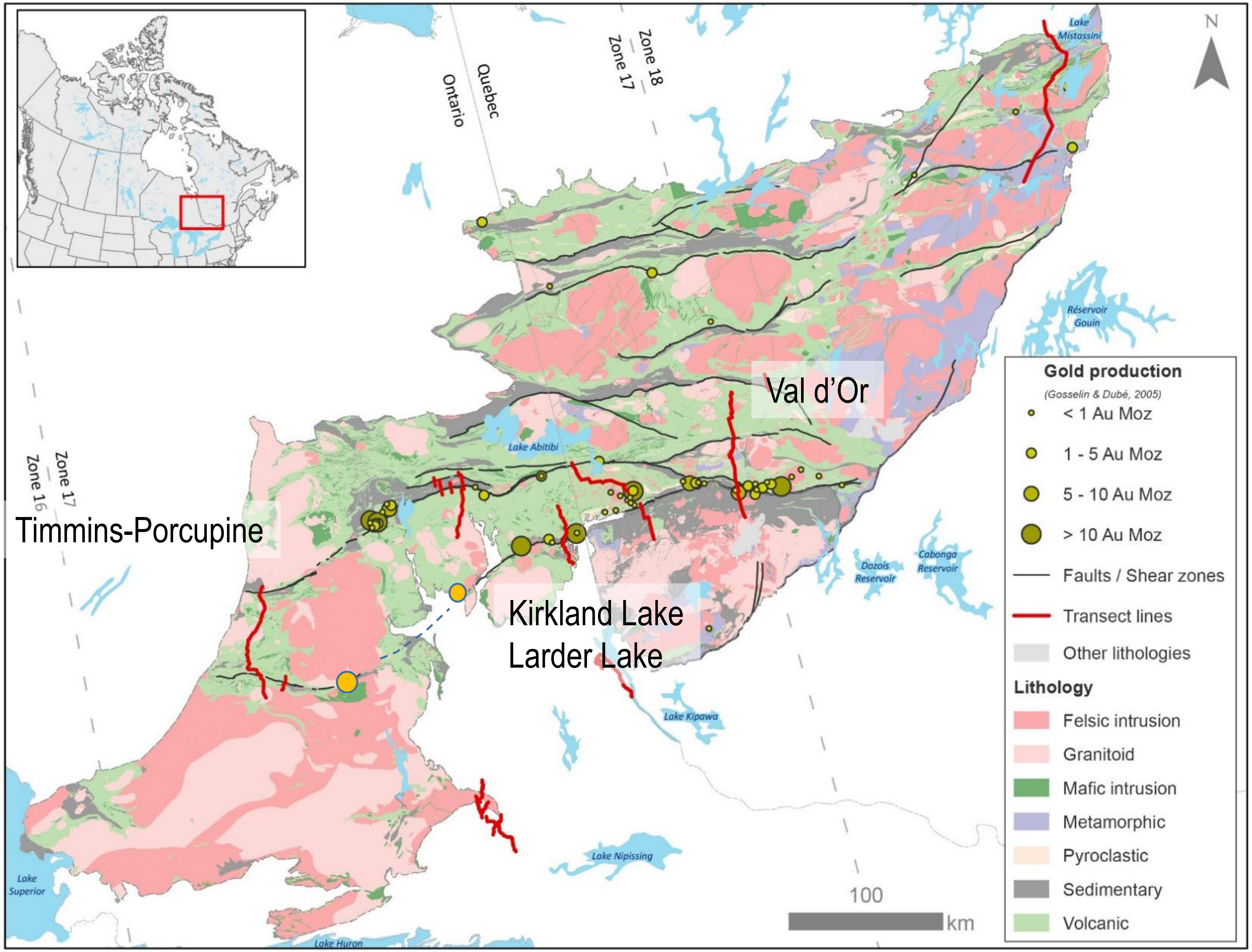
~80 Ma and 4 + events

Syn-intrusion; ca. ~2742Ma
    Cote Gold

Syn-volcanic; ca. ~2700Ma
    Blake River, Horne, LaRonde

Syn-Timiskaming; ca. ~2675 Ma
    U Beaver etc

Post-Timiskaming; ca. ~2660 Ma ?
    Kerr-Addison etc.

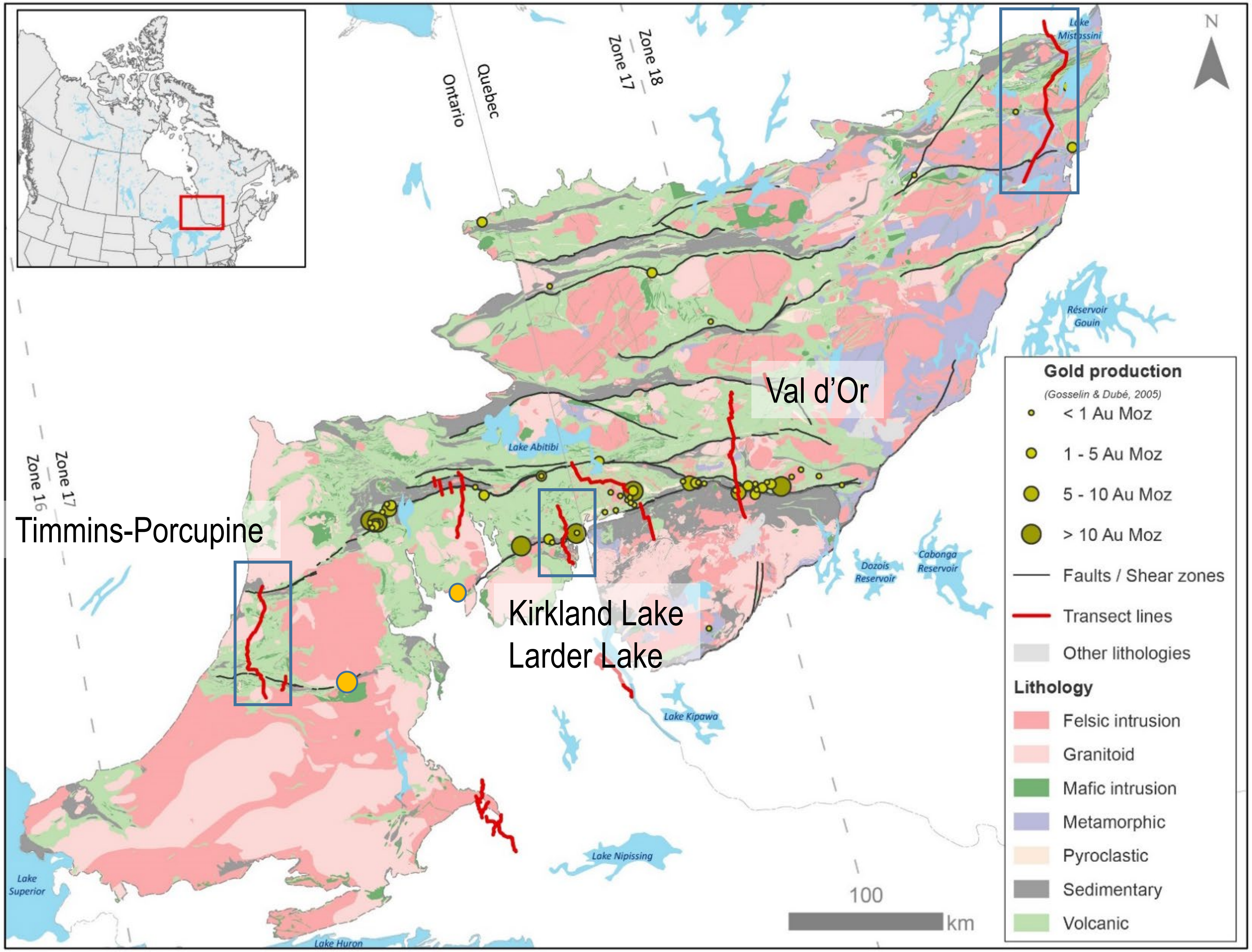


Gold Endowment

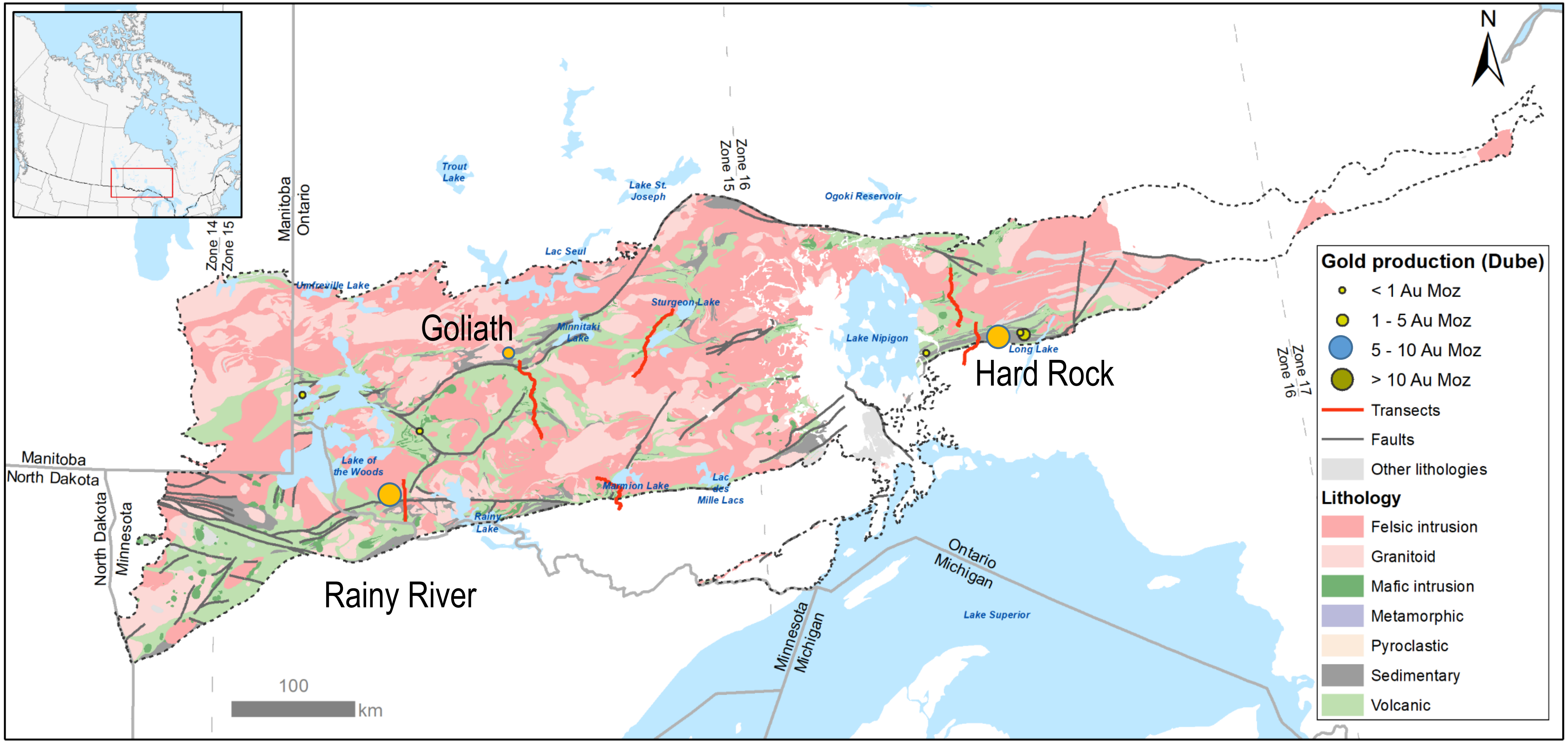
Abitibi Transects

Deposits aligned along the Destor Porcupine fault and the Cadillac Larder Lake

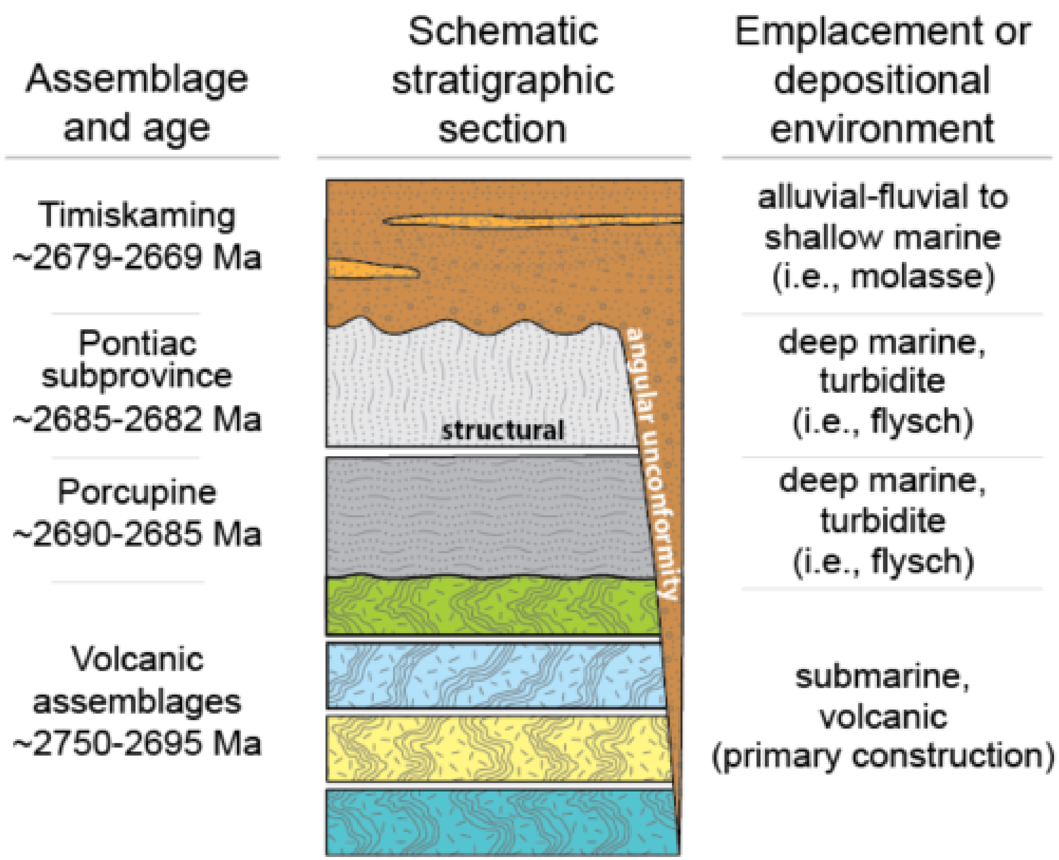
Drawing cross sections across ancestral faults/ volcanic and plutonic complexes of variable metal endowment



Waibigoon Transects

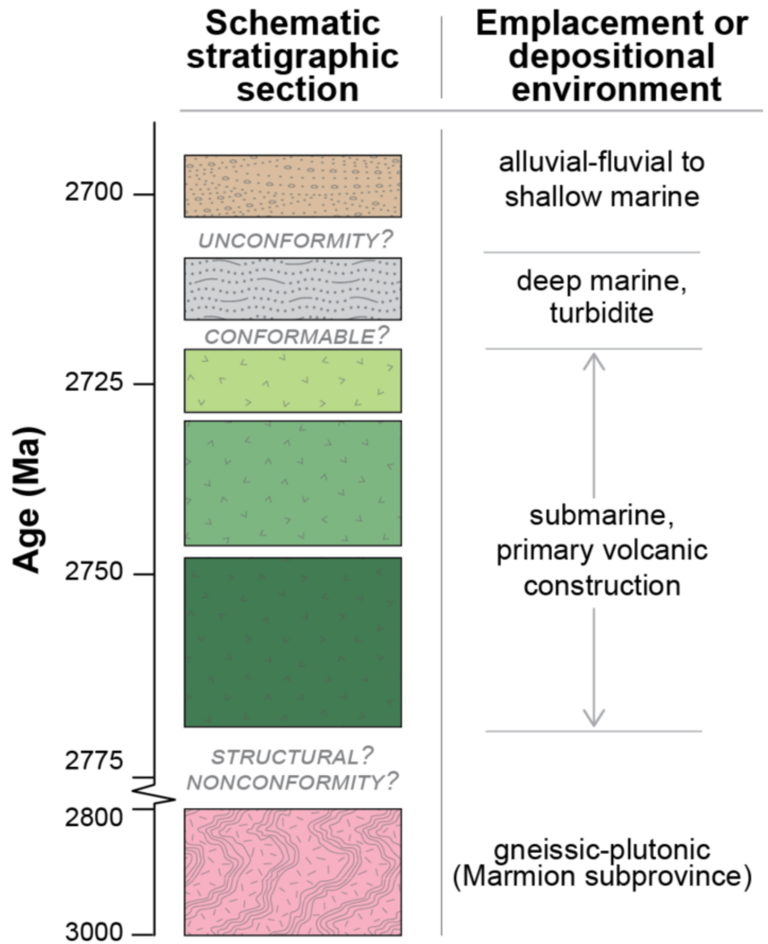


southern Abitibi subprovince



(Frieman, 2018; PhD thesis)

western Wabigoon subprovince



(Frieman, person. com)

STRATIGRAPHICALLY, THE ABITIBI = THE WABIGOON (+10-20 MA)

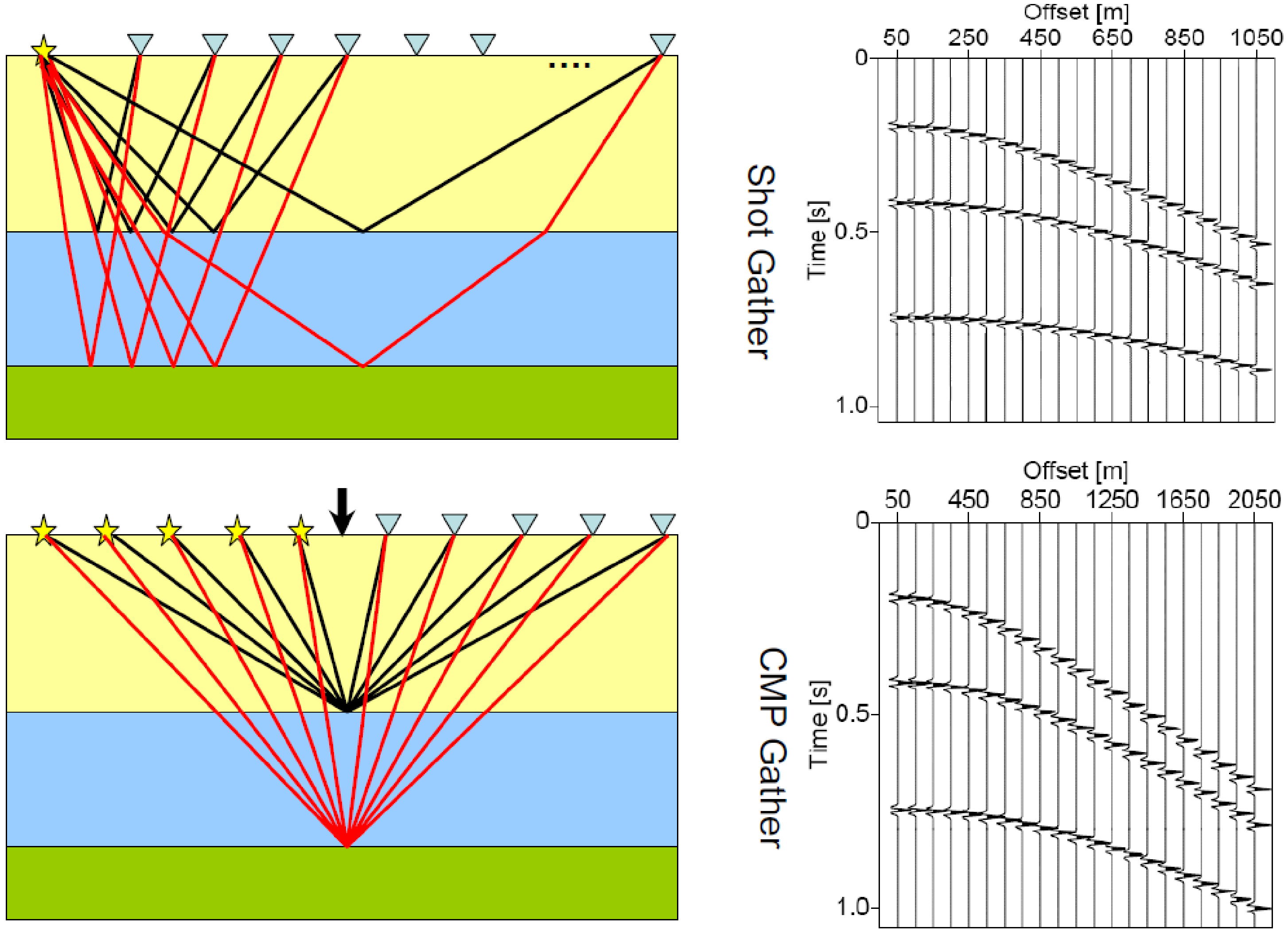
LIMITED GOLD ENDOWMENT IN THE WABIGOON

Reflection Seismic

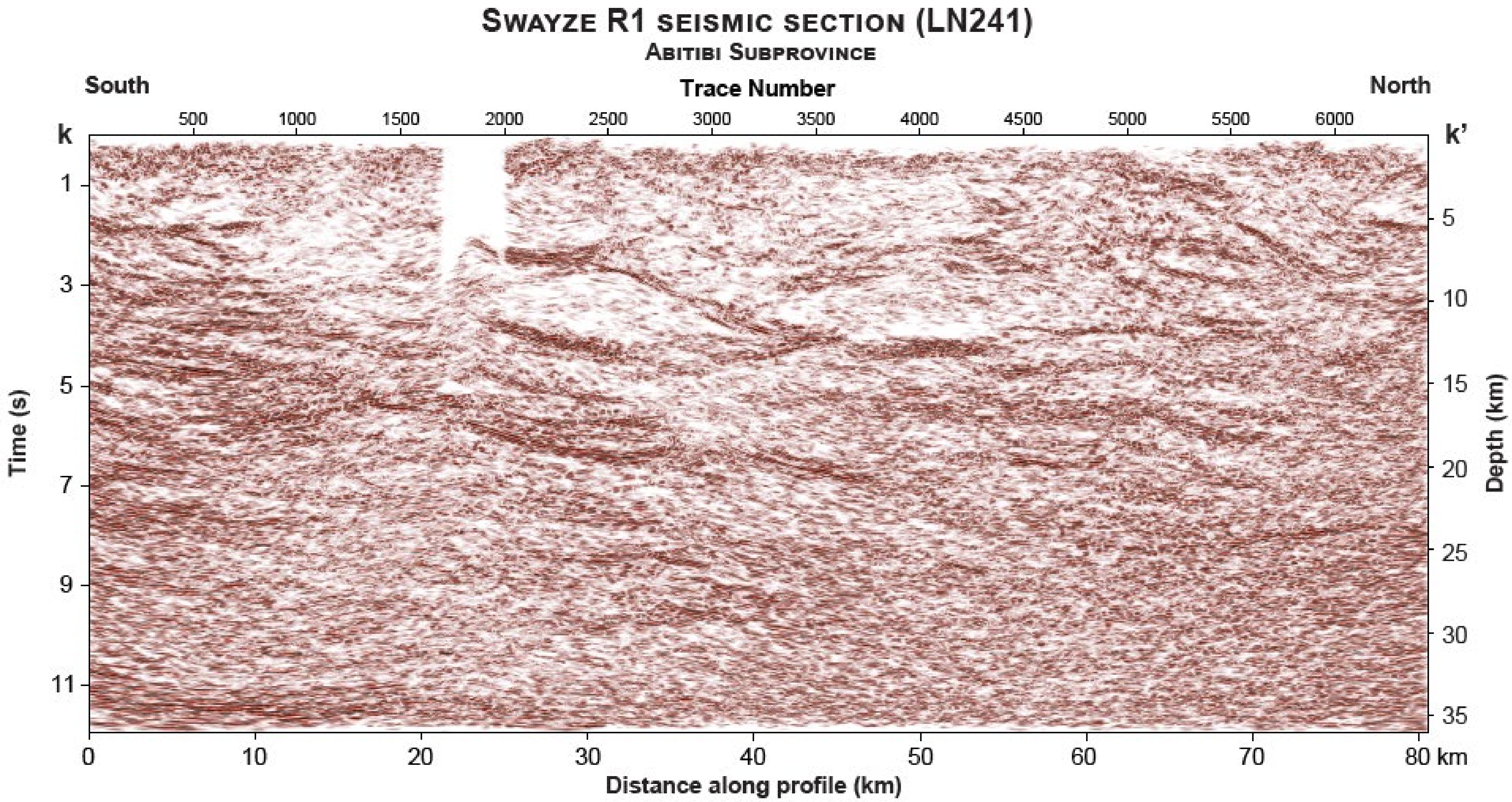
Km 4 of ~1,000 l/km seismic survey

Metal Earth transect work
Geology/geochem/geochron
Seismic
MT
Gravity

Reflection Seismic



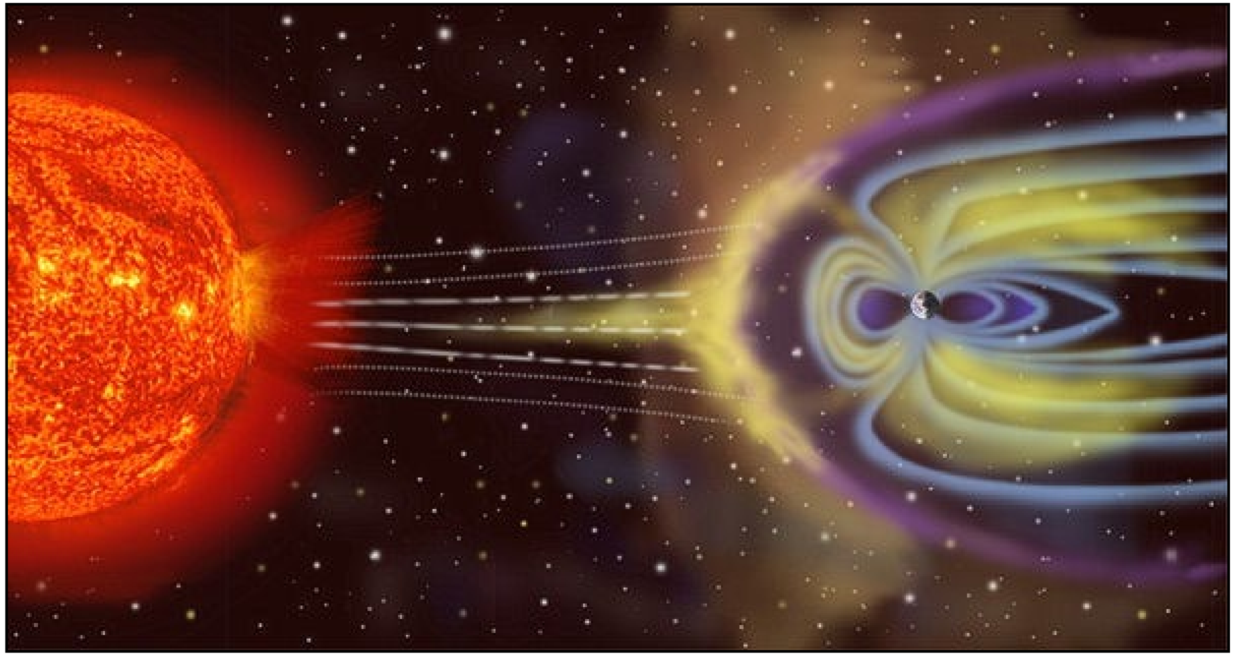
Reflection Seismic



Magnetotellurics (MT-AMT)

Source of Natural Electromagnetic Fields

- Complex interaction between solar plasma (wind) and Earth's magnetosphere
- Long period (< 1 Hz or > 1 s)

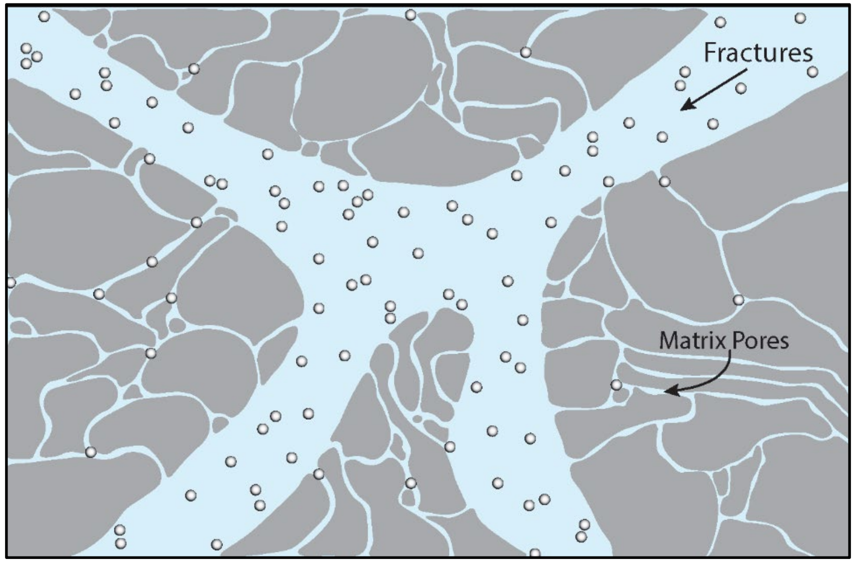


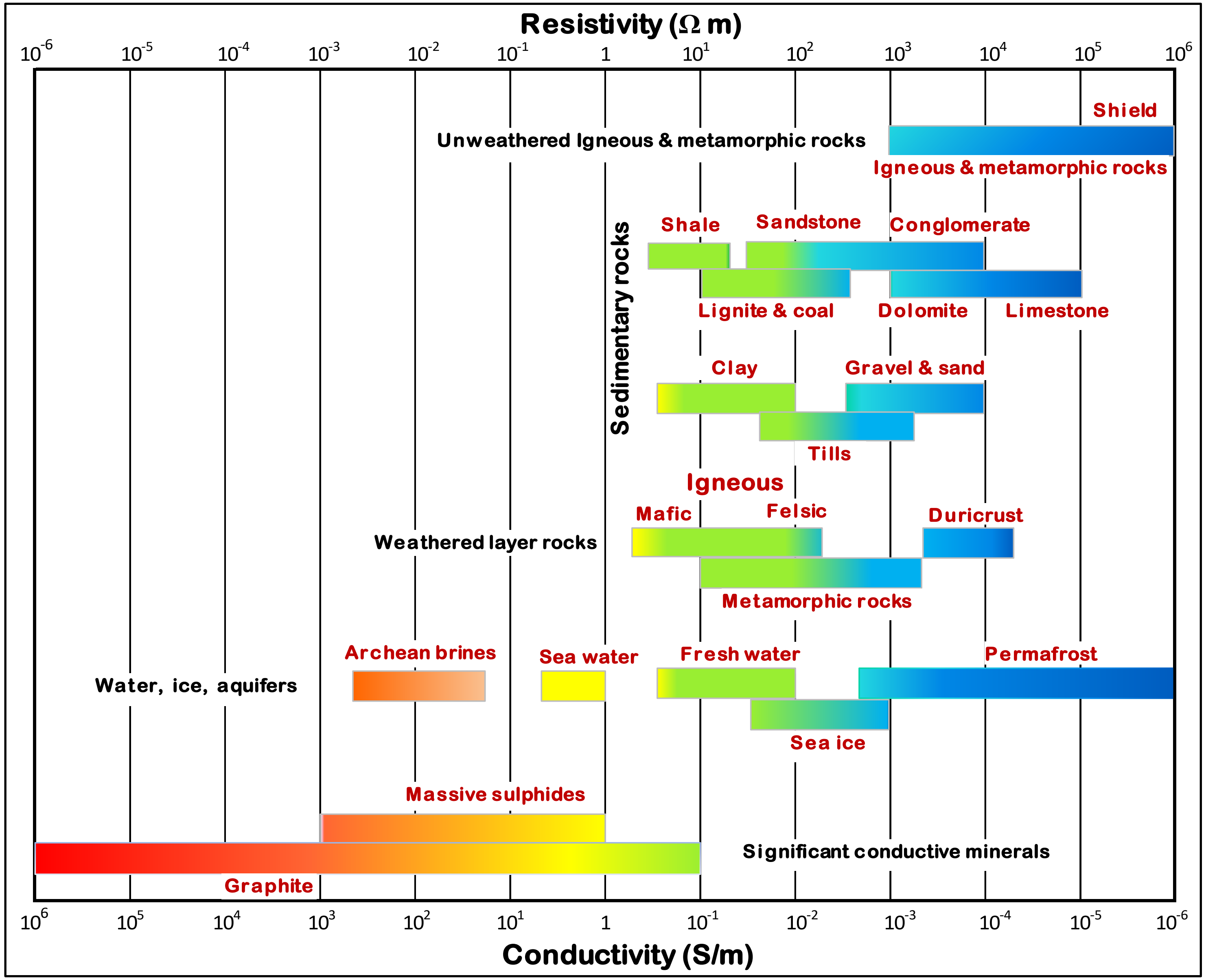
- Lightning
- Short Period (> 1 Hz or < 1 s)

Magnetotellurics (MT-AMT)

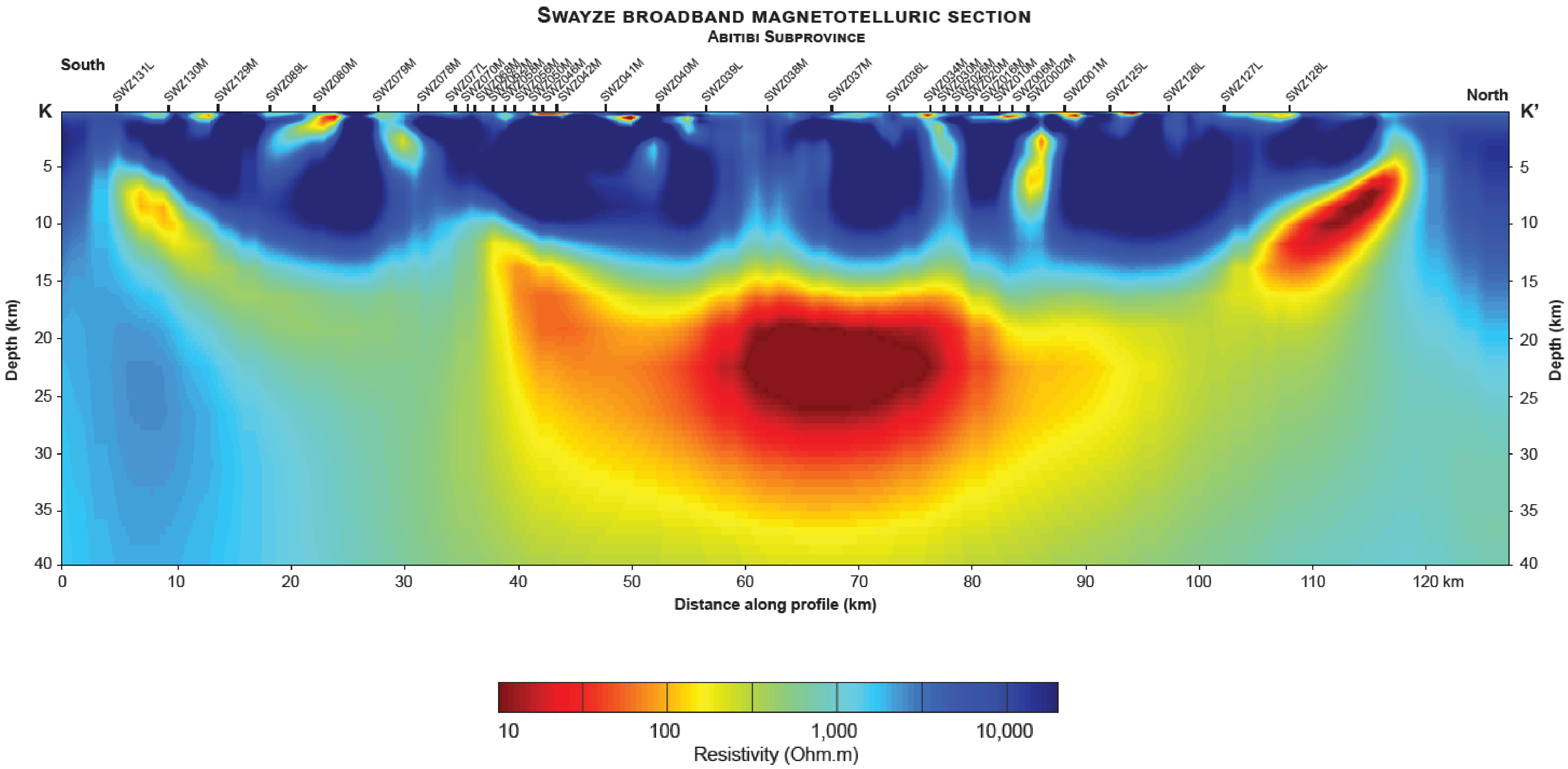
High conductivity (low resistivity) can be caused by large scale interconnected networks of:

- Fluids
- Ores
- Melts
- Graphite
- Sulphide

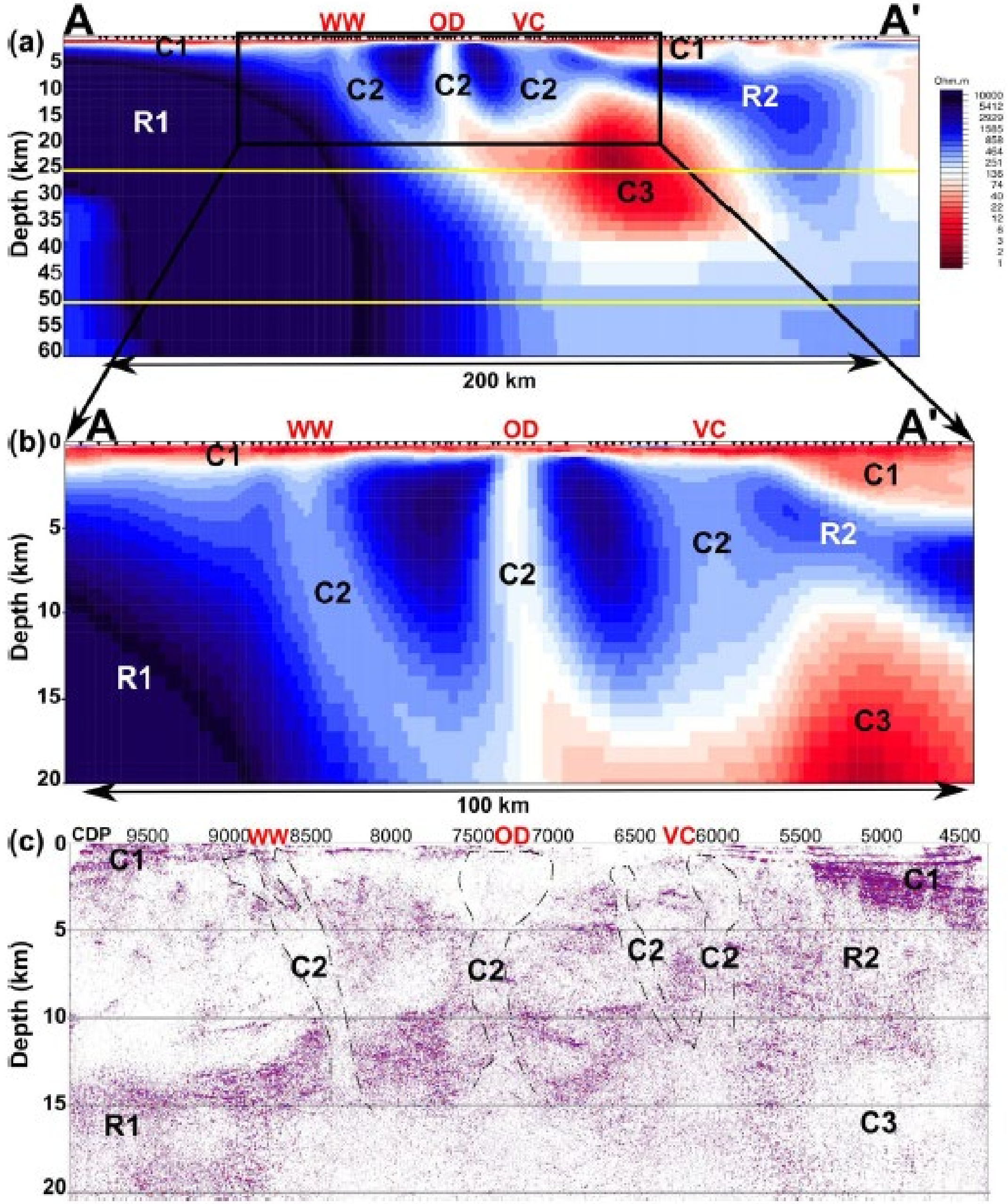




Magnetotellurics (MT-AMT) Resistivity Section



Other Systems



The least resistive zone is remarkably aligned with the world-class IOCG-U Olympic Dam deposit and the other two with significant known IOCG-U mineral occurrences.

These zones are spatially correlated with narrow regions of low seismic reflectivity in the upper crust, and the deeper lower-crust conductor is almost seismically transparent.

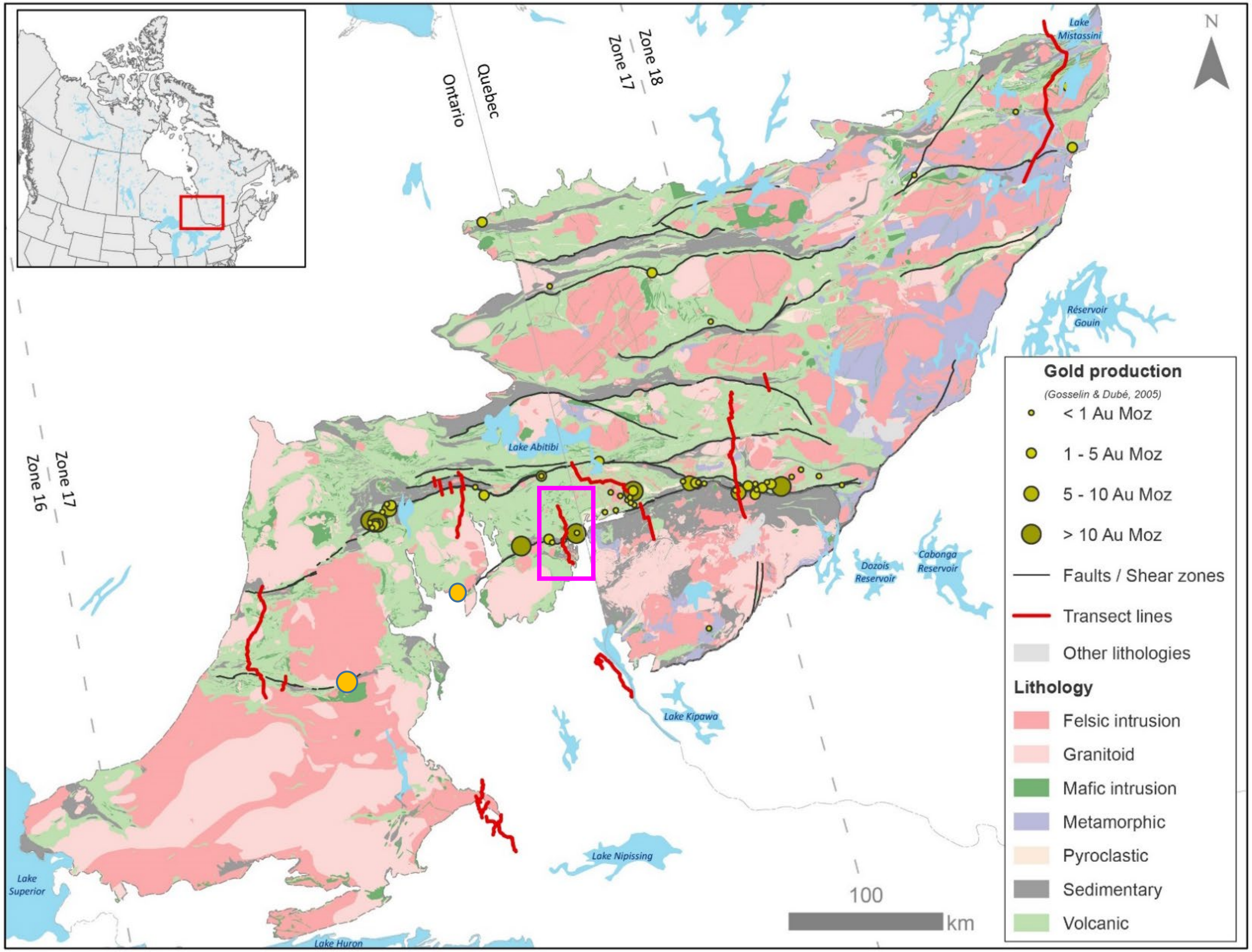
We argue this whole-of-crust imaging encapsulates deep mineral system and maps pathways of metalliferous fluids from crust and mantle sources to emplacement at discrete locations.

Graham Heinson , Yohannes Didana, Paul Soeffky, Stephan Thiel & Tom Wise. Nature Scientific REPORTS | *(2018) 8:10608* | DOI:10.1038/s41598-018-29016-2

Abitibi Transects
Larder Lake

Seismic
MT
Gravity Magnetics
Focused geoscience

Drawing cross sections across greenstone belts

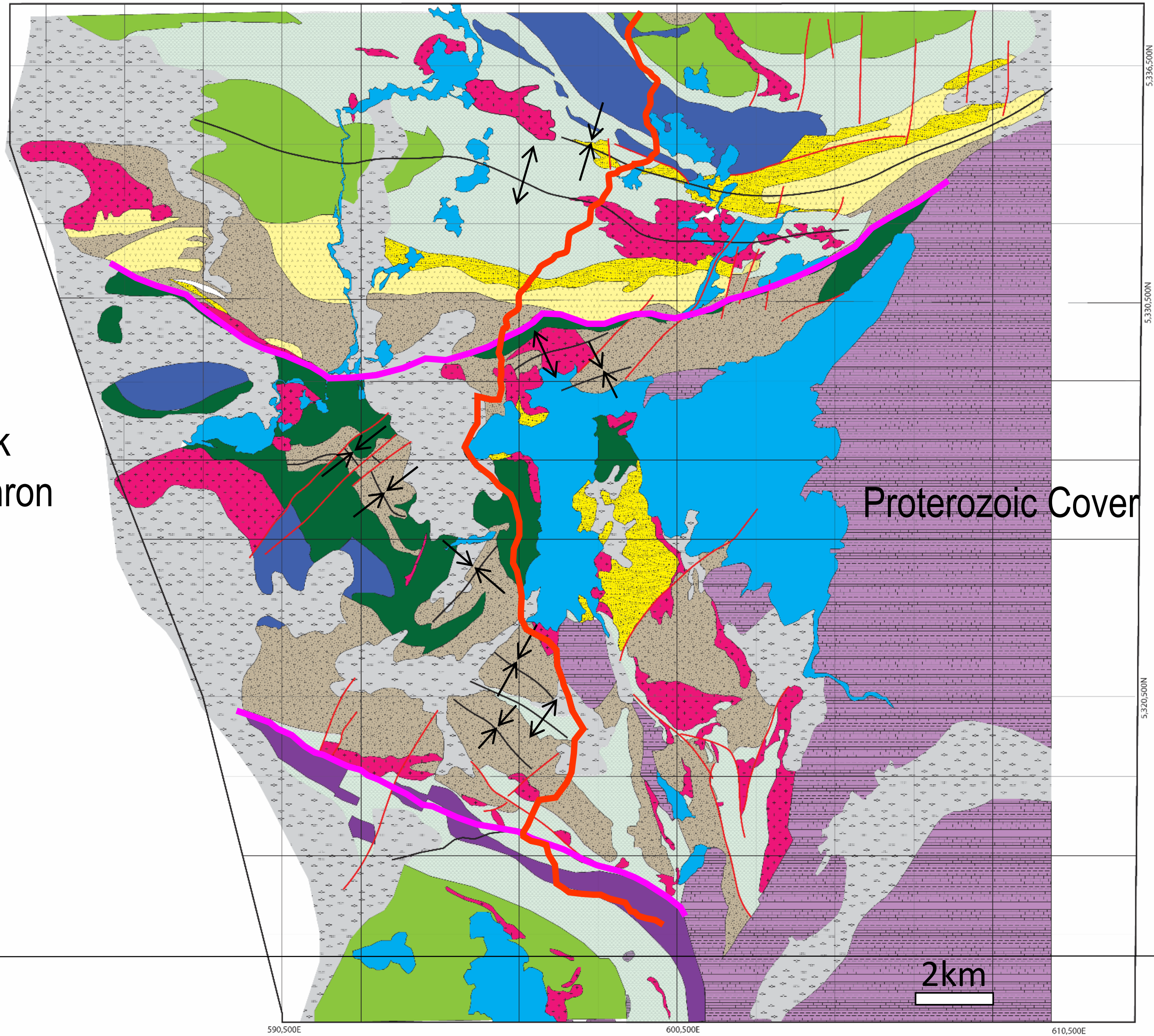


Larder Lake area

CLL deformation zone

Lincoln Nipissing fault

Metal Earth transect work
Geology/geochem/geochron
Seismic
MT
Gravity



From: Jackson, 1995, OGS Map 2628, 1:50,000

Larder Lake area, Mafic Volcanic Rocks

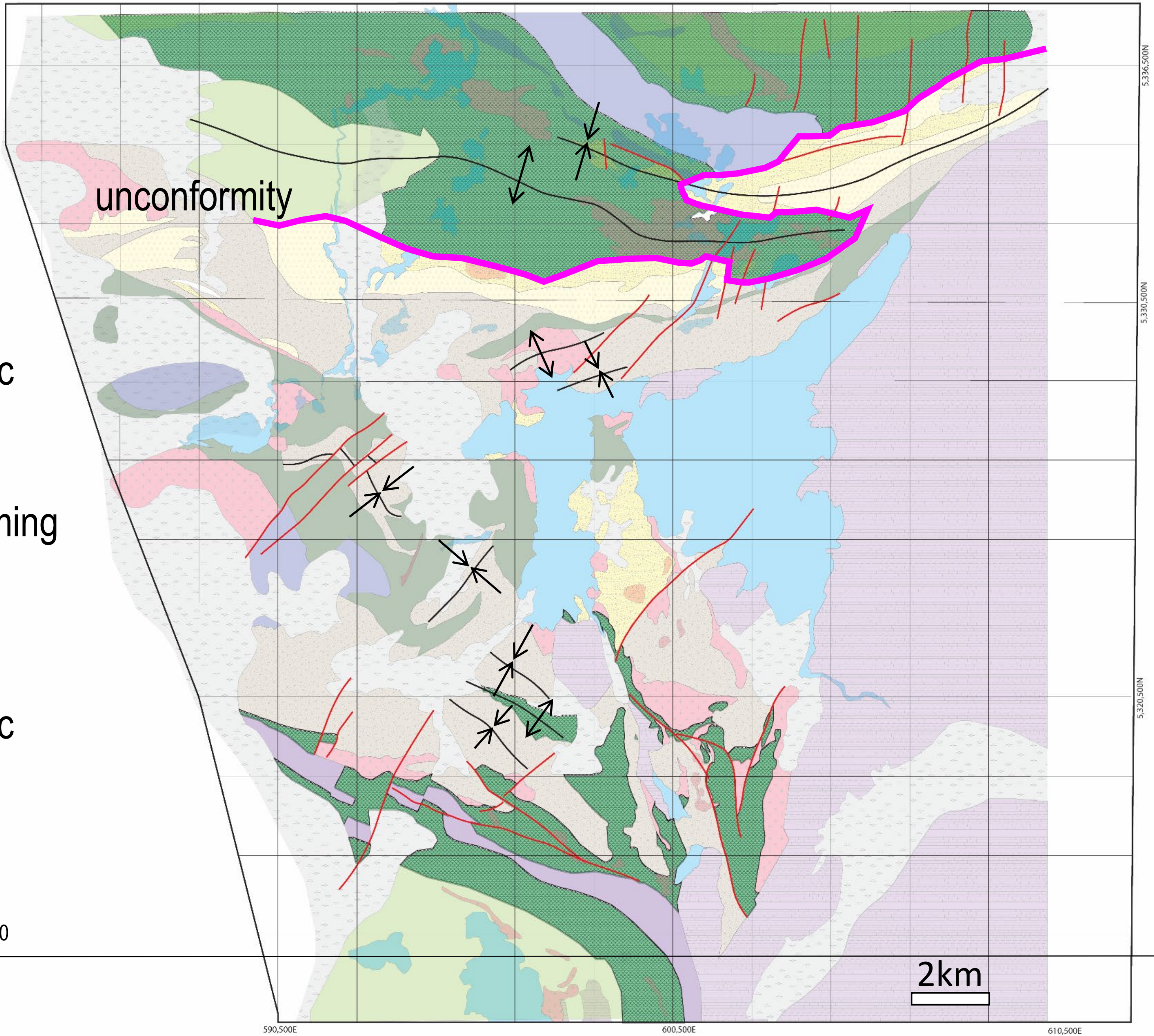
Lower Blake River Grp. (2704–2701 Ma)

Host to VMS deposits in Noranda

Dominantly mafic volcanic rocks

Unconformity at Timiskaming contact

Dominantly mafic volcanic rocks to south



From: Jackson, 1995, OGS Map 2628, 1:50,000

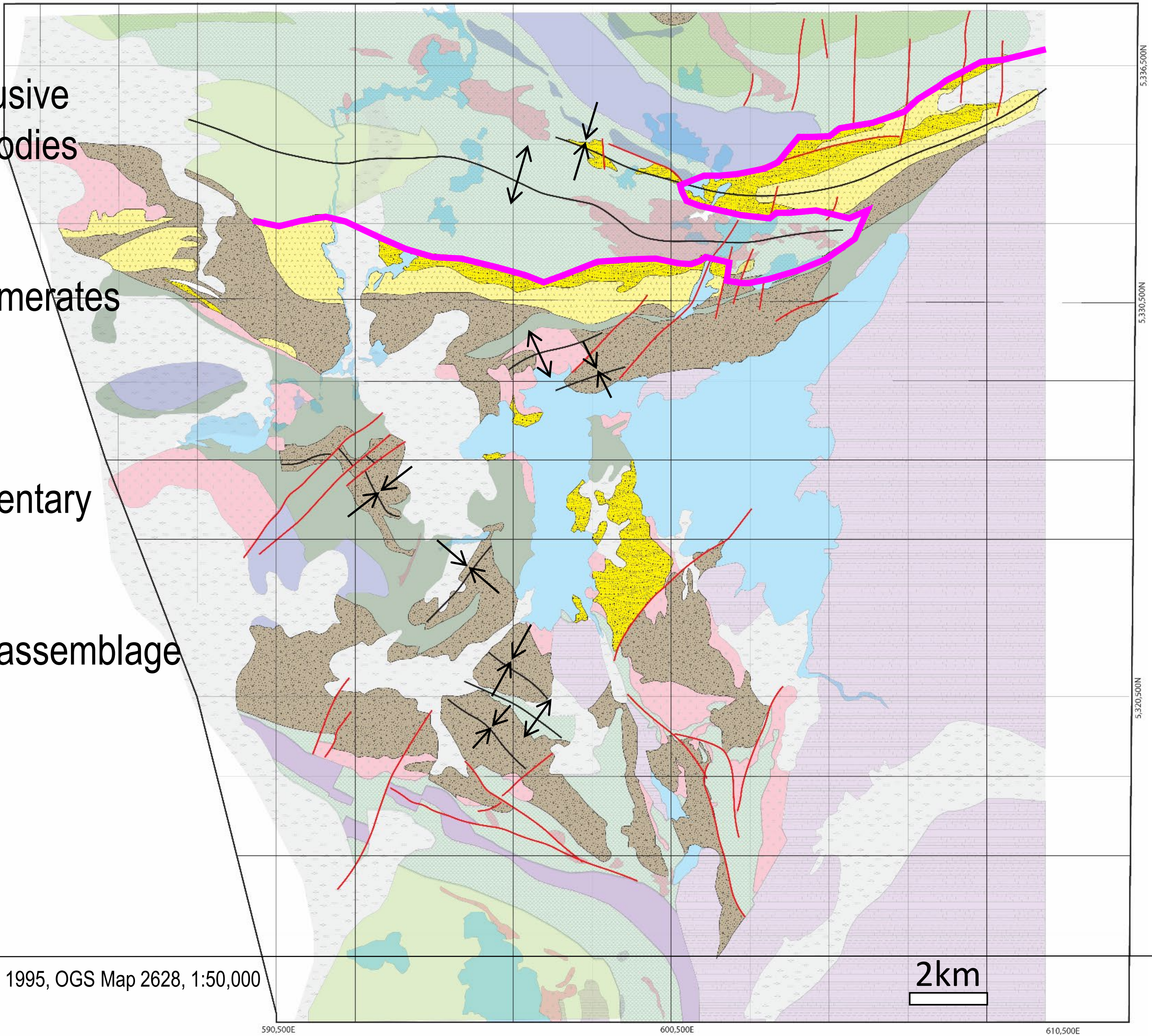
Larder Lake area, Timiskaming Sedimentary and Volcanic rocks and other clastics

Light yellow
Alkalic volcanic rocks extrusive equivalent of the syenite bodies

Dark Yellow, alluvial-fluvial sedimentary rocks, conglomerates and sandstones

Brown
In part Timiskaming sedimentary rocks, marine facies.

To south becomes Hearst assemblage



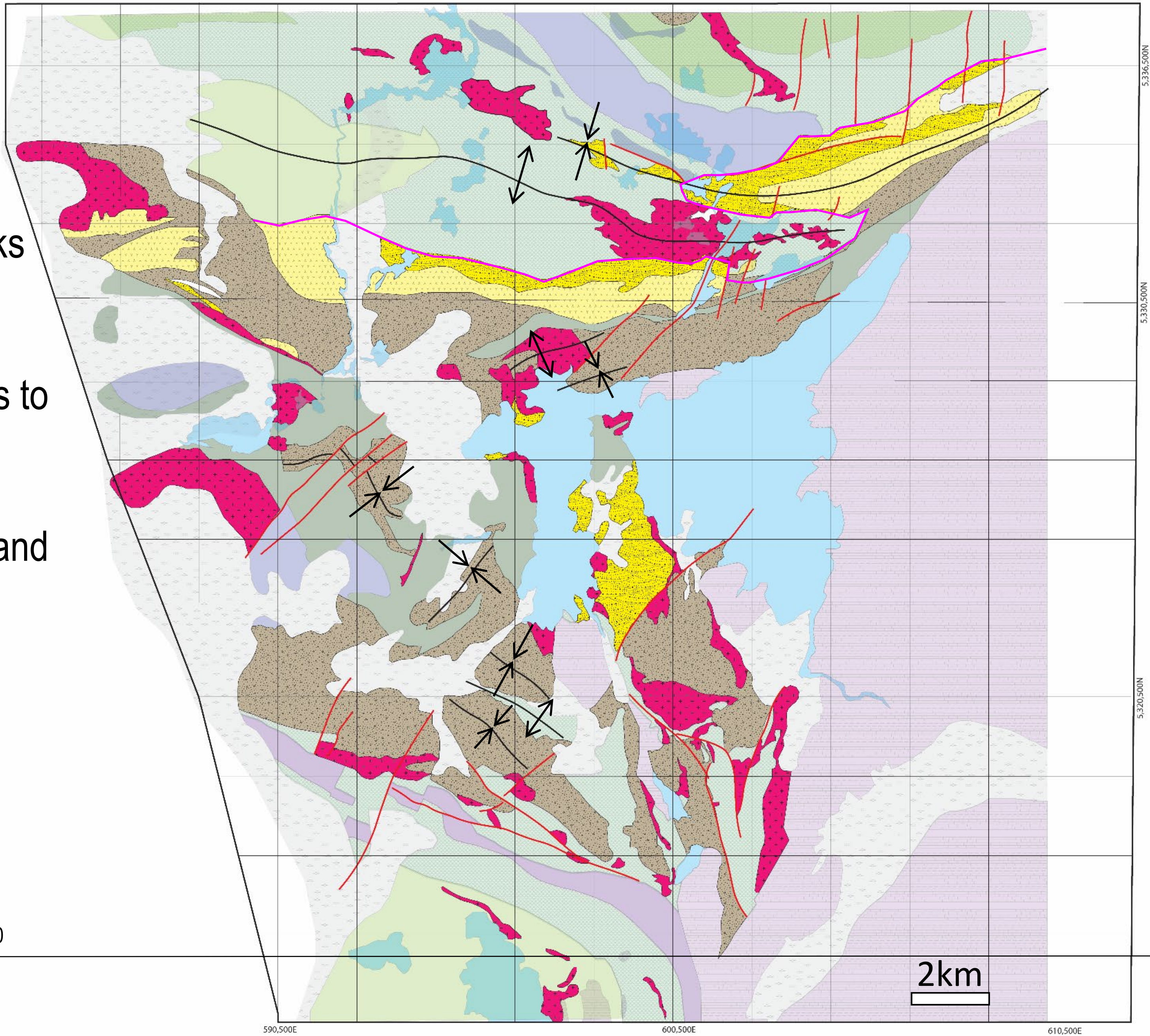
From: Jackson, 1995, OGS Map 2628, 1:50,000

Larder Lake area, Intrusive Rocks

Timiskaming intrusive rocks

Small volume intrusions, variable composition tends to be syenitic

Intrudes along structures and associated with clastic sedimentary rocks



From: Jackson, 1995, OGS Map 2628, 1:50,000

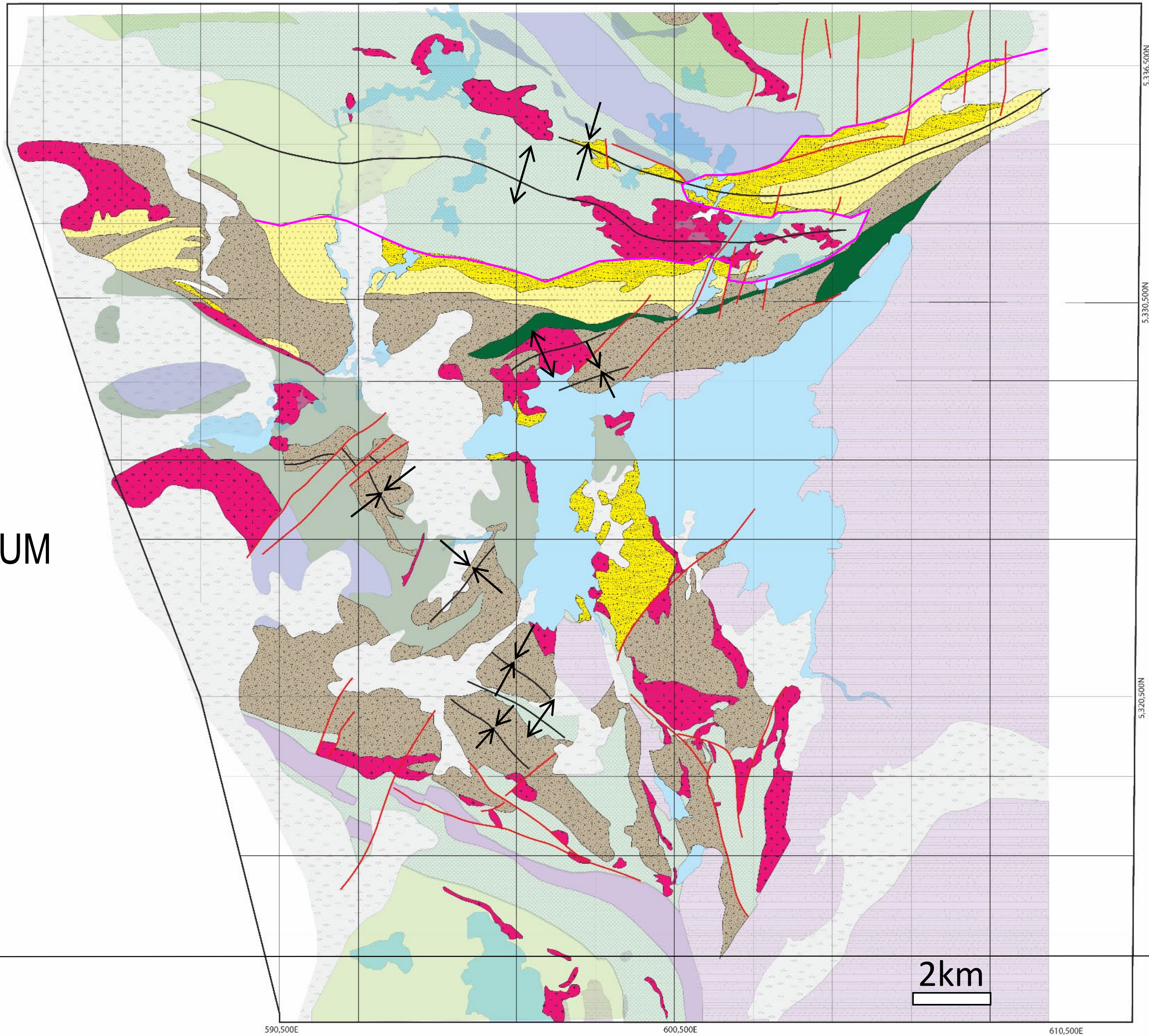
Larder Lake area, Larder Lake grp

Larder Lake group
(ca. 2705 Ma)

Piché group in Quebec

Defines the CLLDZ

Succession of mafic and UM volcanic rocks



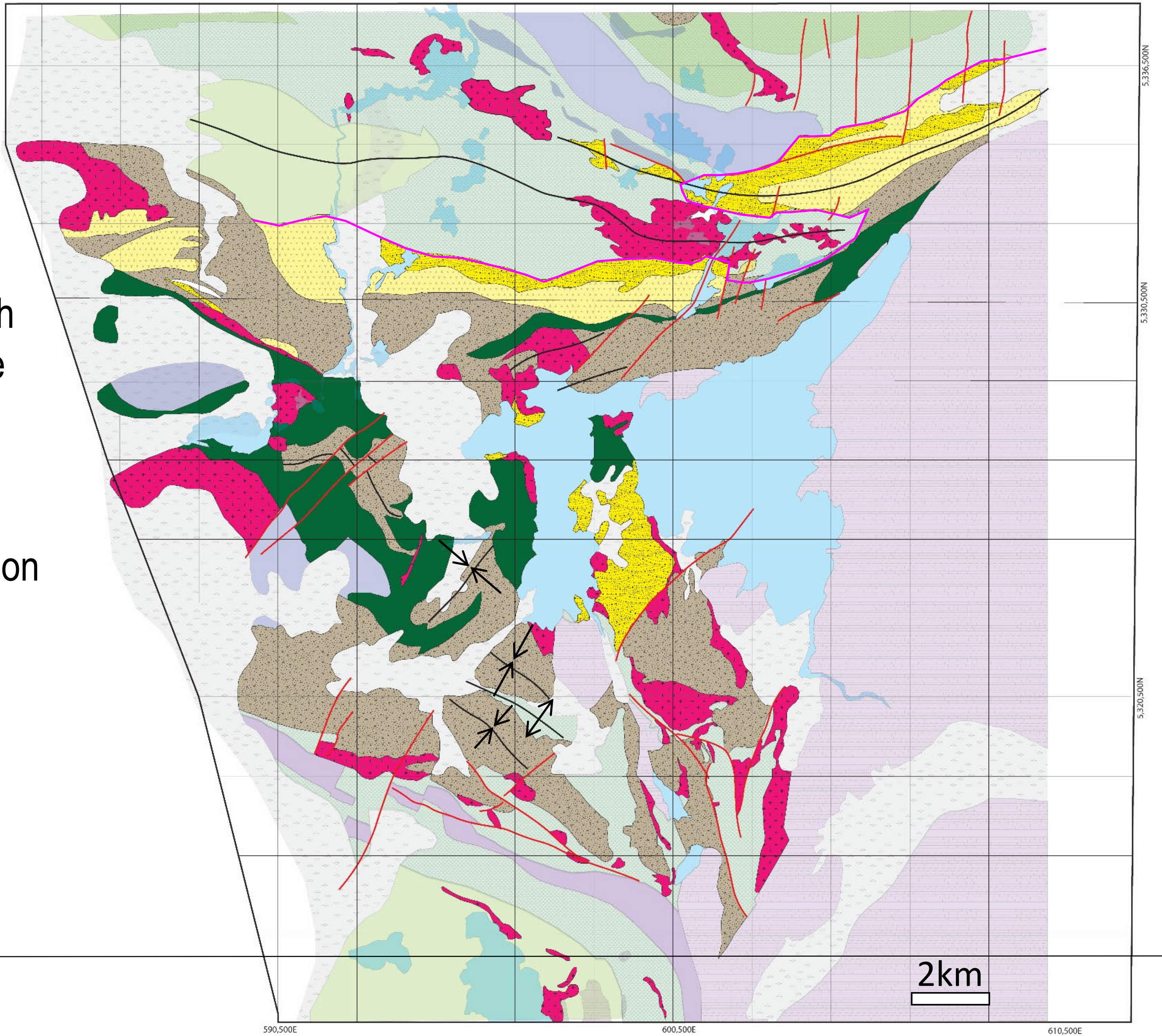
From: Jackson, 1995, OGS Map 2628, 1:50,000

Larder Lake area, Cadillac - Larder Lake Break and Gold Deposits

Larder Lake group

Other mafic-UM volcanic rocks mapped to the south possible extensions of the Larder Lake grp. or the Piché

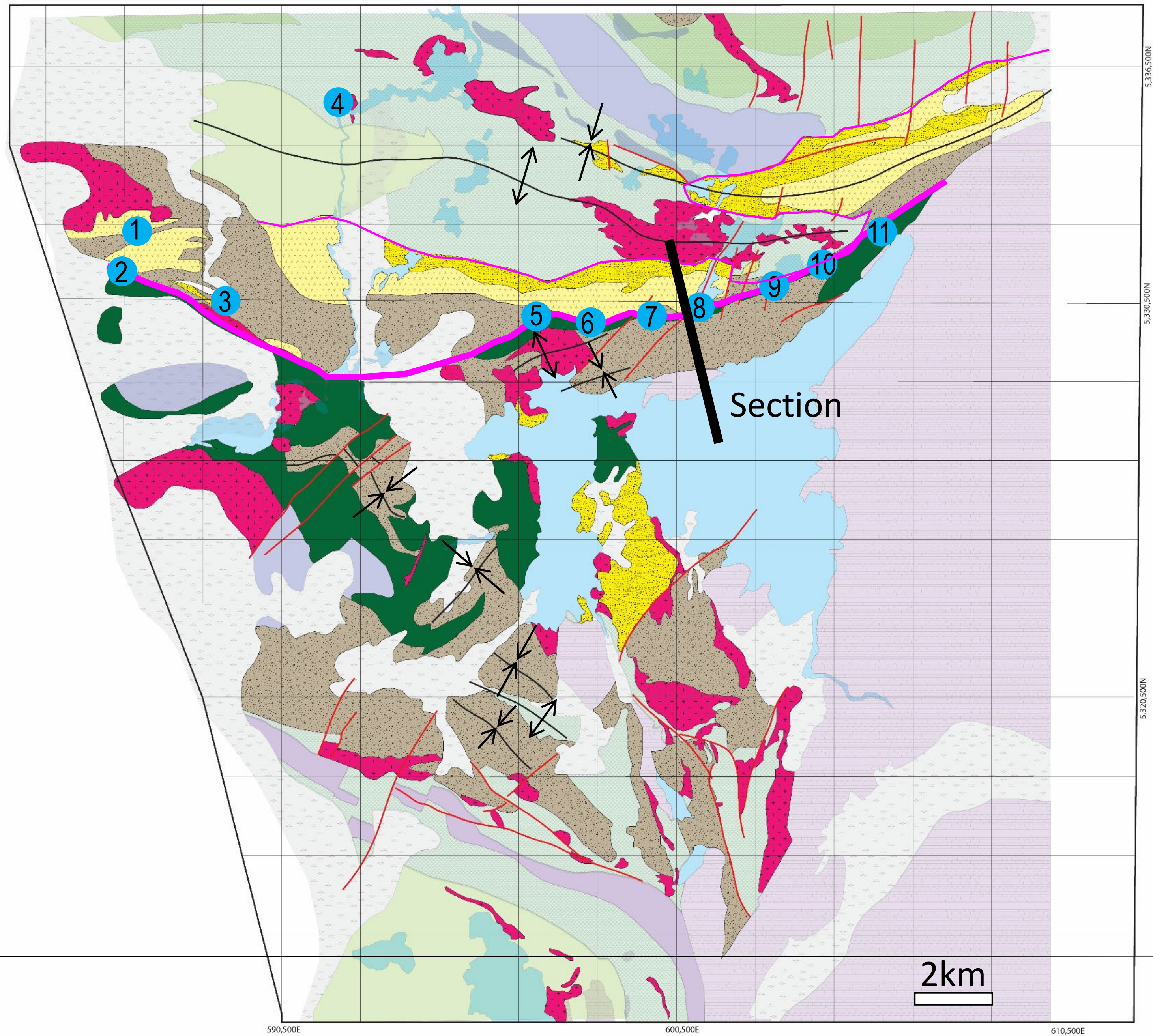
Significant for mineralization



From: Jackson, 1995, OGS Map 2628, 1:50,000

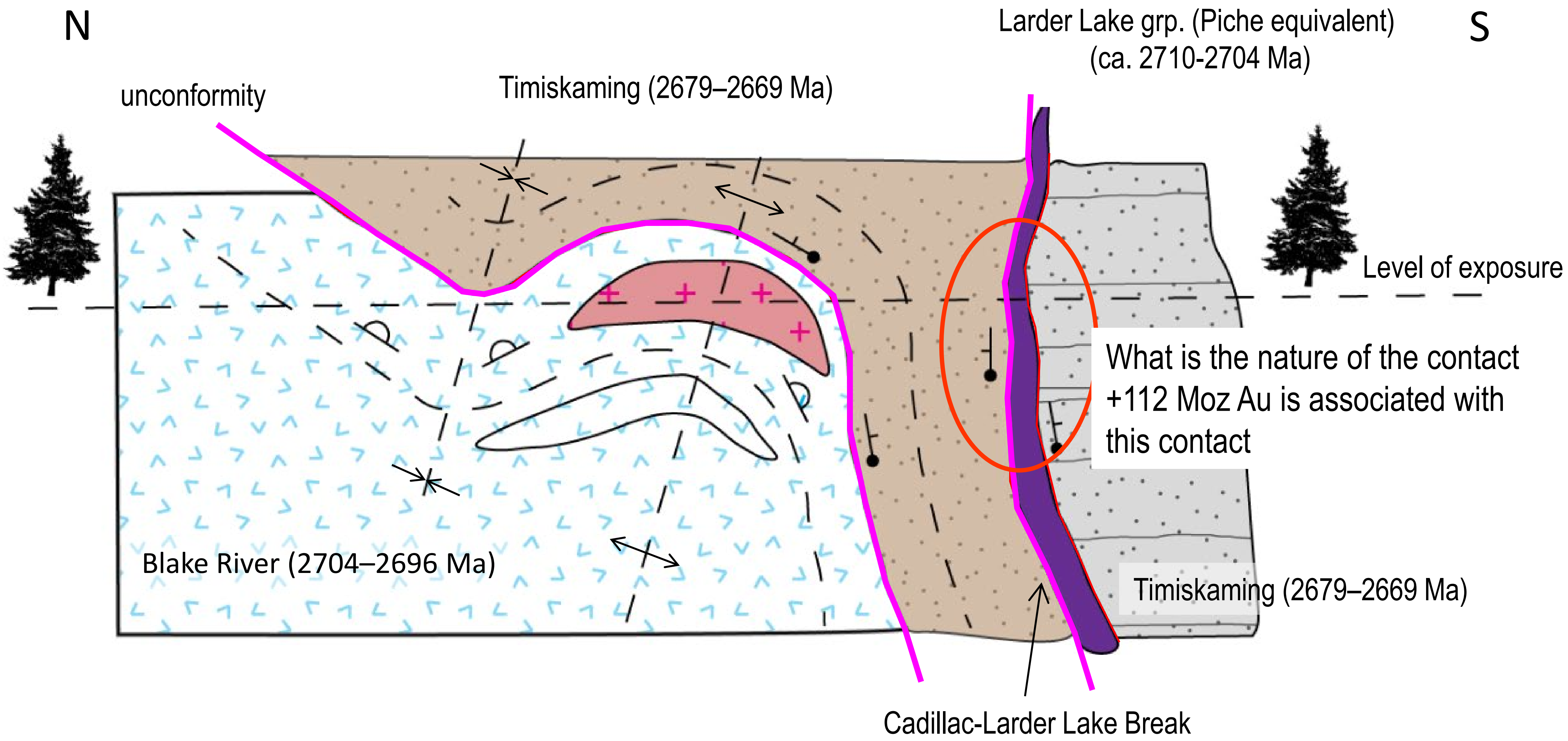
Larder Lake area, Cadillac - Larder Lake Break and Gold Deposits

1. Upper Canada
2. Anoki
3. McBean
4. Upper Beaver
5. Omega
6. Fernland
7. Cheminis
8. Bear Lake
9. Barber Larder
10. McGarry
11. Kerr Addison



From: Jackson, 1995, OGS Map 2628, 1:50,000

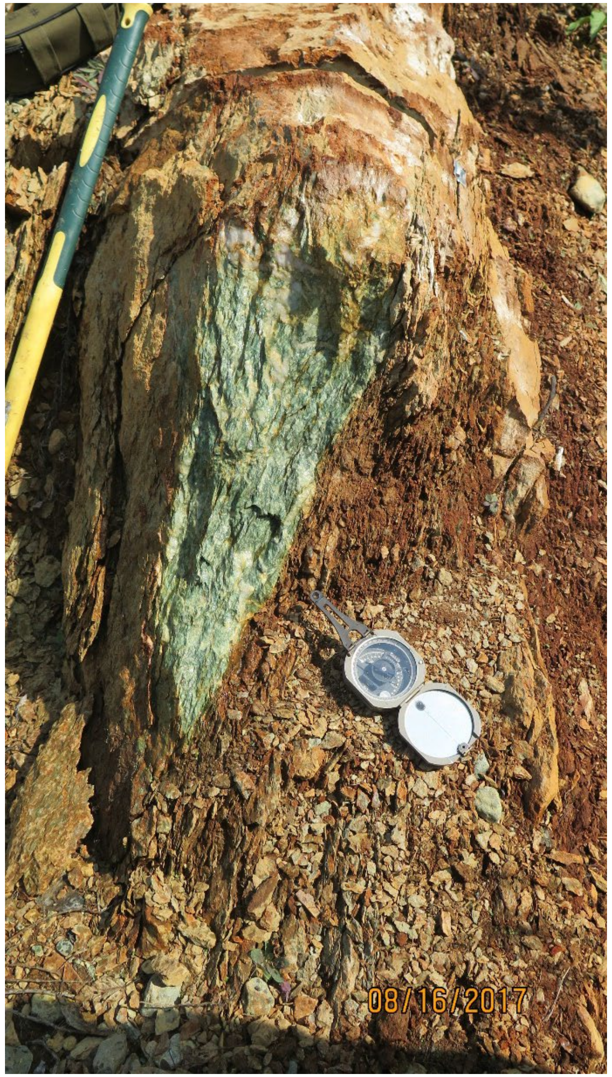
Schematic cross section through the CLLDZ



Poulsen 2018

Surface Exposures of the Cadillac Larder Lake deformation Zone

Strongly deformed Timiskaming sedimentary rocks in contact with Larder Lake group

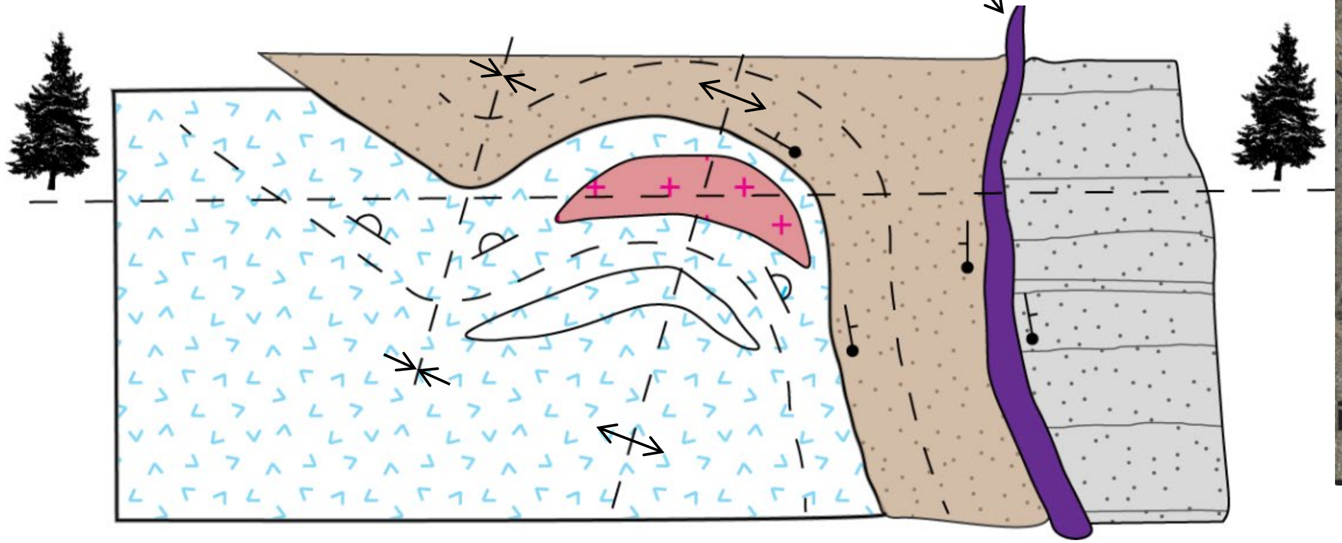


Fuchsite-carbonate altered ultramafic rocks
Larder Lake group

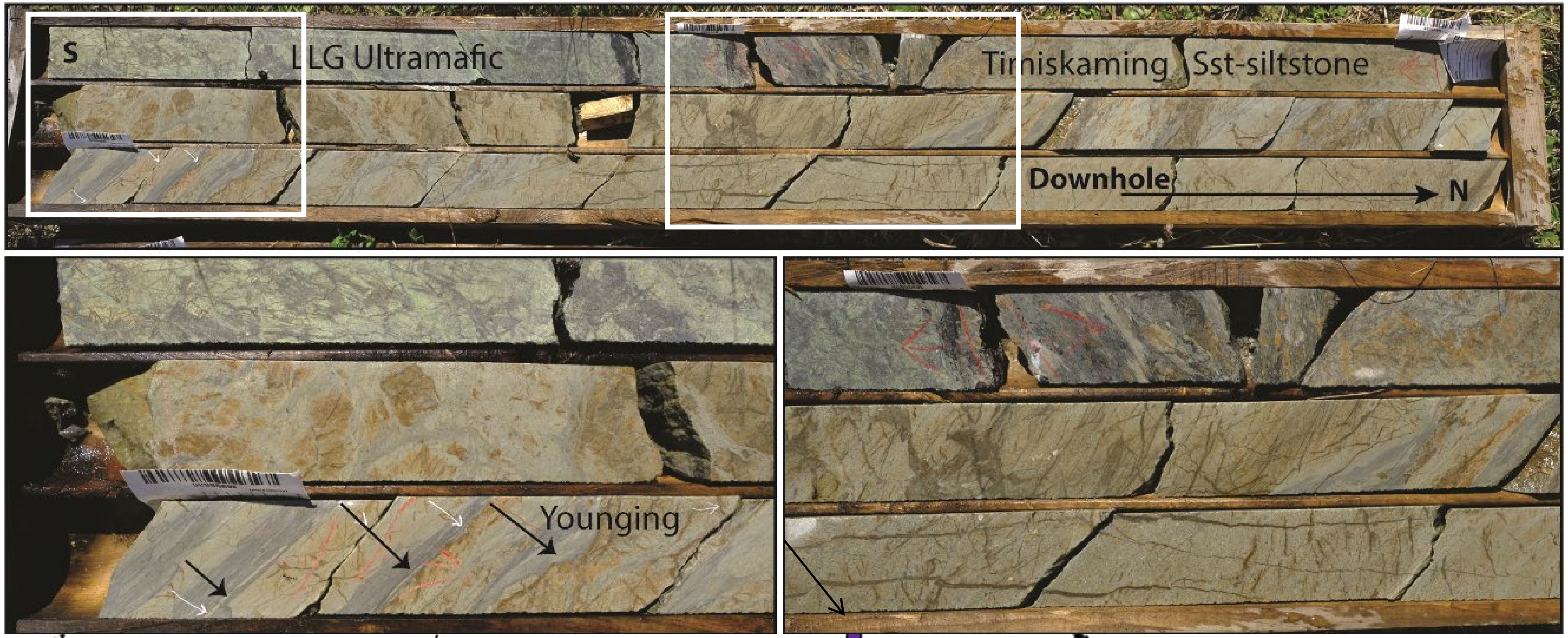
North contact between Larder Lake group and Timiskaming assemblage marked by a “transition zone”

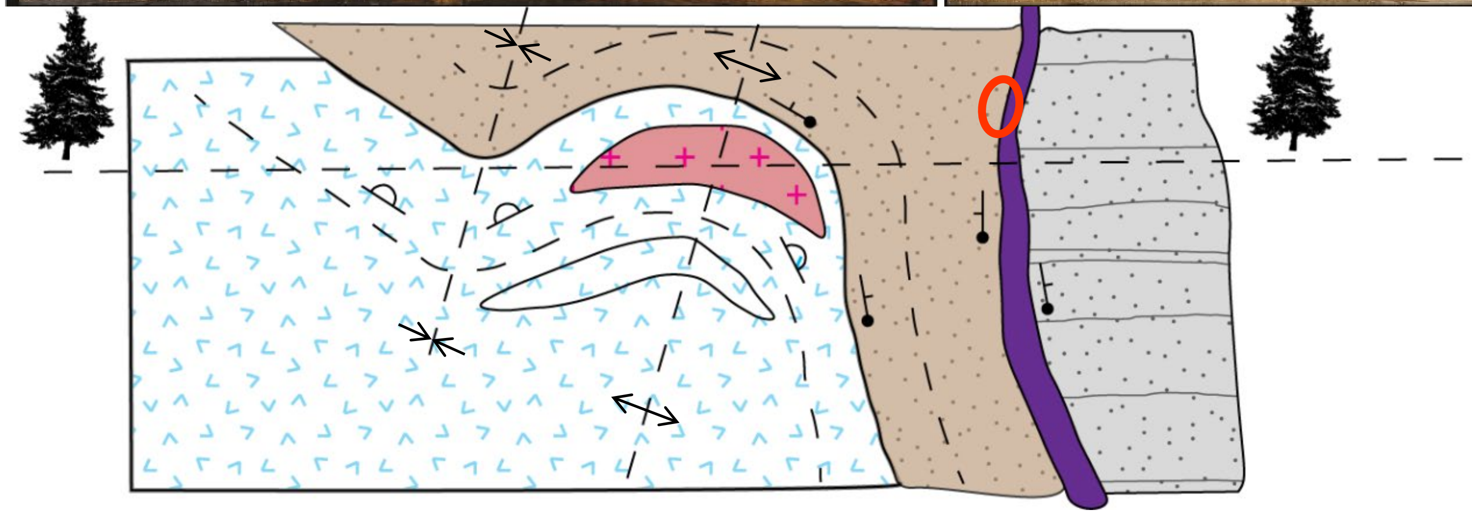
1-3 m of UM-mafic clasts with a sandy matrix

Younging direction away from LLg (north and south)



Photos from Nadia St-Jean MSc thesis





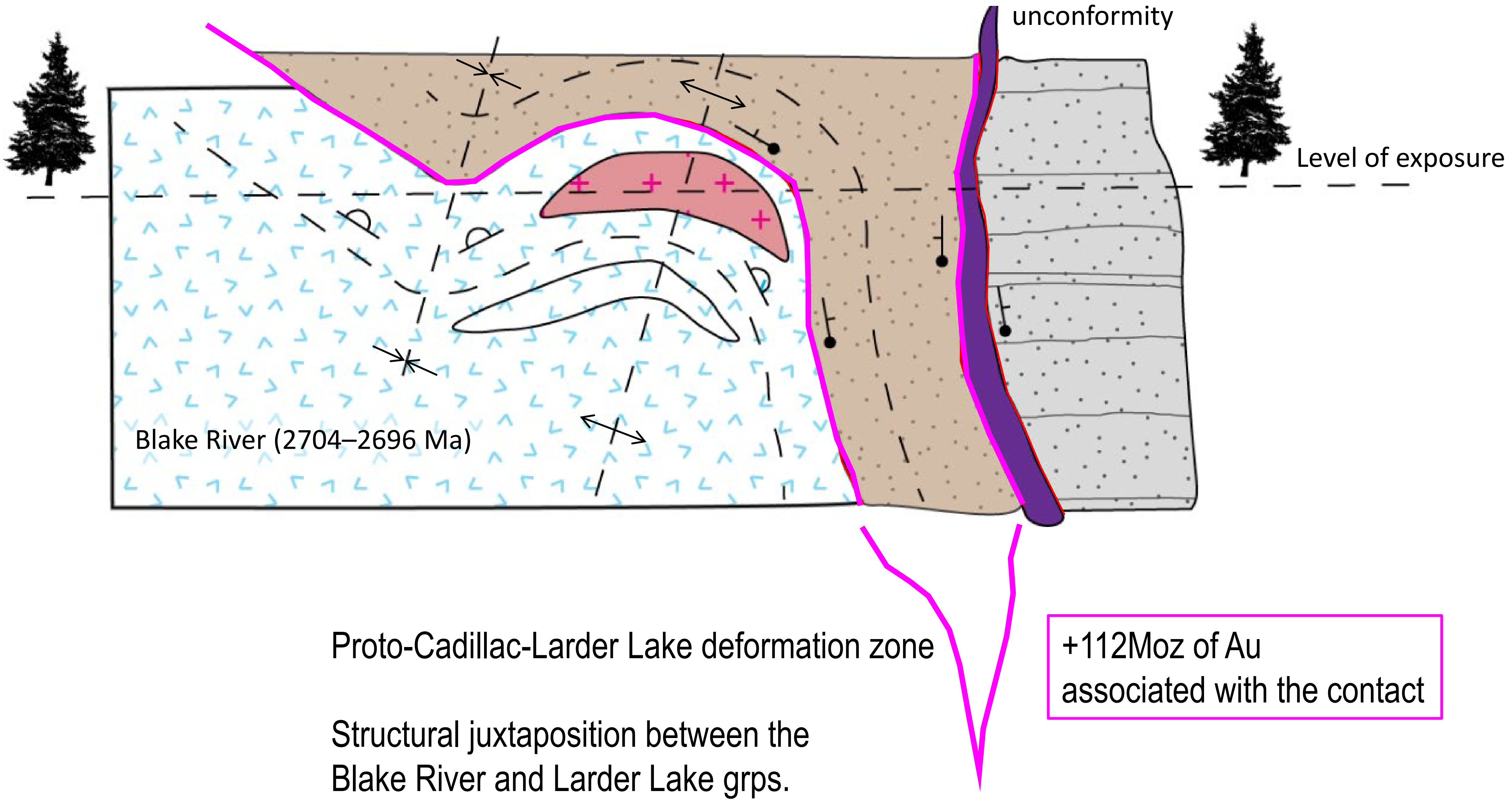
Drill core across the N contact at Cheminis
Youngs away from LLg

Presents as an unconformity

Modified by subsequent deformation

Photos from Nadia St-Jean MSc thesis

Schematic cross section through the CLLDZ



Proto-Cadillac-Larder Lake deformation zone

Structural juxtaposition between the Blake River and Larder Lake grps.

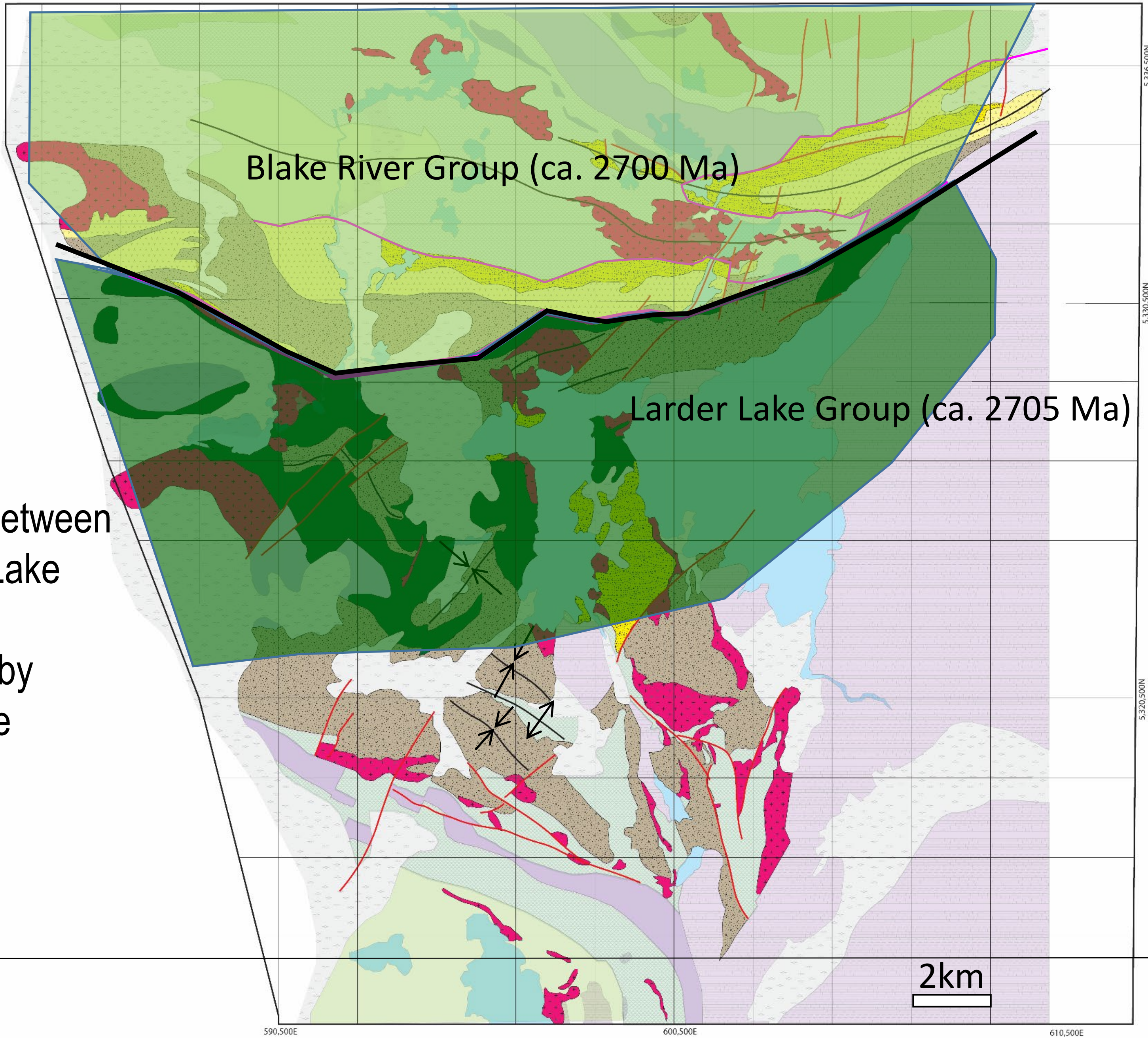
+112Moz of Au associated with the contact

Larder Lake area, Cadillac - Larder Lake Break and Gold Deposits

Ancestral CLLDz

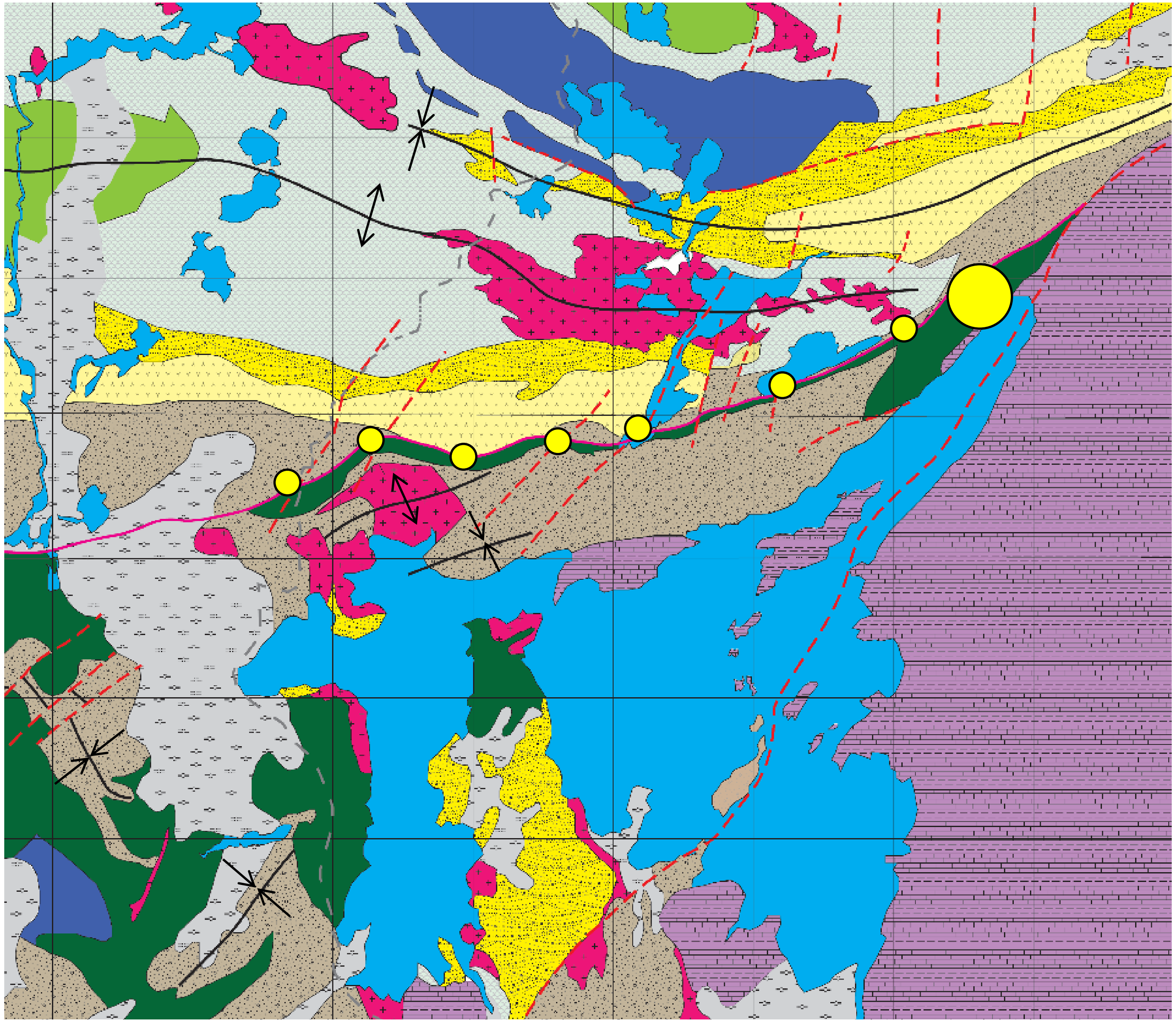
Structural juxtaposition between Blake River and Larder Lake

Unconformable overlain by Timiskaming assemblage



From: Jackson, 1995, OGS Map 2628, 1:50,000

Metal Earth   Role of NE trending faults



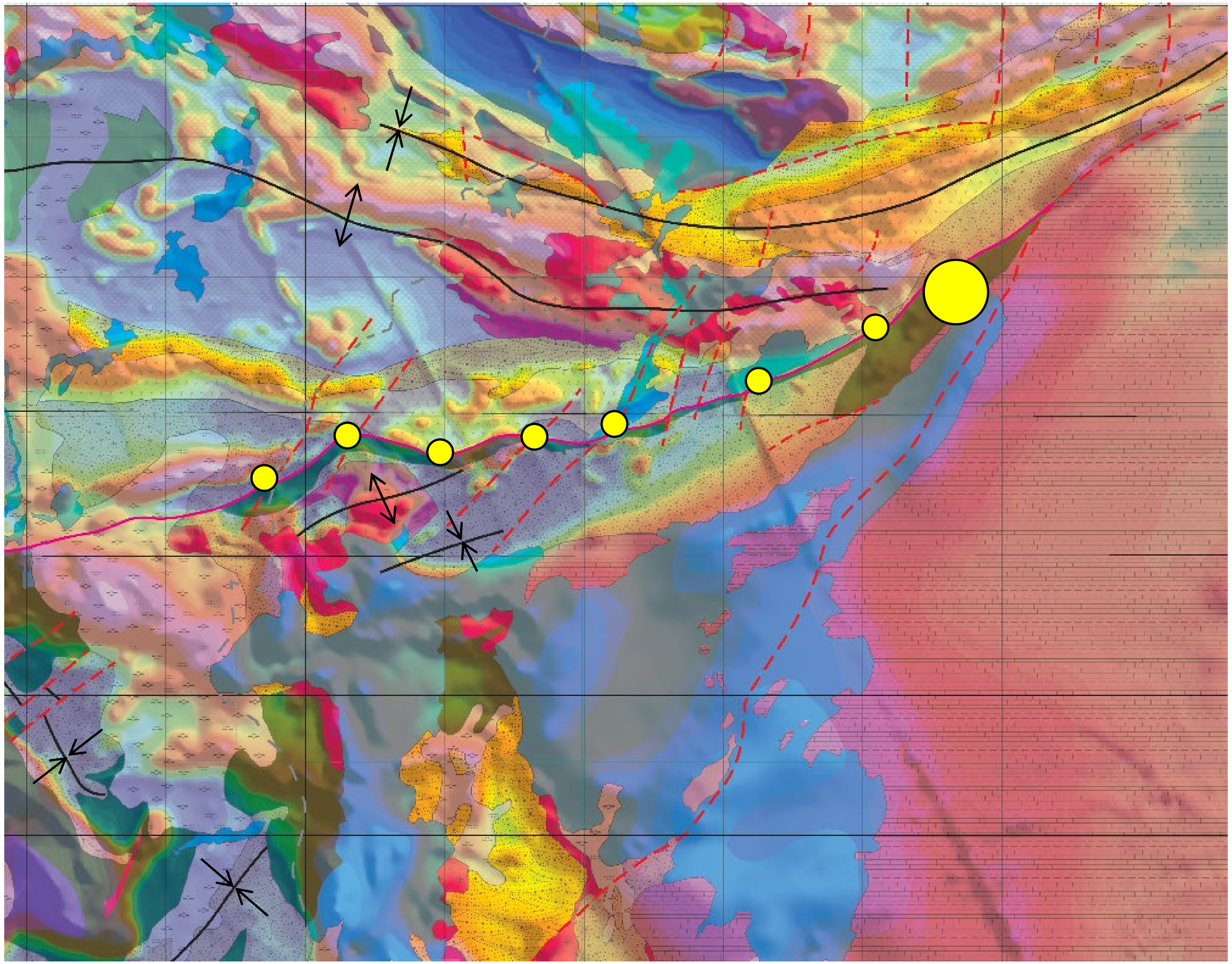
Role of NE trending faults

No offset on lithologic contacts

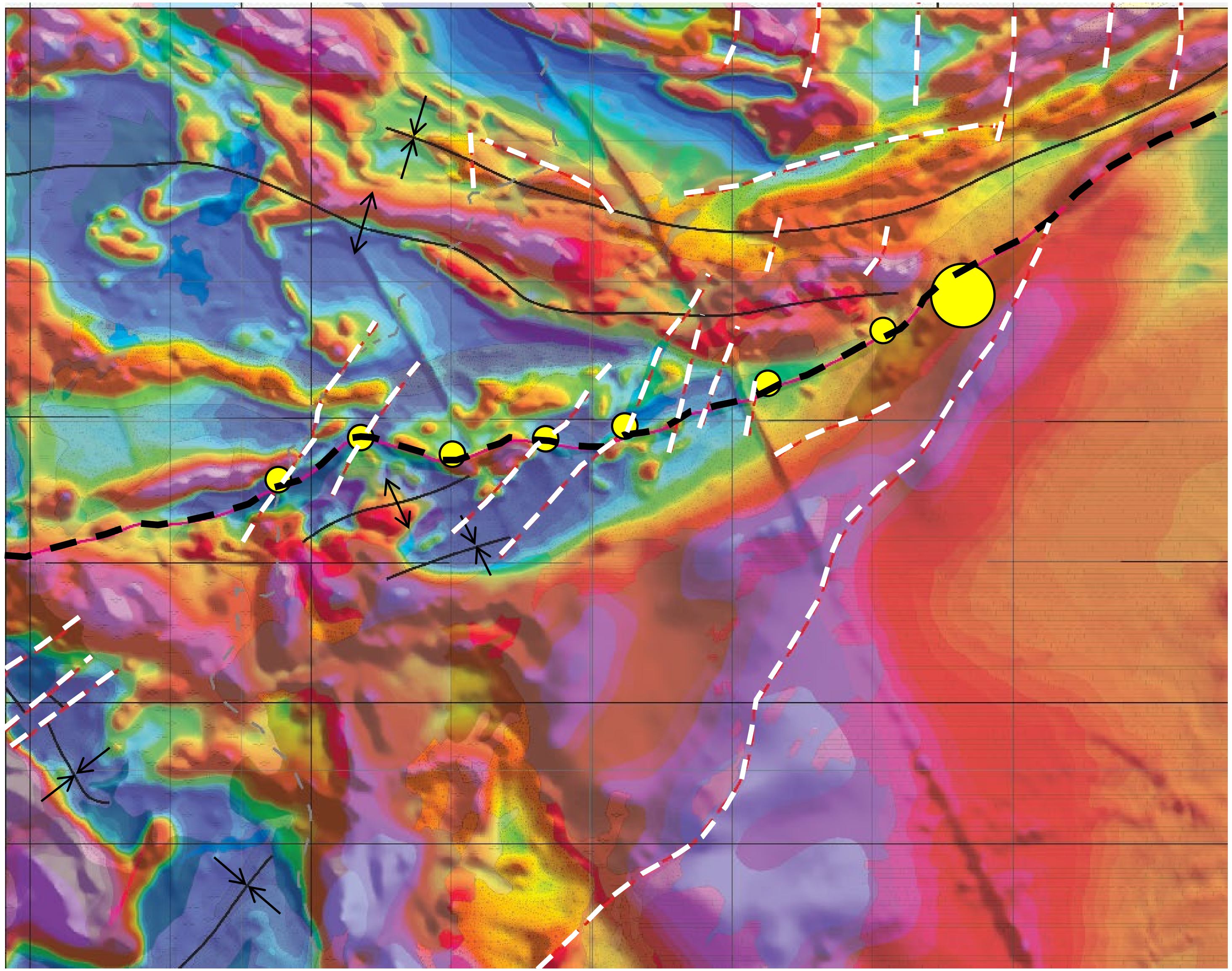
Mainly within the Timiskaming Assemblage

Clearly mapped with magnetics

Metal Earth



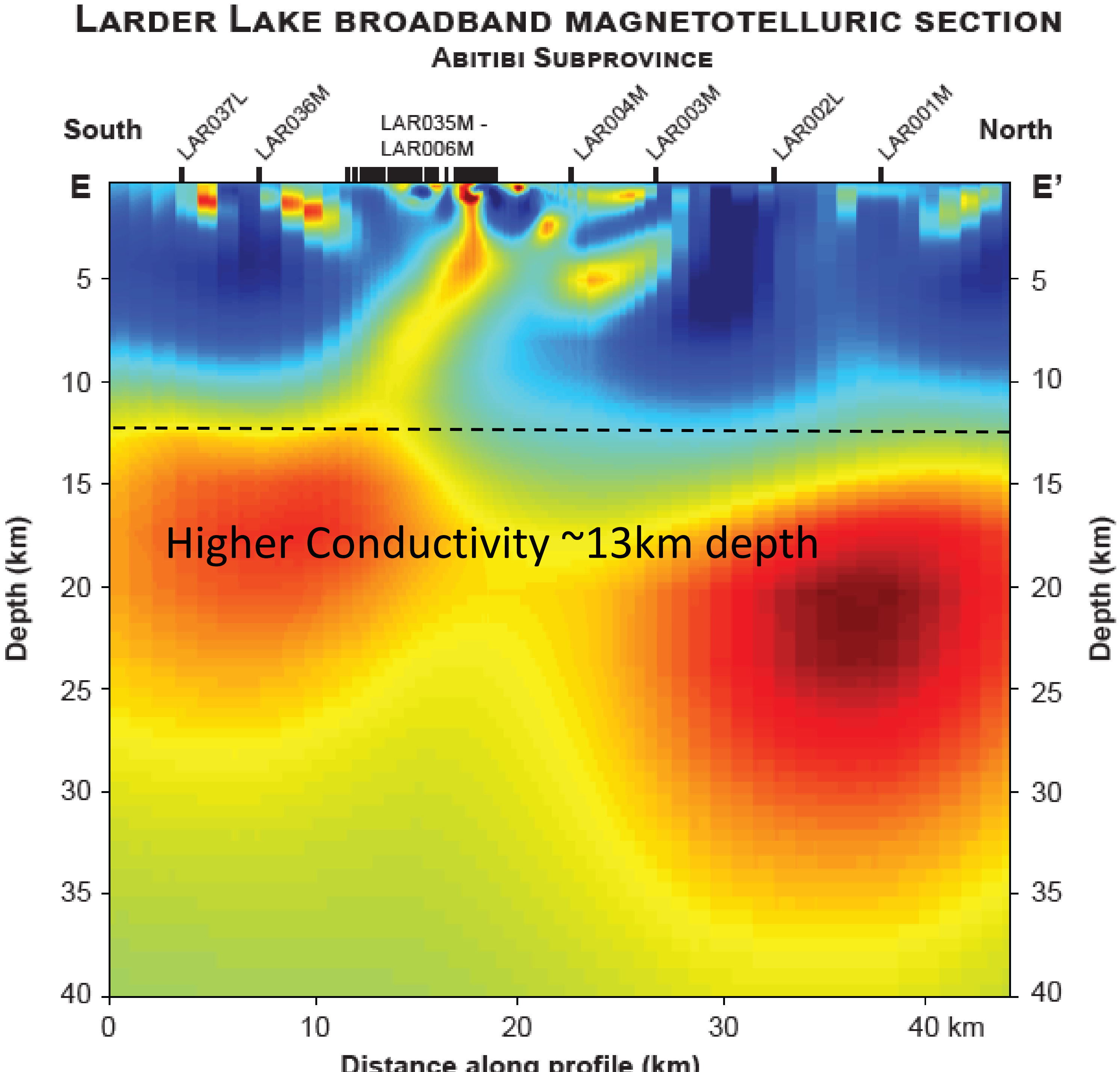
Metal Earth



Intersection of CLLdz
And NE faults
localizes deposits

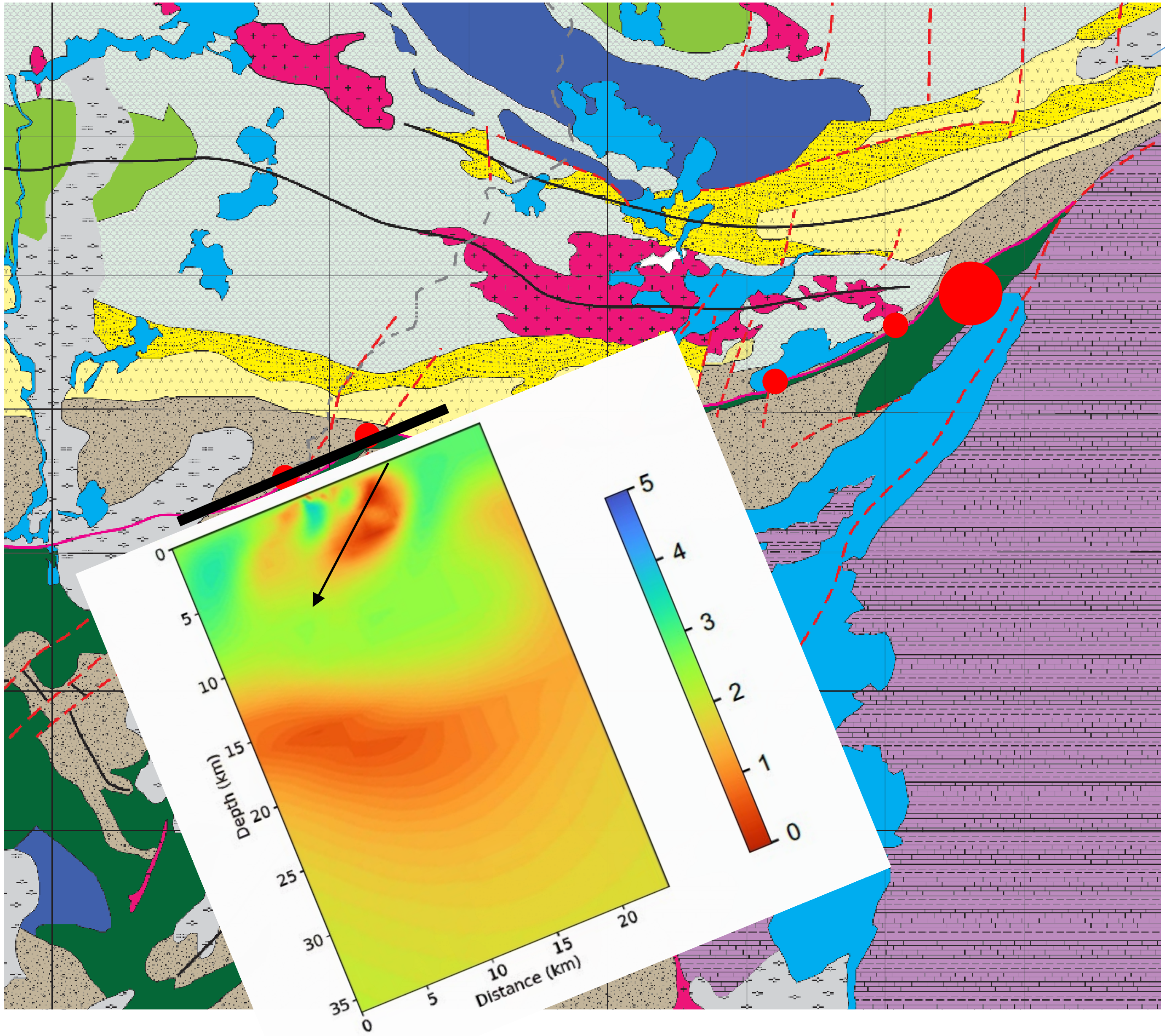
Largest NE fault,
controls Proterozoic
sedimentary rocks
Is the largest gold
deposit

Metal E



MT surveys shows a distinct contrast in the structural hanging wall of the fertile systems.

Metal Earth

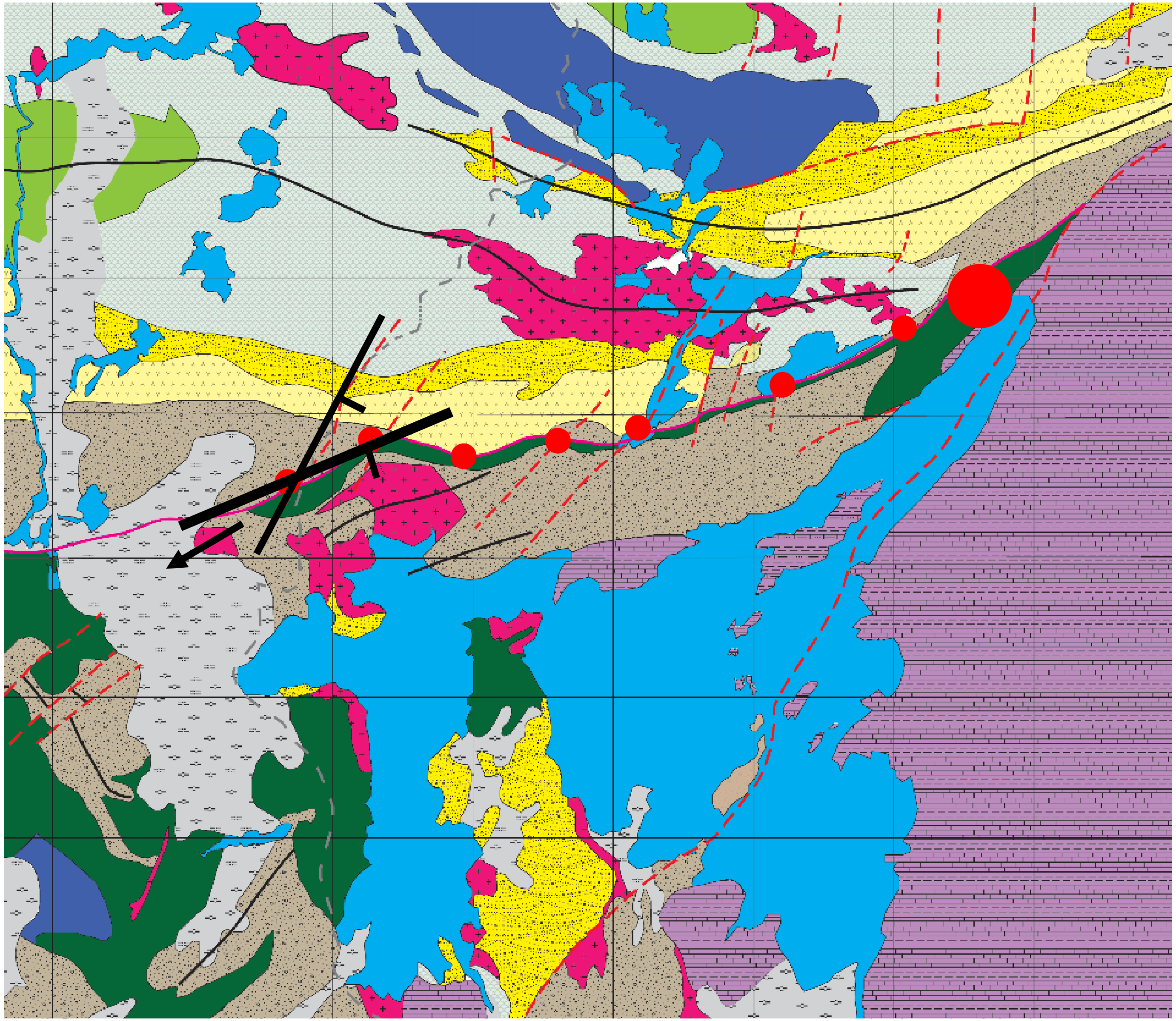


MT Long section

Linear MT body

trends ~220°
Plunges ~45°

Metal Earth



MT Long section

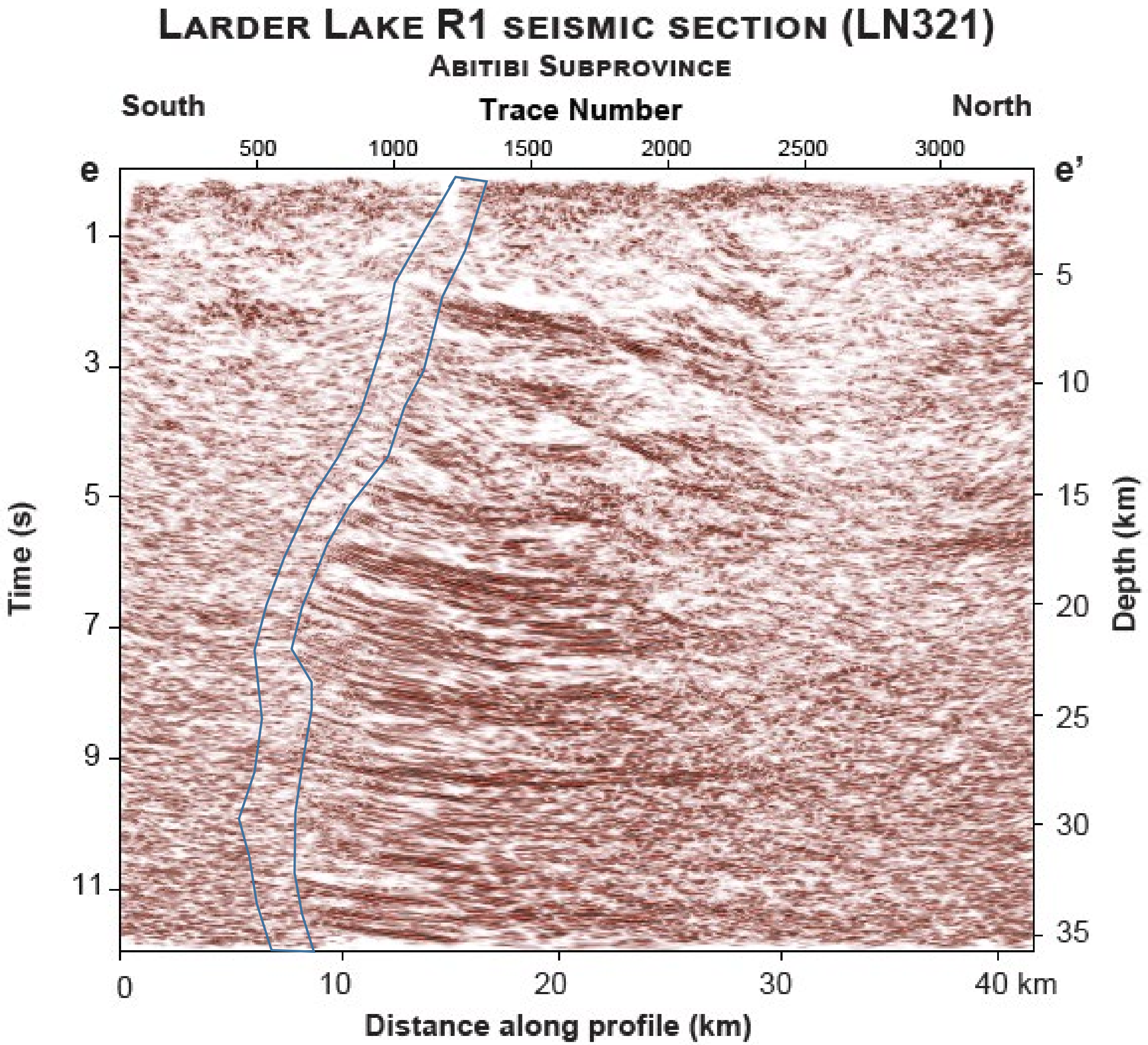
Linear MT body

trends ~220°
Plunges ~45°

Intersection of steep S dipping CLLdf & NE faults steep SE dip

Same geometry

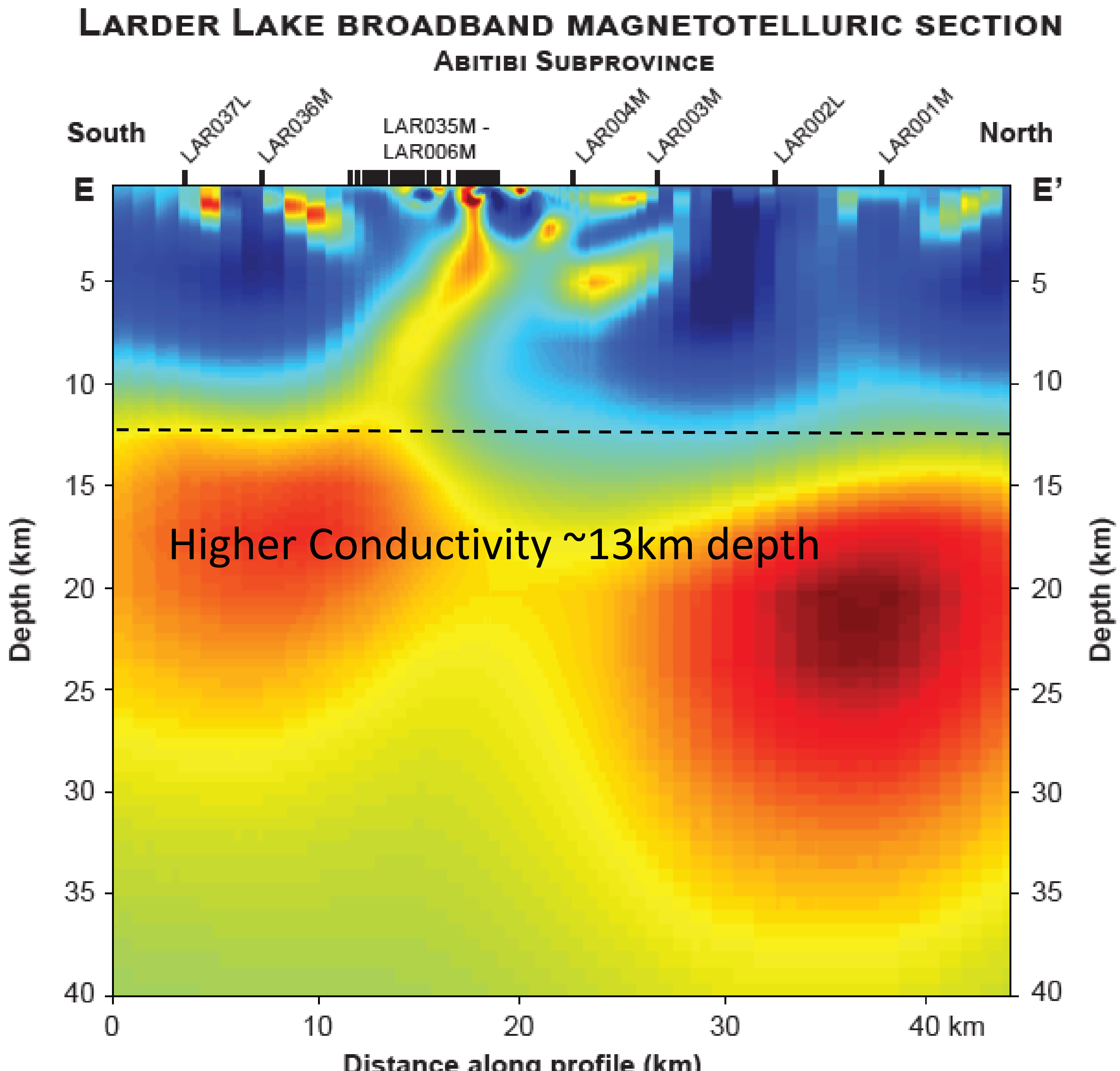
Metal Earth



The fertile, highly endowed faults manifest themselves geophysically as large through going features that separates domains that have distinct physical properties.

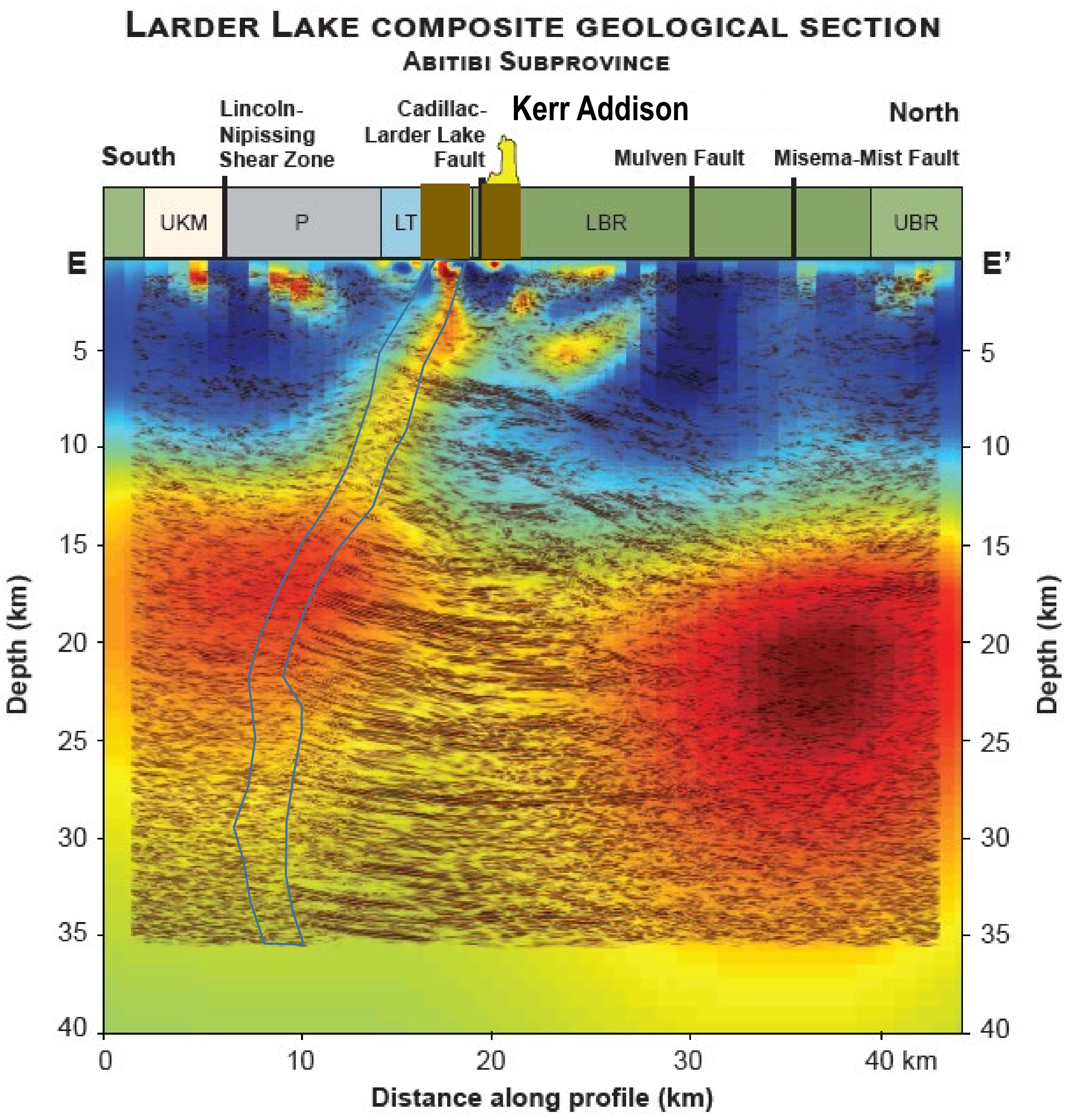
Washed out seismic impedance

Metal E



MT surveys shows a distinct contrast in the structural hanging wall of the fertile systems.

Metal E



The fertile, highly endowed faults are marked by clastic sedimentary assemblages which are inverted during subsequent deformation. Ancestral fault marked by juxtaposition of volc. assemblages

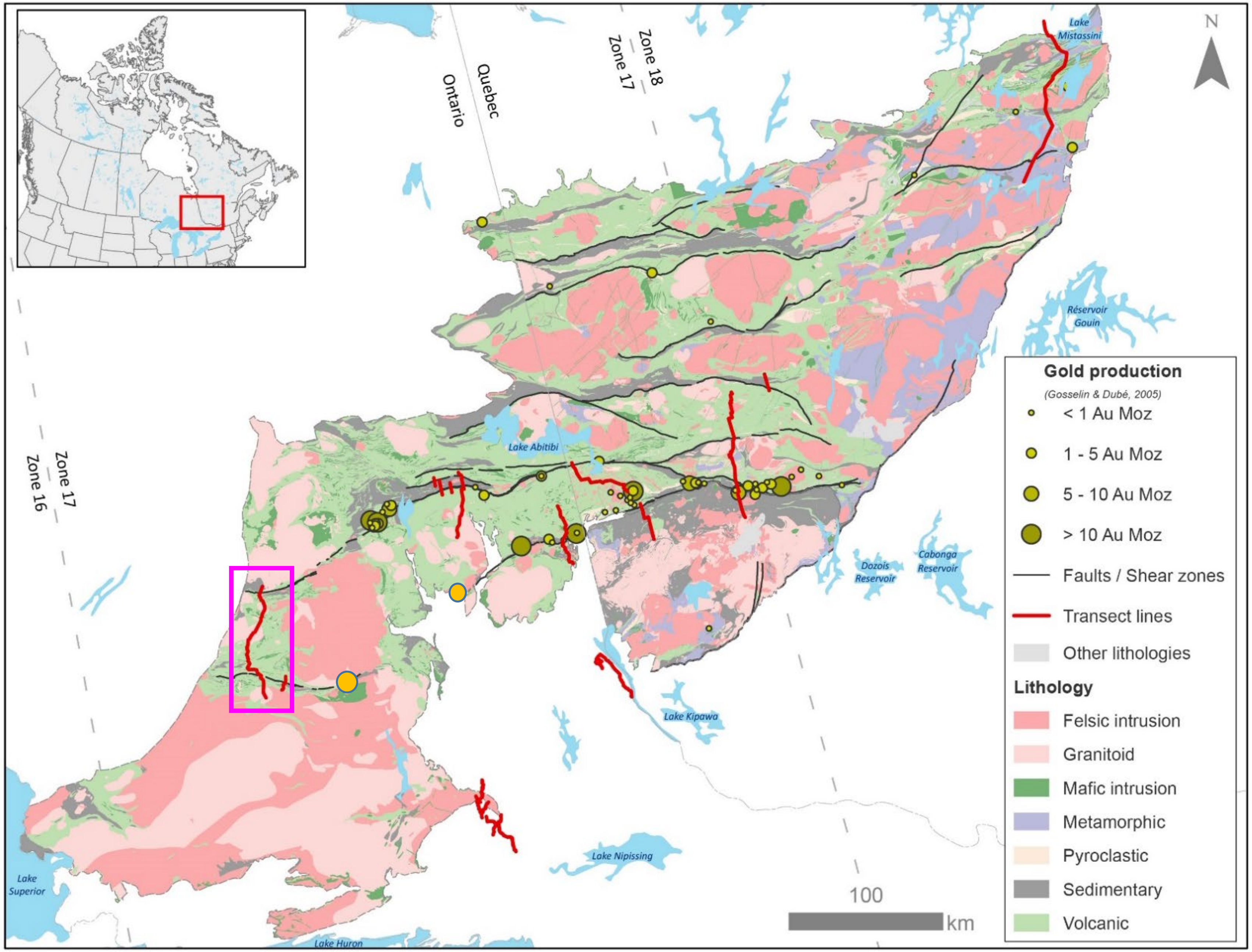
They manifest themselves geophysically as large through going features that separates domains that have distinct physical properties.

MT surveys shows a distinct contrast in the structural hanging wall of the fertile systems.

Abitibi Transects

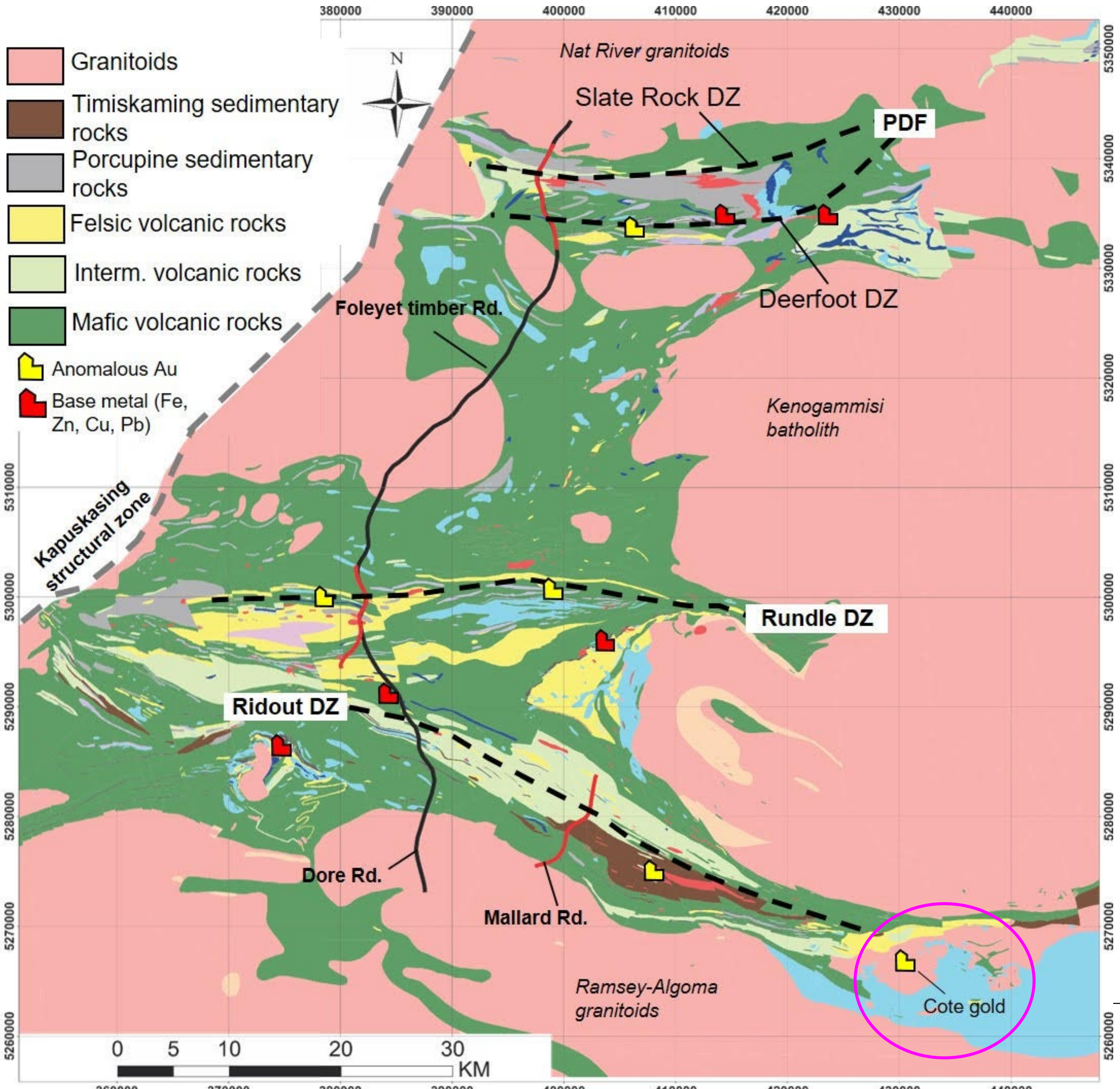
Swayze greenstone belt

Similar to Abitibi in geology, limited gold endowment

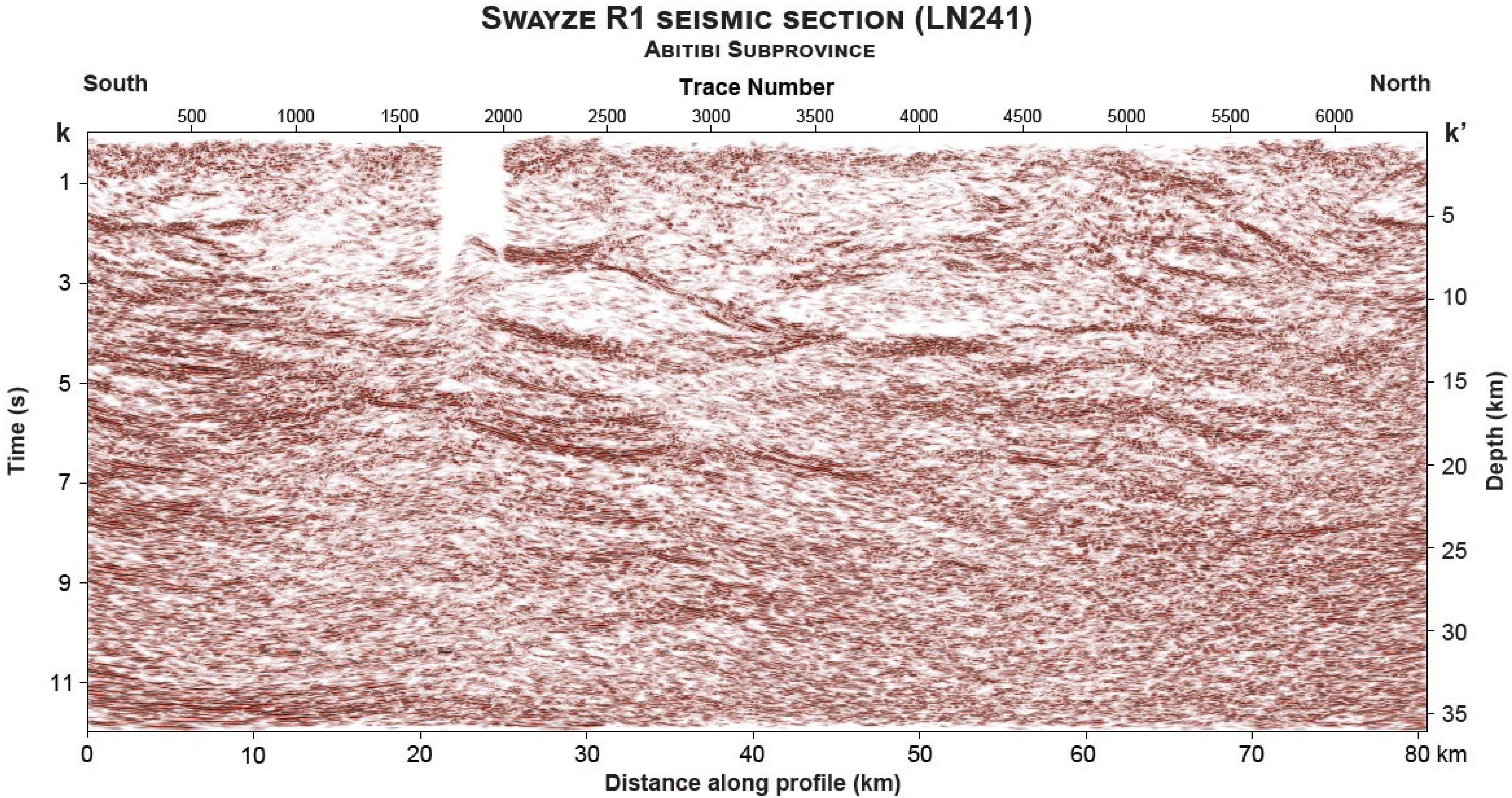


Abitibi Transects

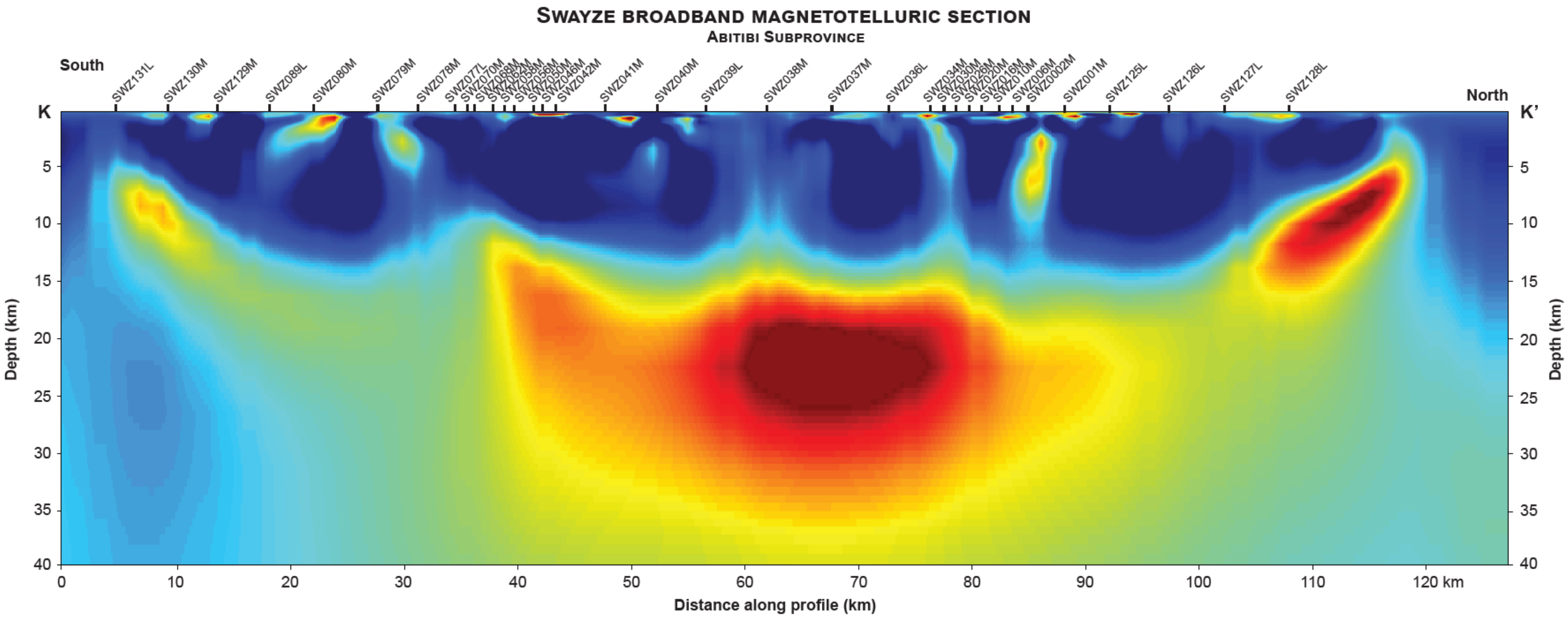
Swayze



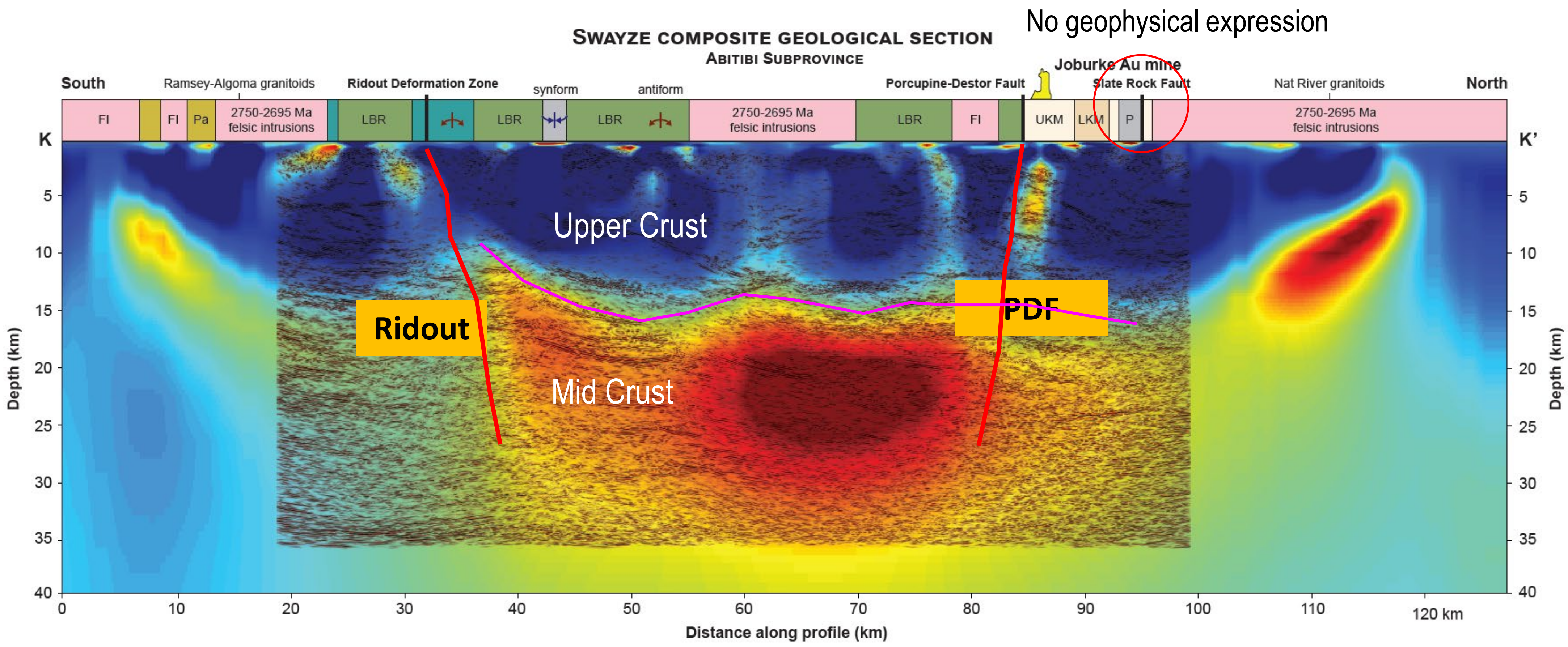
Swayze – A less-endowed greenstone belt? (Gemmell & Haugaard)



Swayze – A less-endowed greenstone belt? (Gemmell & Haugaard)

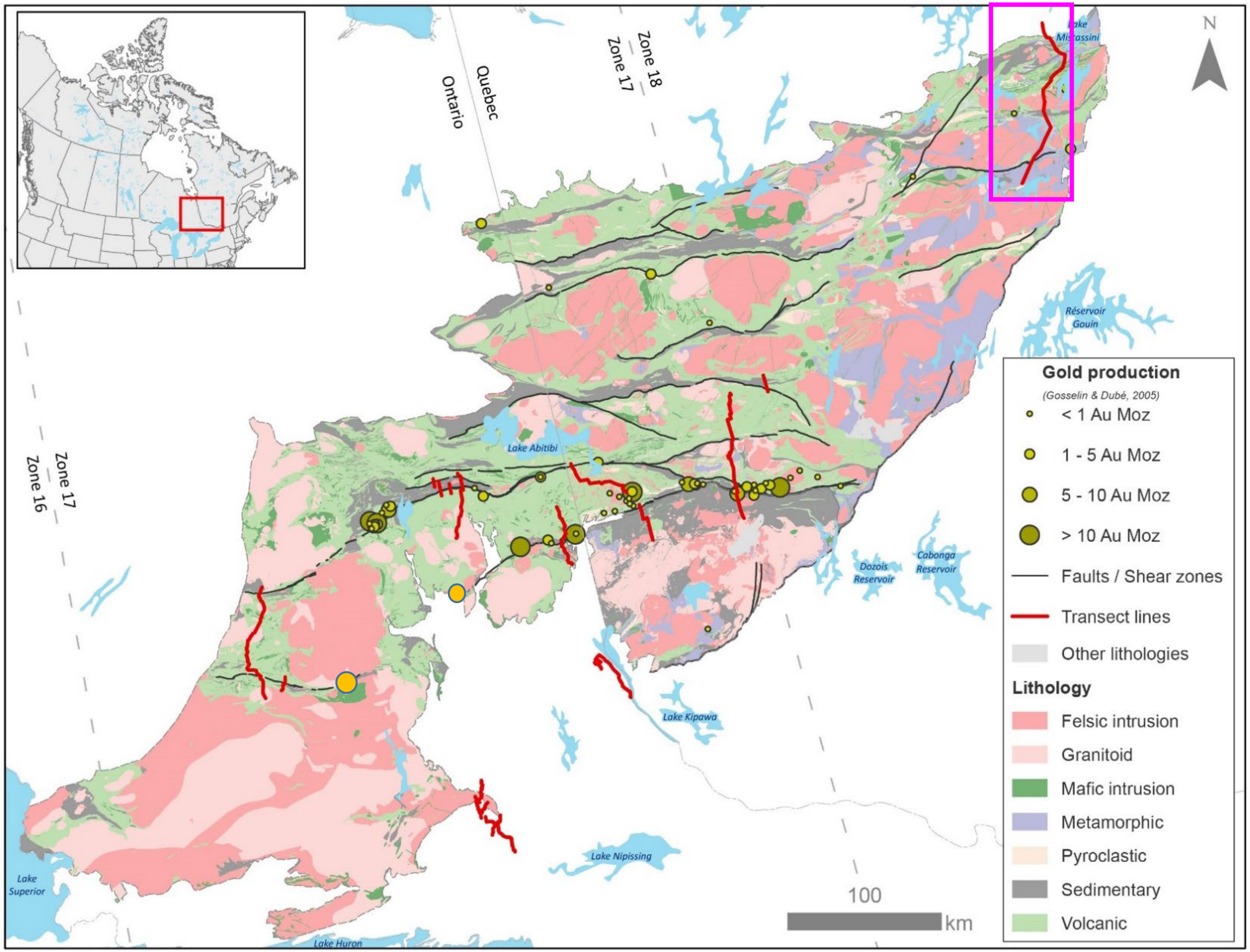


Swayze – A less-endowed greenstone belt? (Gemmell & Haugaard)



Abitibi Transects
Chibougamau

NE part of Abitibi
Copper dominated



Chibougamau

Deep Into the Chibougamau Area, Abitibi Greenstone Belt: Structure of a Neoarchean Crust Revealed by Seismic Reflection Profiling

Lucie Mathieu[1], David B. Snyder[2], Pierre Bedeaux[1], Saeid Cheraghi[2], Bruno Lafrance[2], Phil Thurston[2], and Ross Sherlock[2]

Copper-Gold camp, associated with intrusive rocks

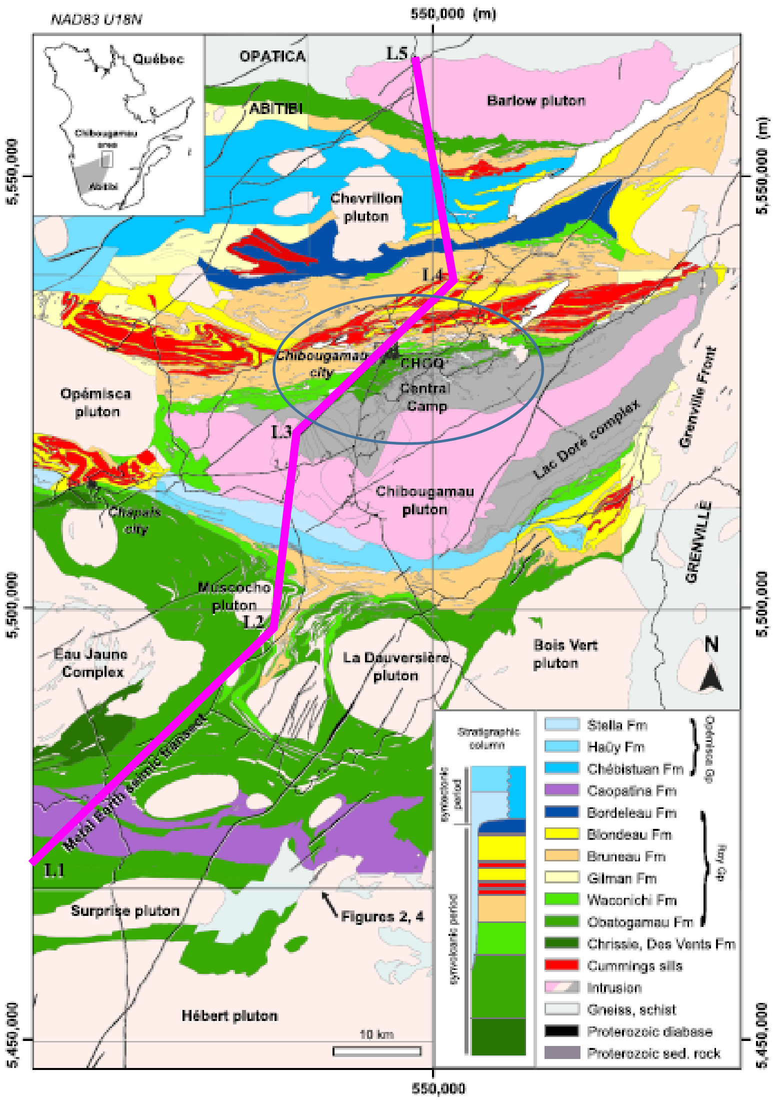


Figure 1. Geological map of the Chibougamau area, showing the main volcanic, sedimentary, and intrusive phases. The geological map is modified from the Ministère de l'Énergie et des Ressources Naturelles (MERN), Québec (SIGEOM, 2020). The projection is UTM NAD83 Zone 18N. The simplified stratigraphic column is inspired by the most recent stratigraphic interpretation (Leclerc et al., 2017). From base to top, the Cummings sills correspond to the Bourbeau, Venture, and Roberge sills. The Caopatina Formation is not integrated to the stratigraphic column because it has a poorly constrained age and an unresolved relationship with the Opémisca Group. The Gilman Formation is a remnant of a former stratigraphic interpretation (Leclerc et al., 2017). The permanent broadband station (CHGQ) is located in Chibougamau city (49.9105°N, 74.374833°W).

Citation:

Mathieu, L., Snyder, D. B., Bedeaux, P., Cheraghi, S., Lafrance, B., Thurston, P., & Sherlock, R. (2020). Deep into the Chibougamau area, Abitibi greenstone belt: Structure of a Neoarchean crust revealed by seismic reflection profiling. *Tectonics*, *38*, e2020TC006223. https://doi.org/10.1029/2020TC006223

Chibougamau

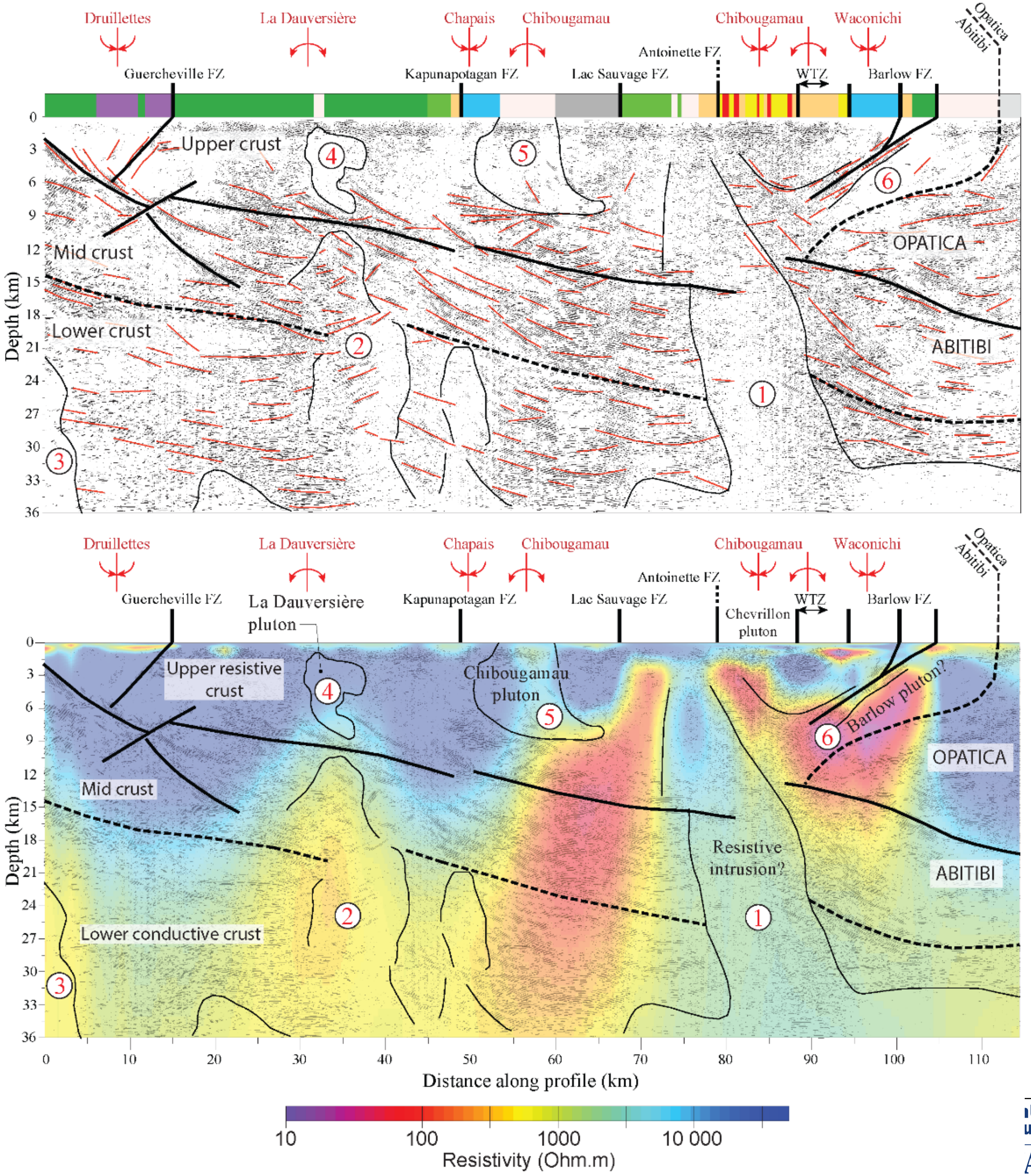
Main Features of Transect

1. Large intrusive complex, resistive and seismic isotropic, lower crust source, melting mafic volcanics ? No surface expression

2. Intrusive complex from lower crust

5. Chibougamau pluton, rootless in upper crust. Main Cu-Au system

6. Barlow fault, Abitibi thrust over Opatica



Chibougamau

Chibougamau is a Cu-Au mining camp known for its magmatic-hydrothermal deposits centered on the Chibougamau pluton (Pilote et al., 1997).

The imbrication of parts of the oceanic crust followed by rapid devolatilization and melting of mafic rocks to produce TTG suites, seems favorable to the production of Cu-Au-bearing hydrous magmas.

Continued shortening during terrane imbrication caused additional burial and metamorphic devolatilization, producing fluids that induced orogenic gold style of mineralization in the Chibougamau area (Leclerc et al., 2017)

However, the paucity of economic Au deposits in the Chibougamau area likely reflects the absence of major transcrustal fault systems similar to those observed in the southern part of the Abitibi greenstone belt.

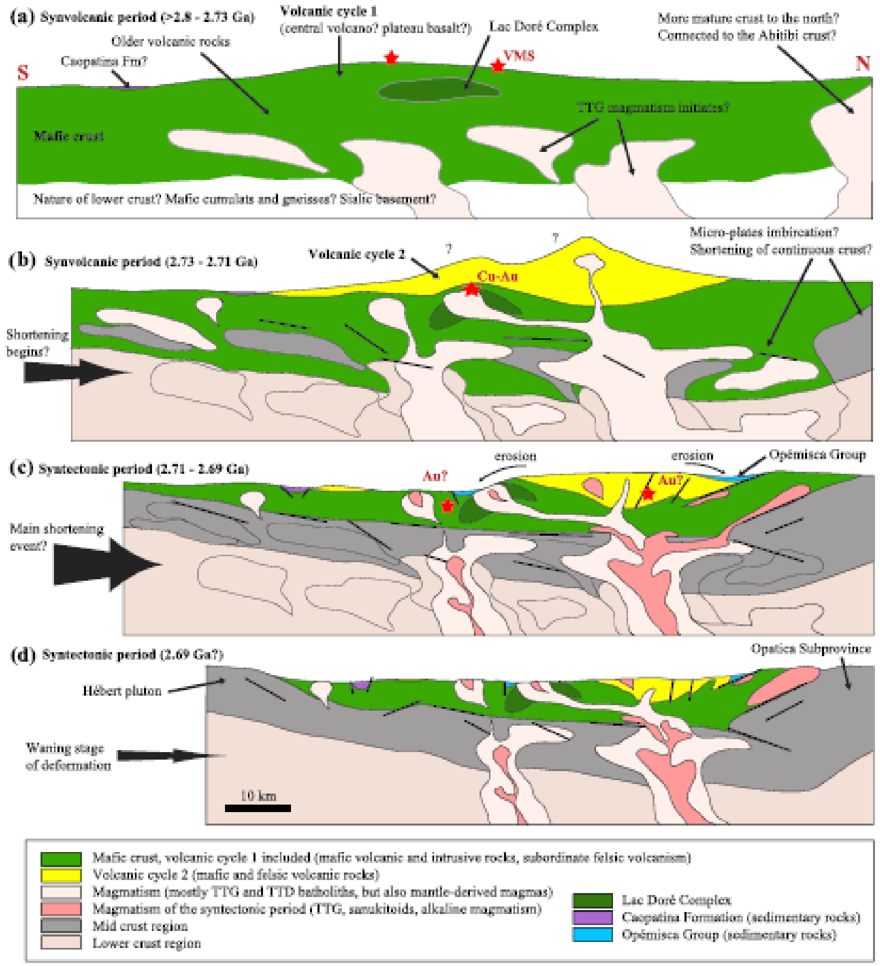
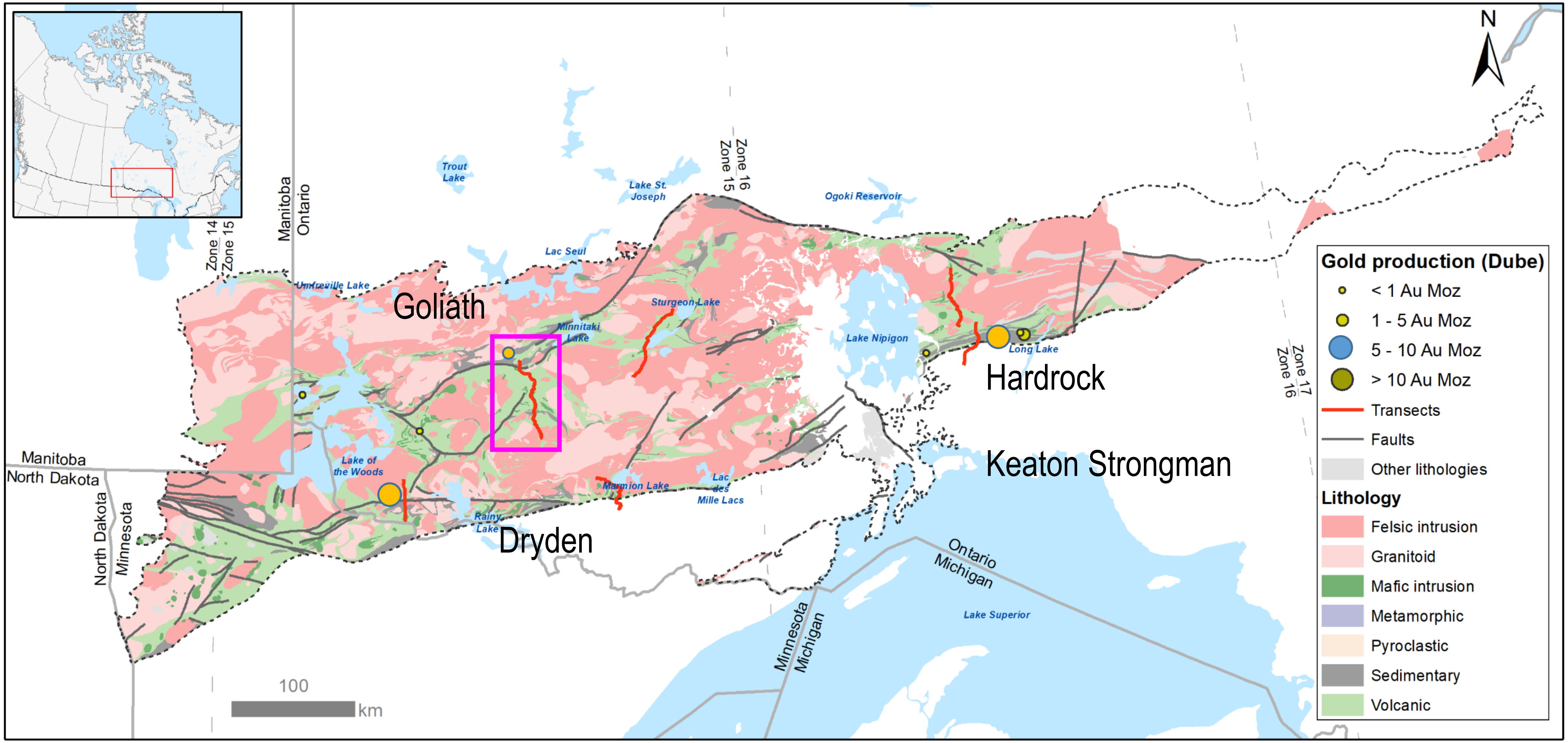


Figure 8. Evolution of the crust exposed in the Chibougamau area, between 2.80 and 2.69 Ga (see text for explanation). The vertical scale for surface top arbitrary. The base of the diagram is located, from (a) to (d), at about 30-km depth (normal Archean oceanic crust) to >35-km depth toward the end shortening event, prior to thinning related to post-Kenoran (?) and post-Grenville orogens extension (present-day crust is 35 km thick in the study area). crust evolved into more felsic midcrust and lower crust through metamorphism, magma injections, and local anatexis.

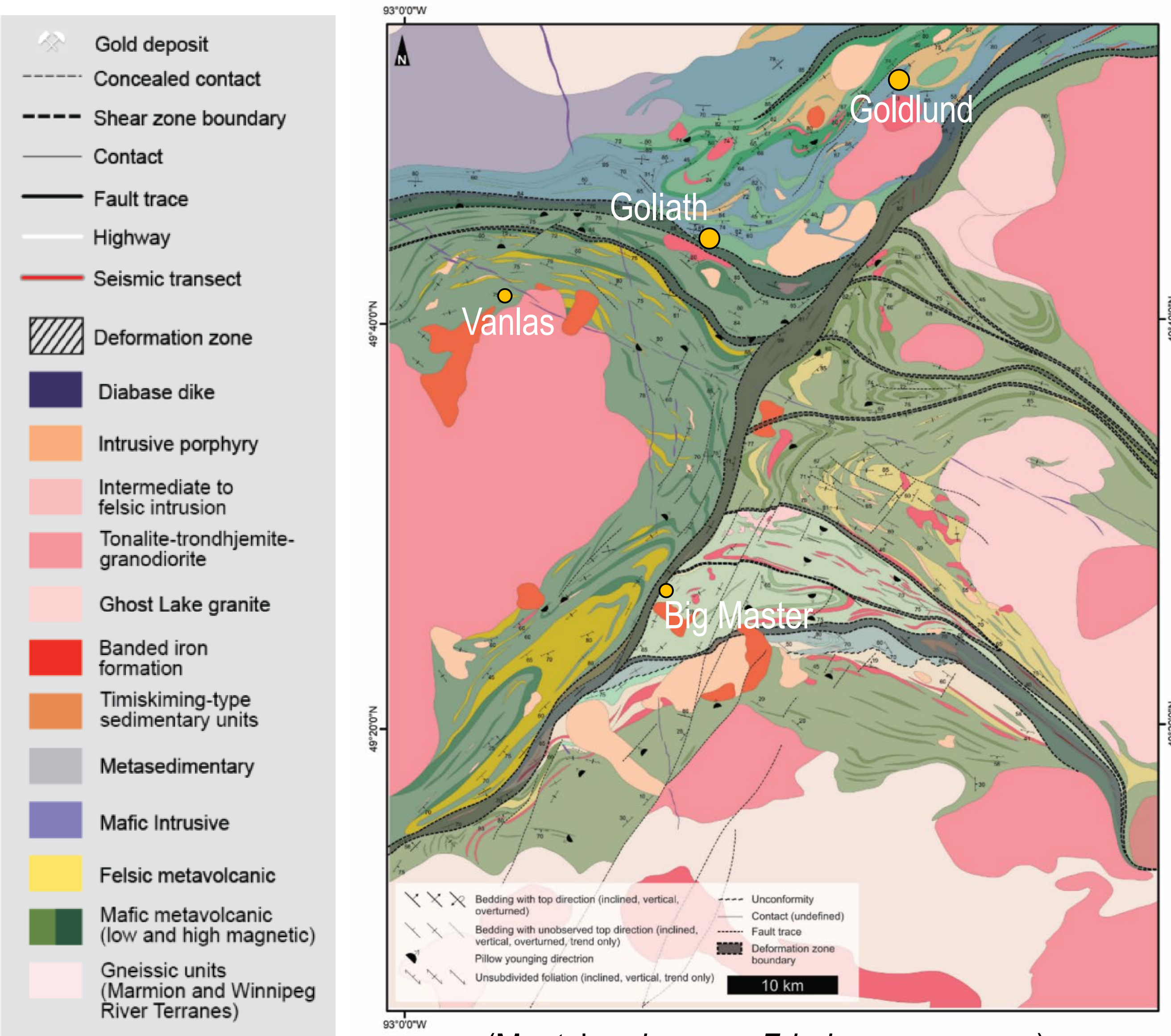
Deep Into the Chibougamau Area, Abitibi Greenstone Belt: Structure of a Neoarchean Crust Revealed by Seismic Reflection Profiling

Lucie Mathieu[1], David B. Snyder[2], Pierre Bedeaux[1], Saeid Cheraghi[2], Bruno Lafrance[2], Phil Thurston[2], and Ross Sherlock[2]

Waibigoon Transects



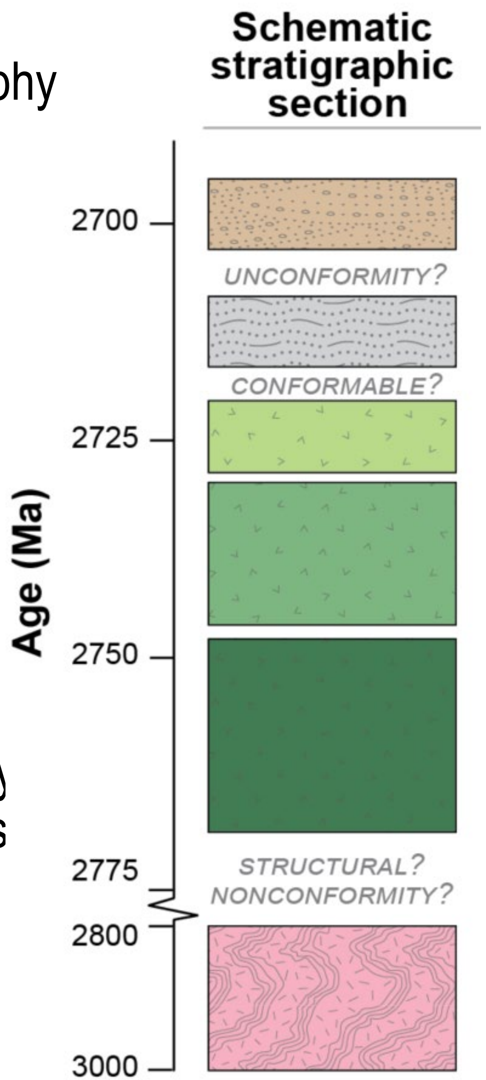
Dryden Area Geology



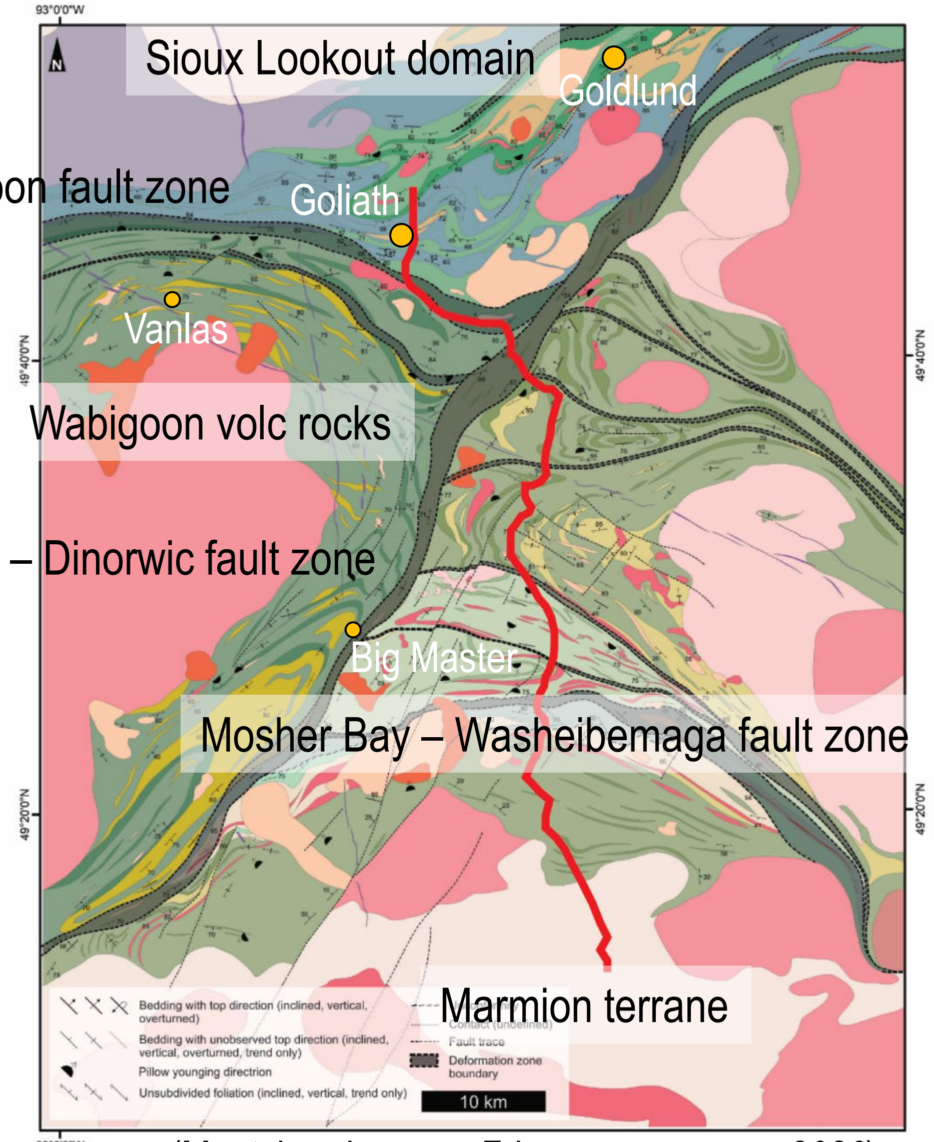
(Montsion, *in prep.*, Friedman pers. com)

Supracrustal stratigraphy

- ~2750-2715 Ma bimodal volcanic successions
- 2715-2710 Ma turbiditic rocks (Sioux Lookout domain)
- 2705-2695 Ma coarse clastic sequences (Stormy and Manitou Lakes Groups)



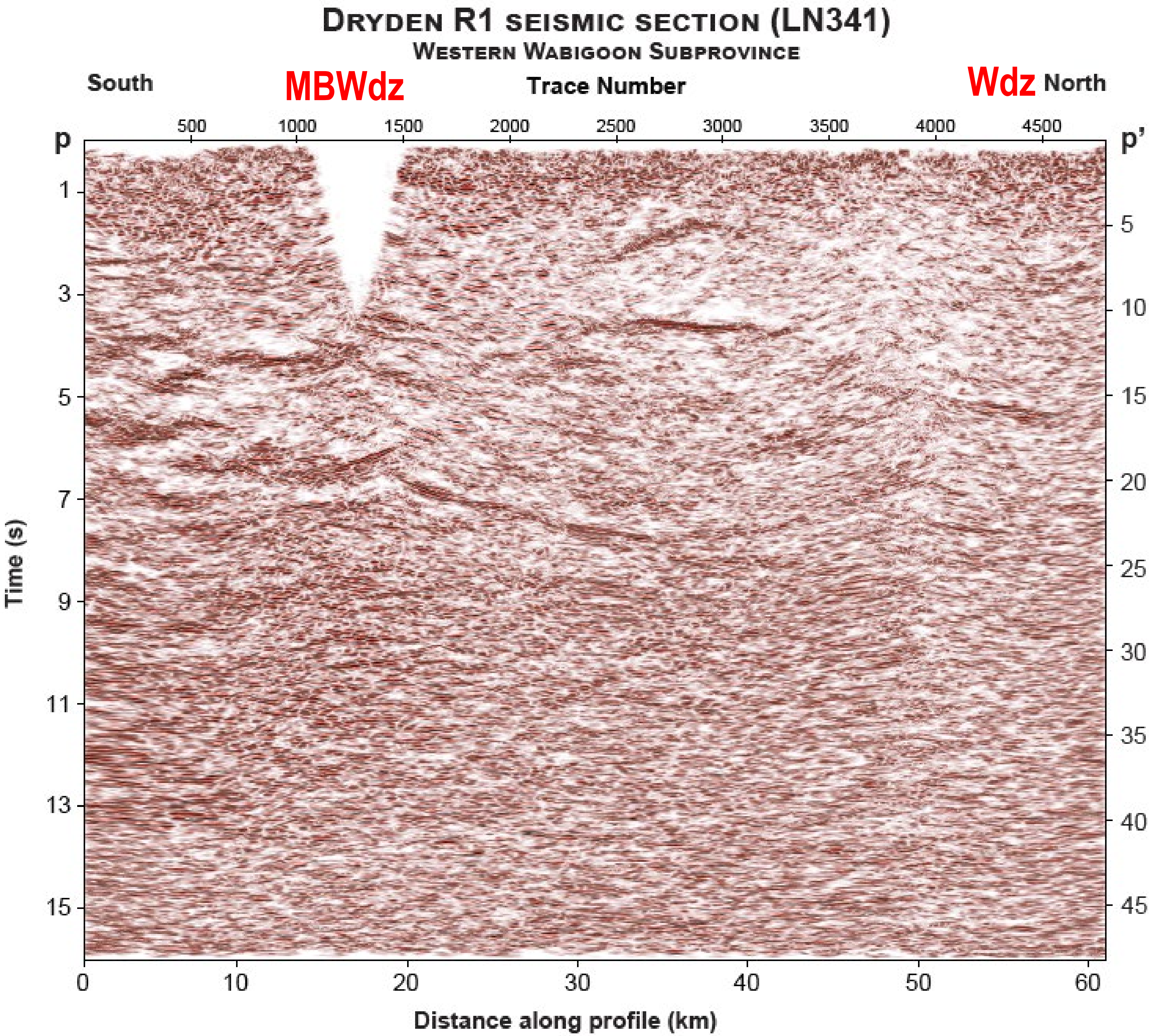
Dryden Area Geology



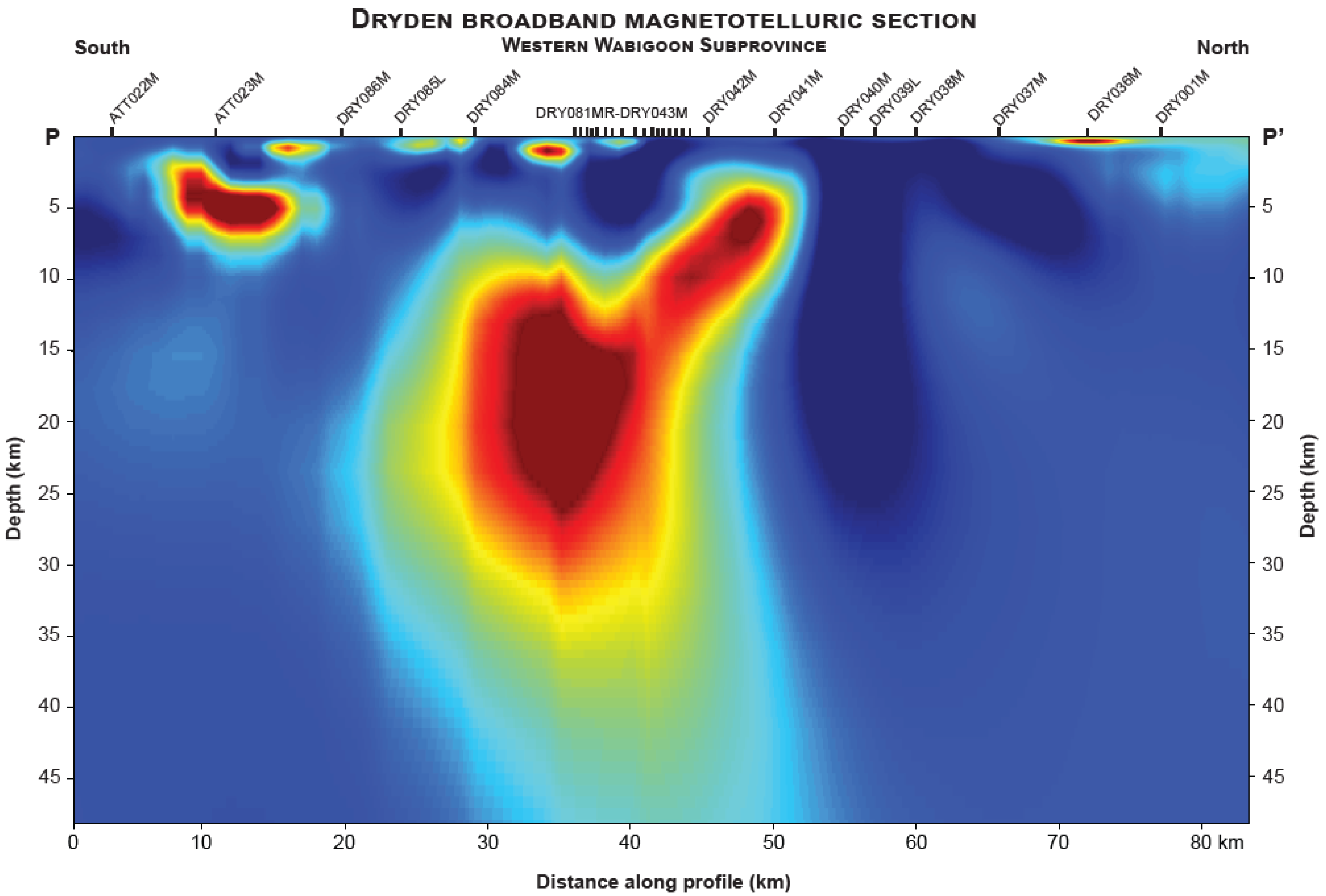
(Montsion, *in prep., Frieman pers. com. 2020*)

Dryden Ar

No seismic transparency zones



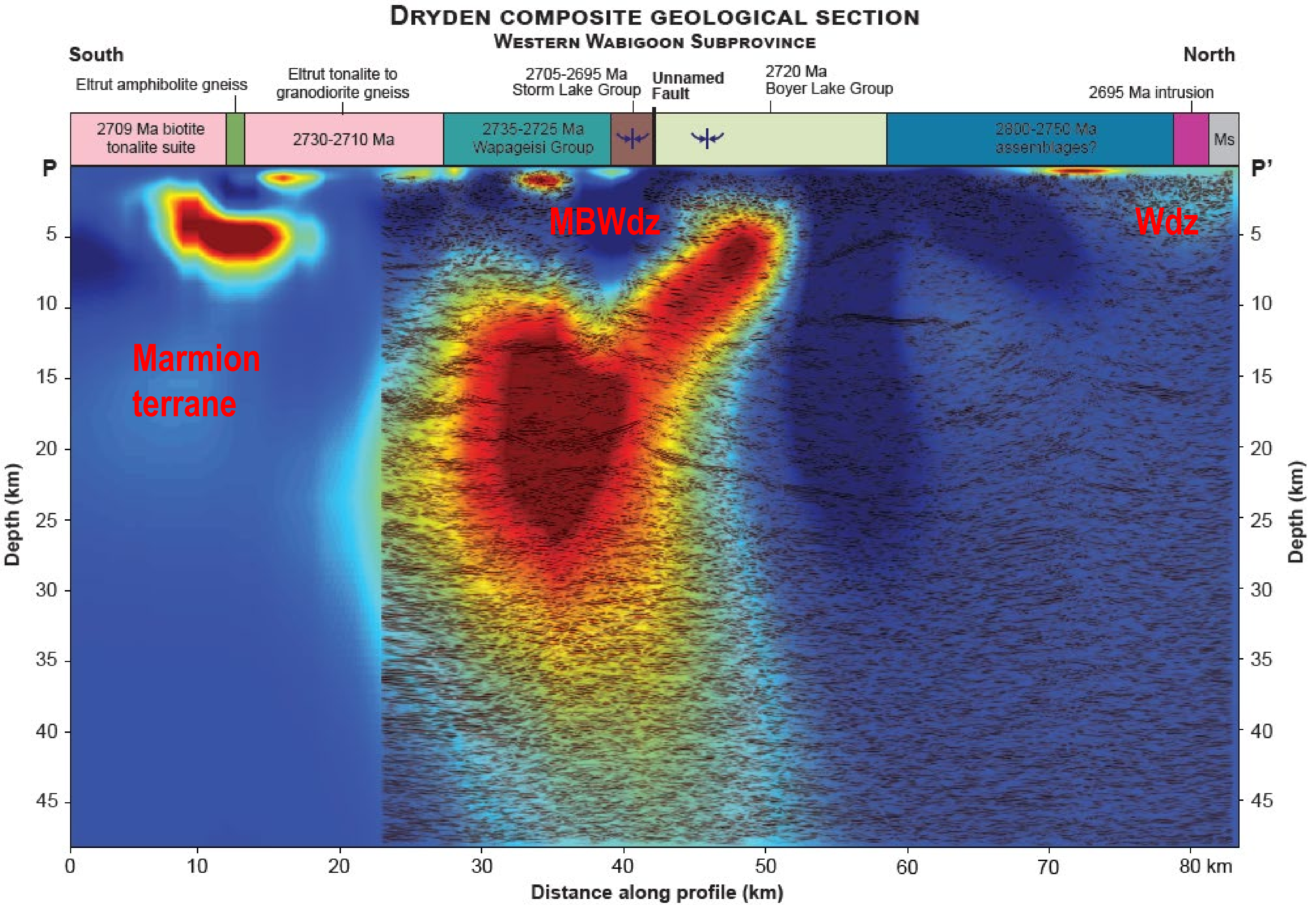
Dryden Area Seismic



Dryden Are

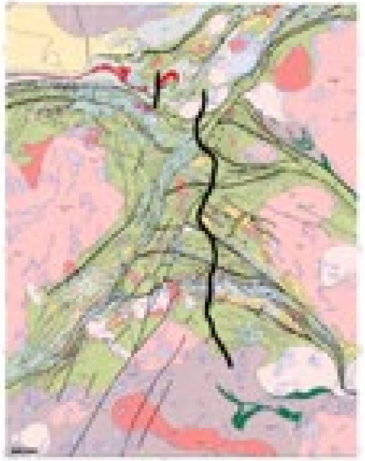
No seismic transparency zones

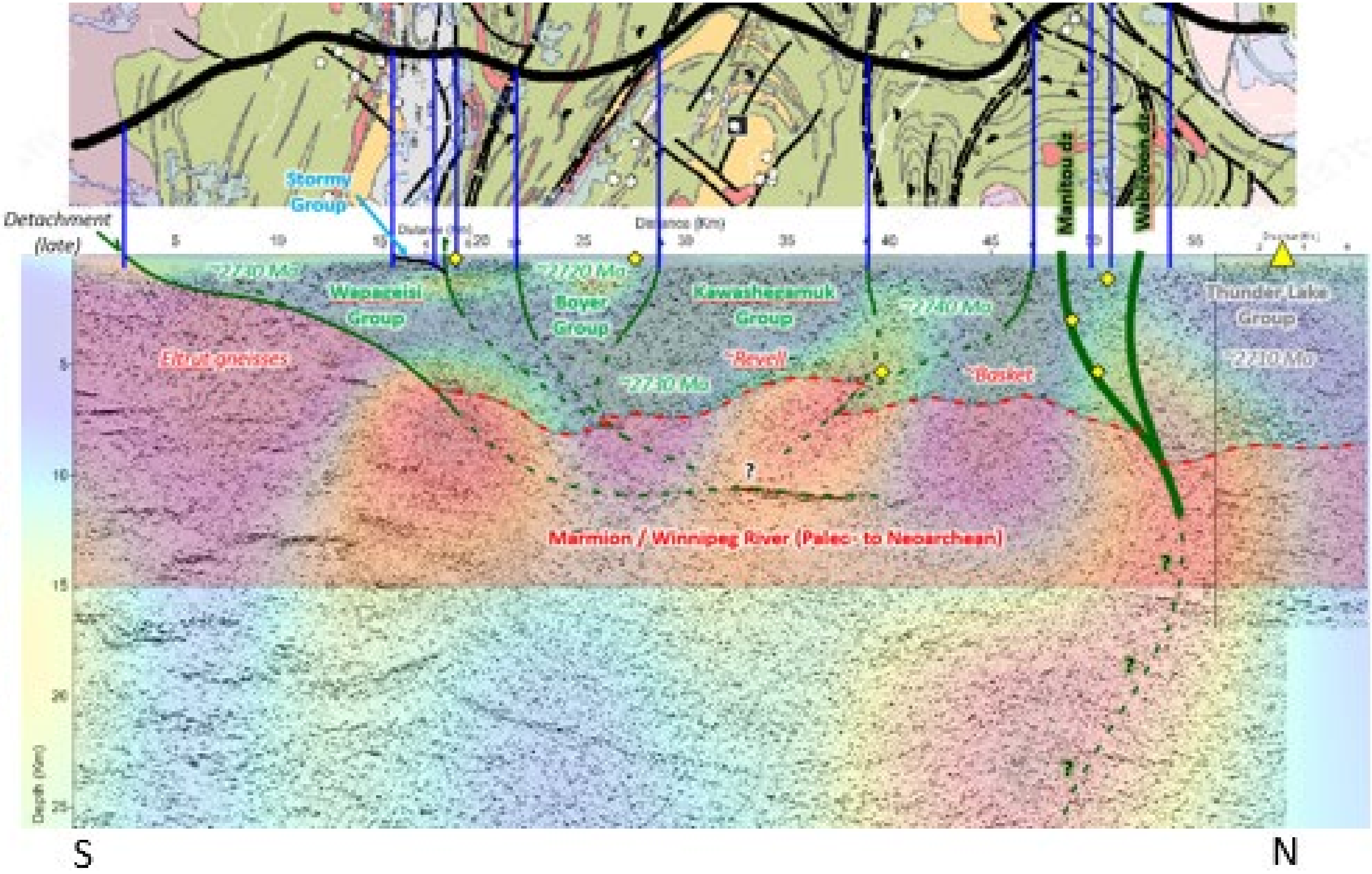
No upper – mid crust conductivity contrast



Dryden Area Seismic / MT

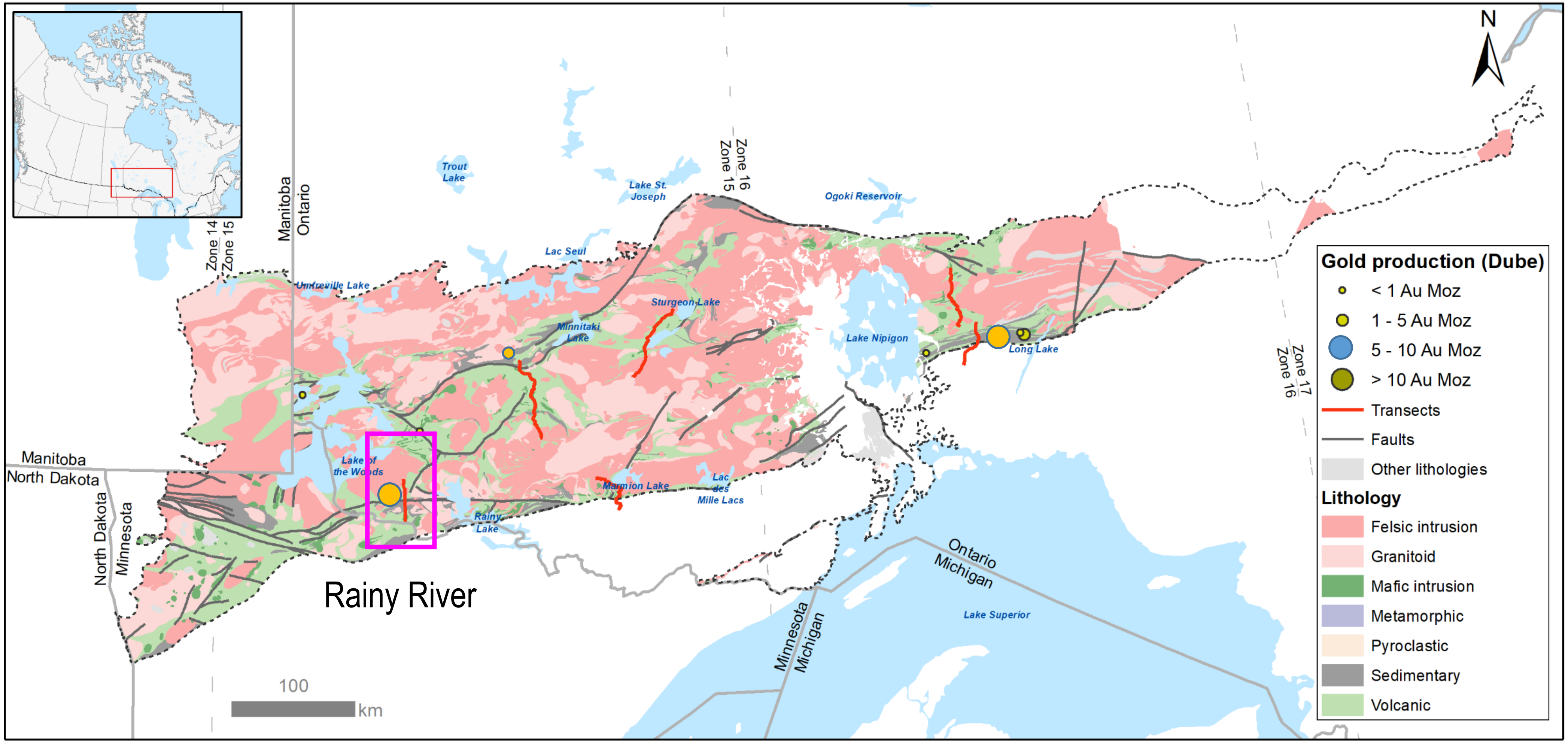
Seismic
& MT





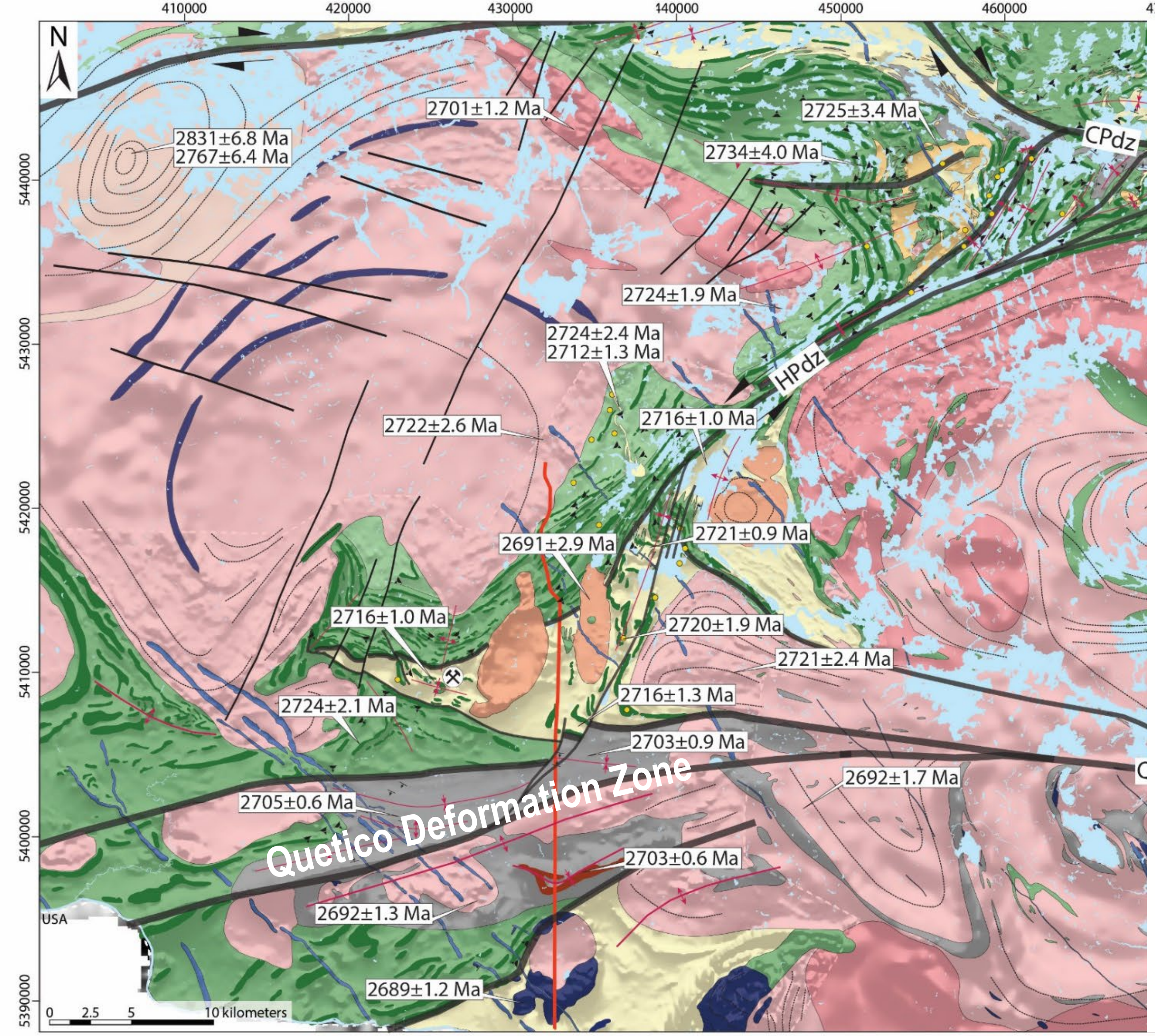
- More resistive crust
- Few if any conductive zones reaching surface
- Listric , shallower faults
- Underplatted by Marmion terrane

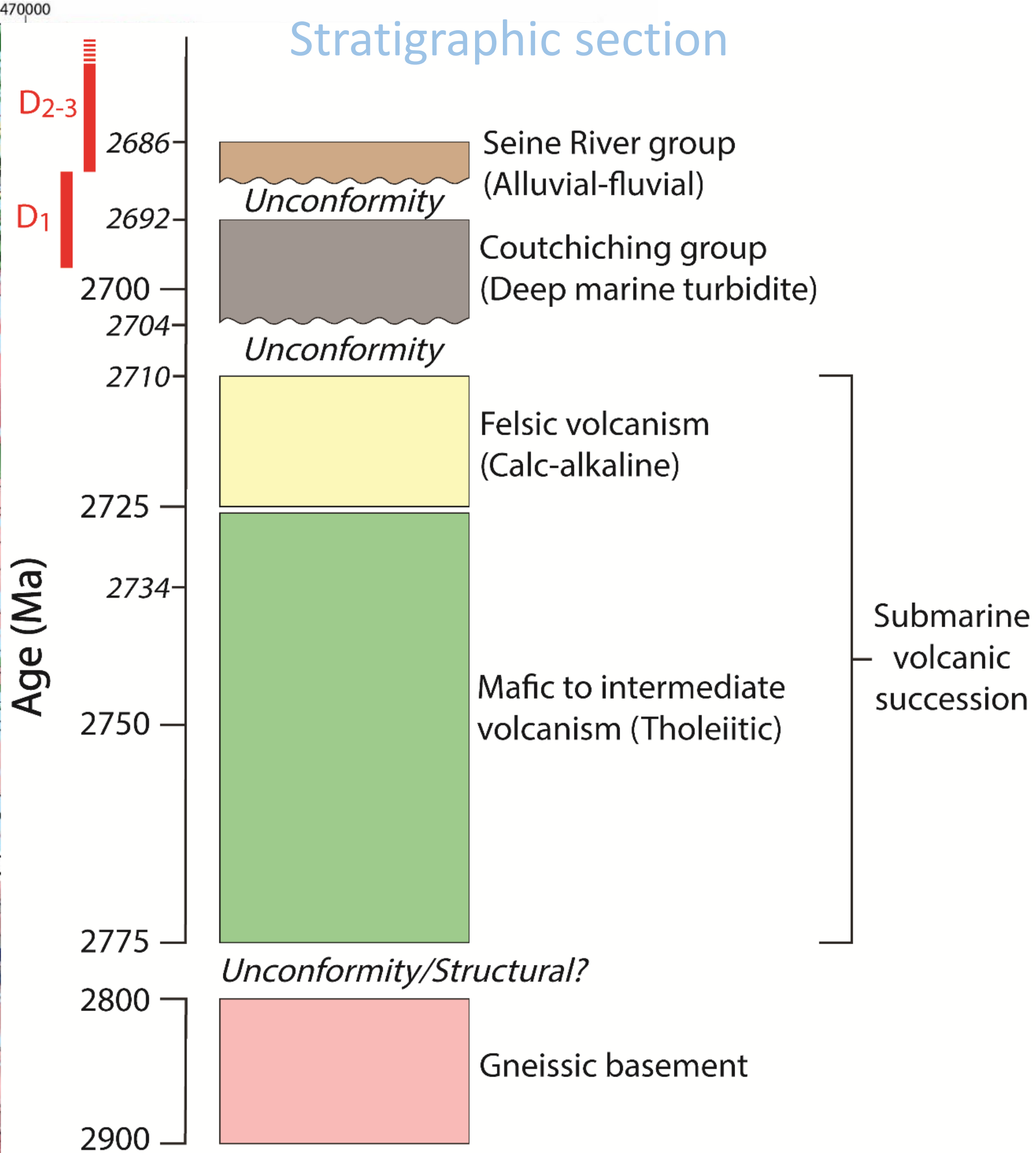
Waibigoon Transects



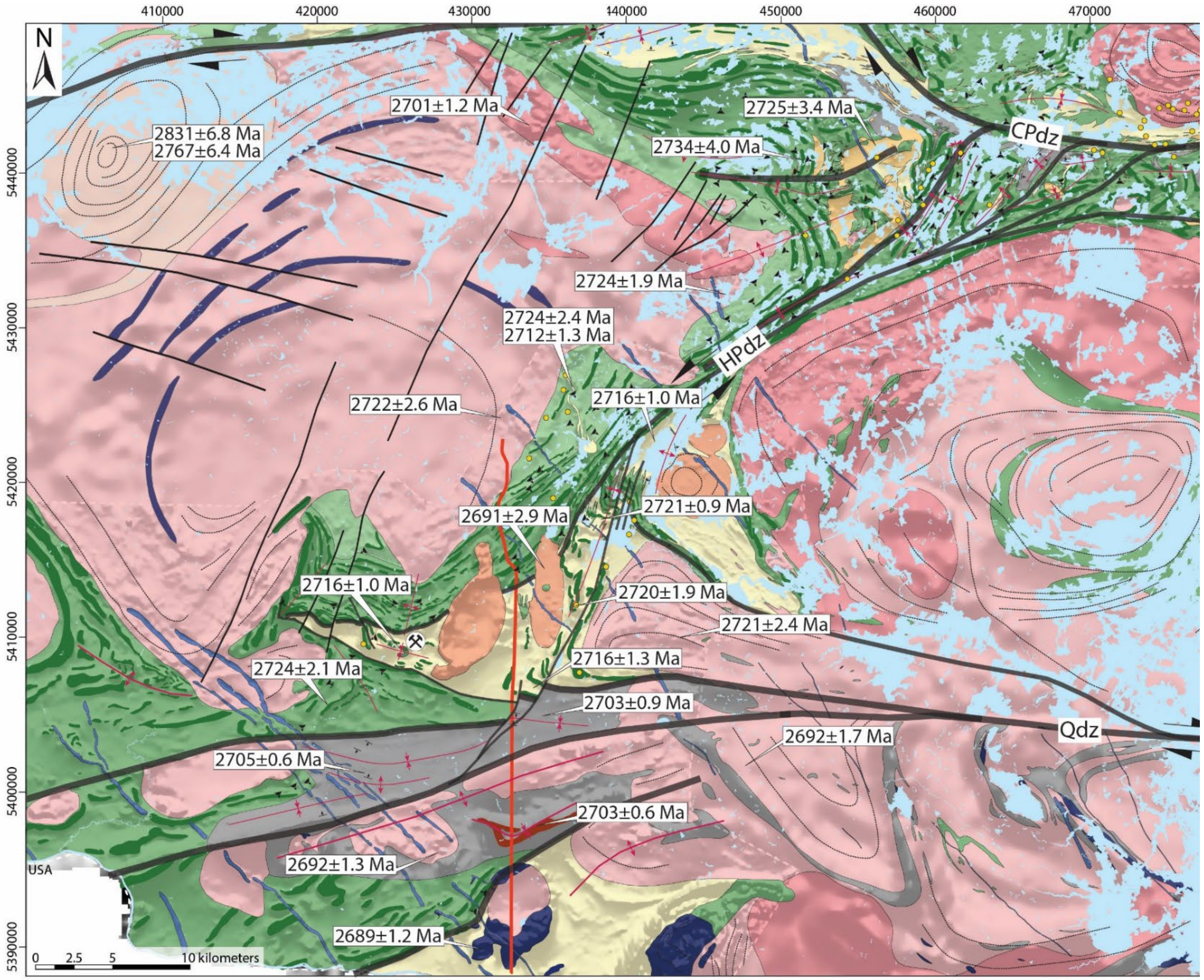
Rainy River transect – Regional geology

New geologic map increased geochron constraints





Rainy River transect – Regional geology

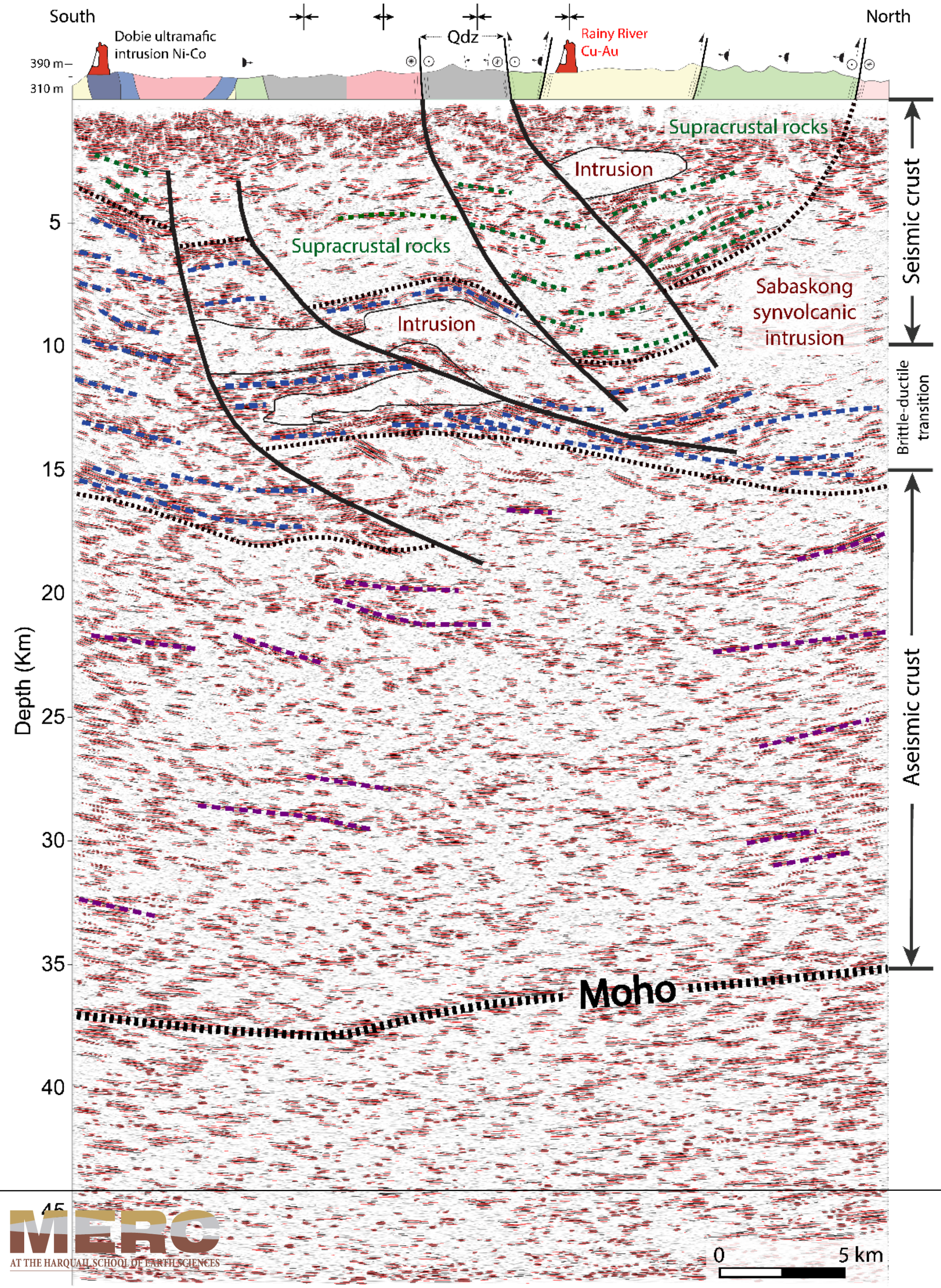


- **Synvolcanic Au-Ag-rich sulphide deposits (Rainy River 3.7 Moz of Au/9.4Moz of Ag):**
  - Relationship with Qdz?
- **Synorogenic sedimentary basins and major deformation (Qdz) zones**

BUT poorly endowed:

- Crustal stratigraphy and architecture
- Comparison with endowed transects from the Abitibi subprovince
- What parameters control the endowment of deformation zones?

Crustal architecture of the RRGB – R1 seismic profile



Upper crust:

- Weak seismic reflectivity
- Reflectors (sills/dikes?) dip toward to the S in the northern part and toward to the N in the southern part (Dome-and-keel structure?)
- Lower limit of the RRGB at ~5-9 km

Middle crust:

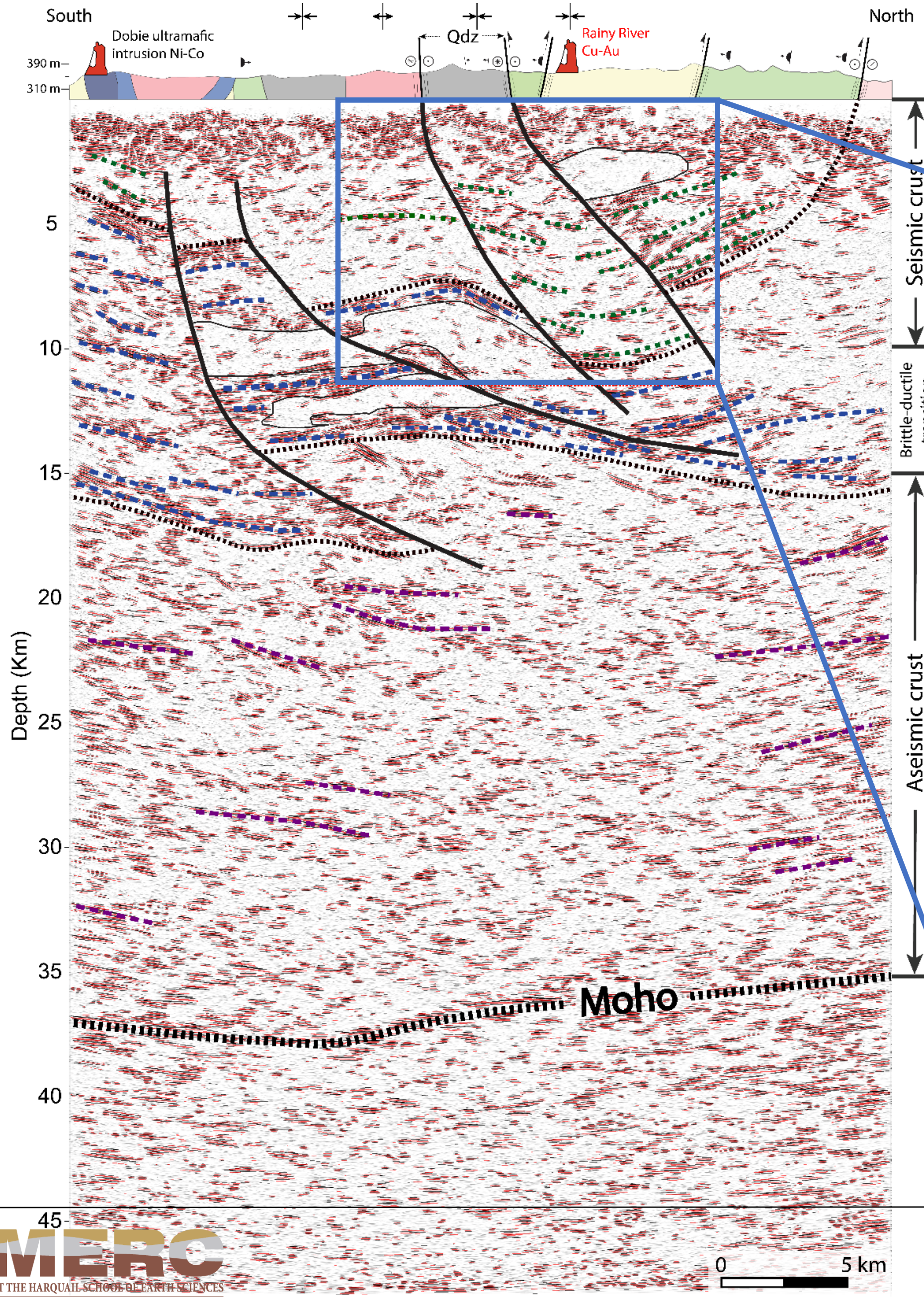
- Reflective crust between 9 and 15 km
- Less reflective domains = probable intrusions
- Interlayered mafic and TTG gneiss
- Depth extent of faults ~12-15 km

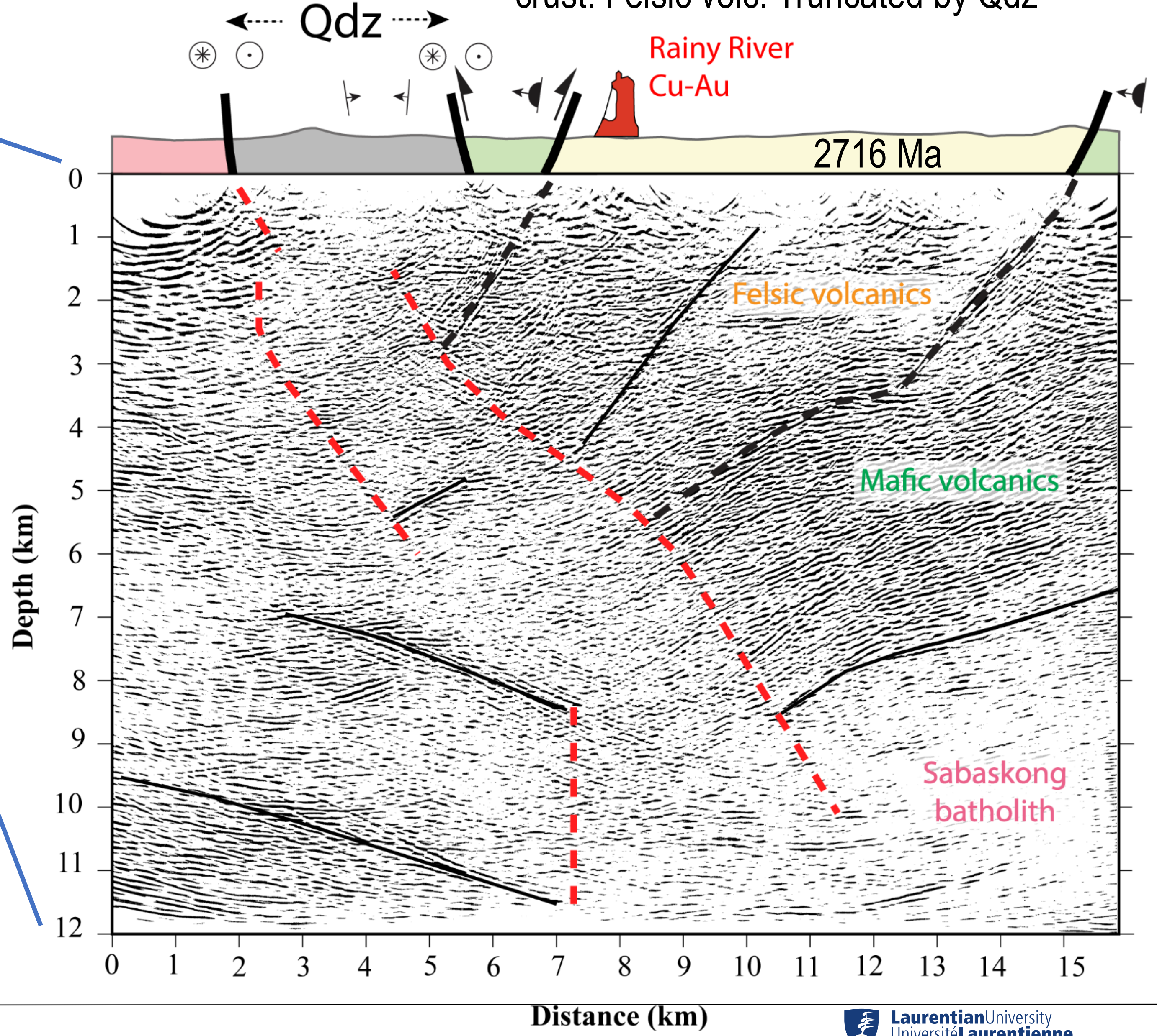
Lower crust:

- Weak seismic reflectivity
- Subhorizontal reflectors
- Ductile homogeneous crust?
- Moho at ~37 km

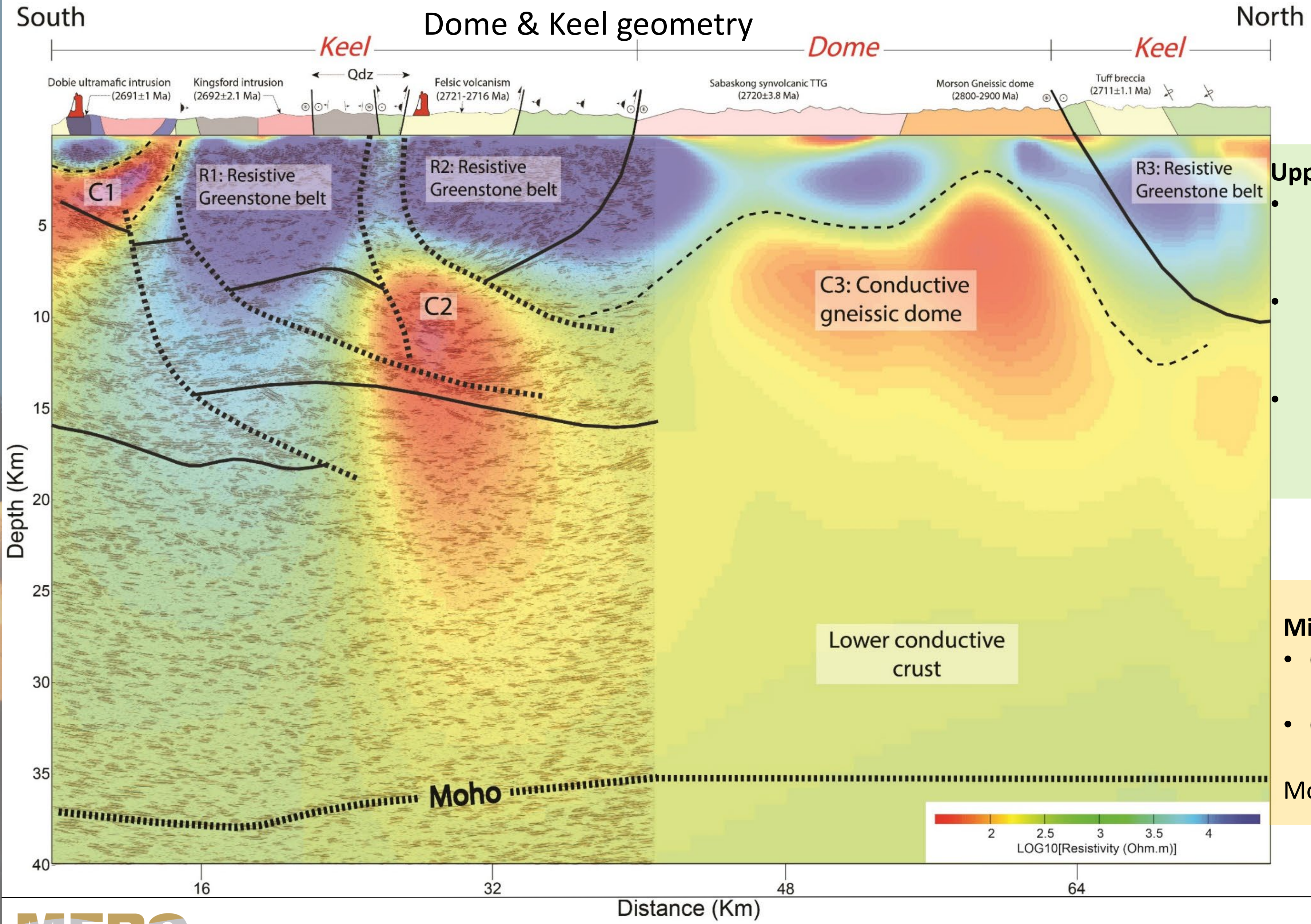
Crustal architecture of the RRGB – R2 seismic profile

No strong geophysical response to lower crust. Felsic volc. Truncated by Qdz





Crustal architecture of the RRGB – Full crustal seismic and MT



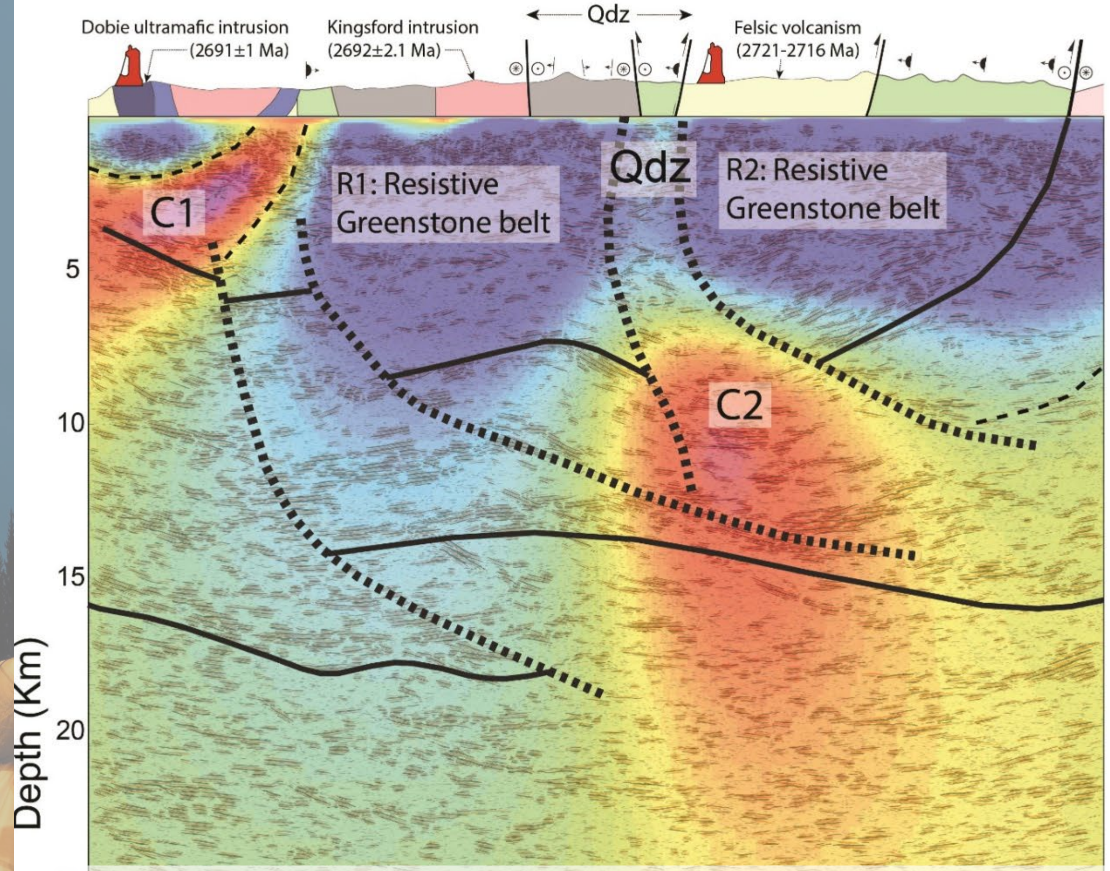
Upper crust:

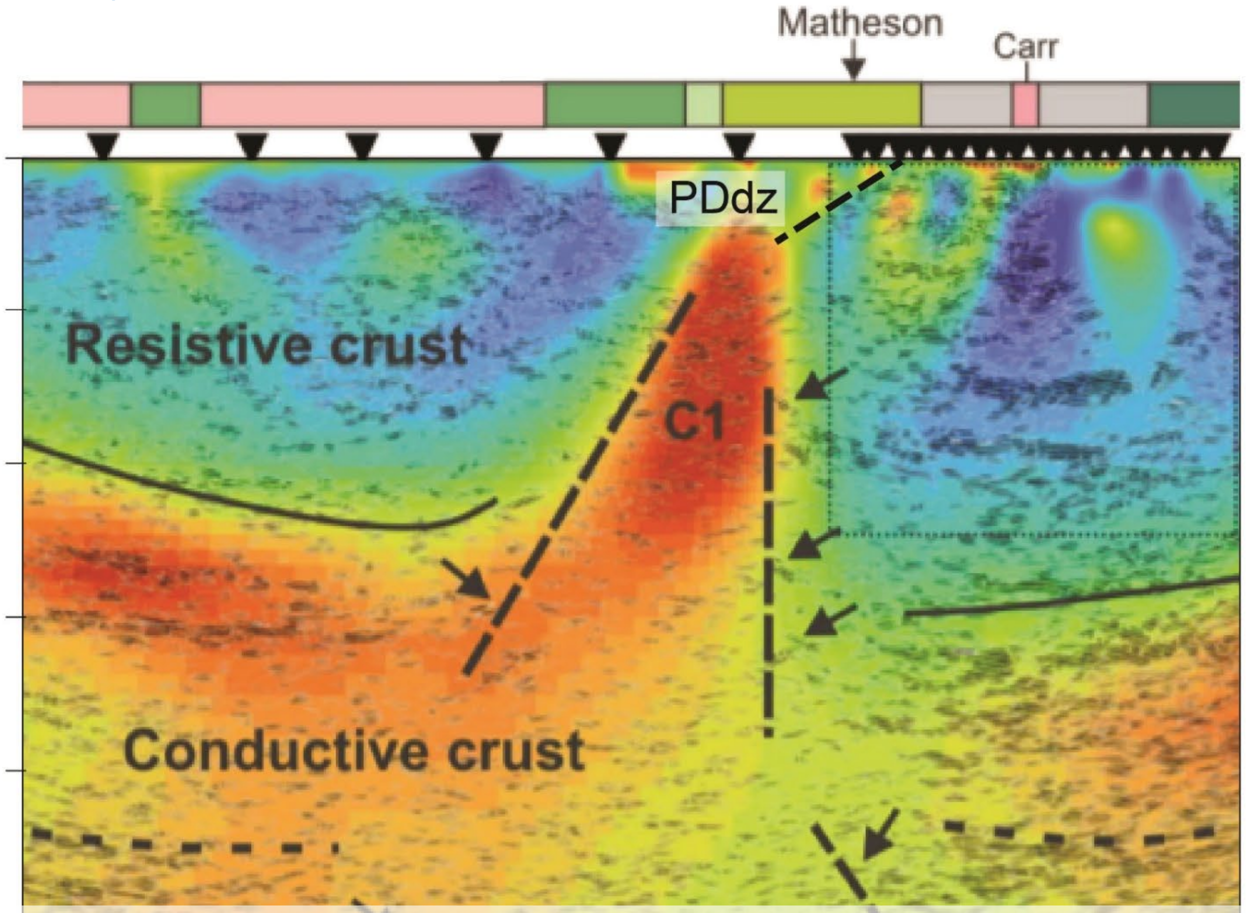
- Resistive crust (R1, R2 and R3 anomalies)
  = Greenstone belts
- Subvertical relatively conductive corridor (C2) = depth extension of the Qdz?
- Conductive zone to the South (C1)
  = Ni-Cu Dobie ultramafic intrusion

Middle and lower crust:

- Conductive lower crust
  = TTG gneisses
- C3 conductive anomaly
  = Gneissic dome related to Morson gneissic dome on surface?

Effects of fault geometry on gold endowment? – Comparison with the Matheson transect





Rainy River transect:

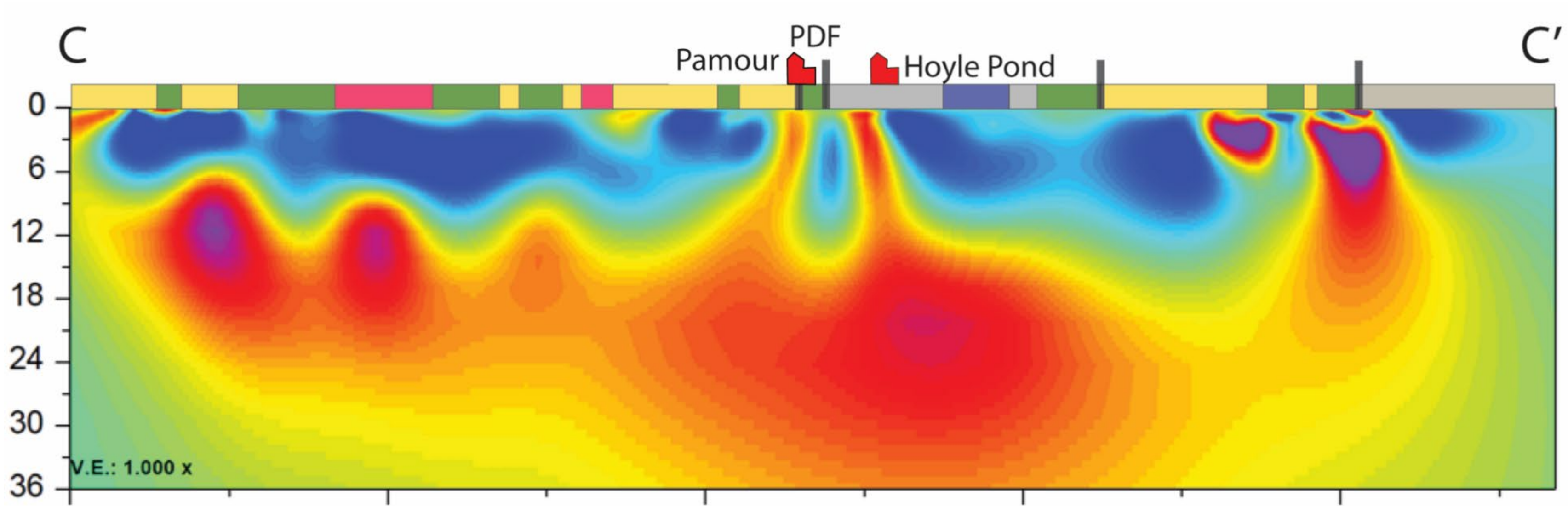
- Limited depth extension of the Qdz (~12 km)
- Faults are listric at depth
- Moderate conductive corridor = moderate alteration and fluid flow
- Absence of a deep seated mineralizing system
- **Absence of gold deposits on surface**

Matheson transect:

- Deep rooted PDdz (~30km)
- Faults are steep
- A deep-crustal conductive corridor connects the lower crust with the surface geology
- Existence of a deep seated mineralizing system – PDdz
- **Gold deposits on surface**

Haugaard et al., 2021

Geophysical signatures – Characteristics of fertile faults



All models display similar characteristics:

- Marked by clastic sedimentary rocks, some fertile some less fertile
- Largely resistive upper crust, base of greenstones
- Localized low resistivity zones (fingers) in upper crust linked to laterally extensive mid-lower crust/upper mantle. Mapping fertile breaks
- Seismic opaque
- Interp as changes to rock properties as a result of fluid flow, in large breaks cutting the greenstones

What are the differences between sections of variable endowment

Areas with weaker metal endowment why ?? Grossly similar geology

- Weaker precious and base metal fertility in the supracrustal rocks ?
- Difference in volcanic rocks (ultramafic flows are notably absent in the Wabigoon)
- Was the timing of fluid generation different that the timing of deformation in the fault system
- Differences in overall lithospheric architecture, under plating by different substrate ?
- Differences in the geodynamic processes

Great Bear Resources Corp. presentation, June 2021

Major Structures Control the Gold

Two places in Red Lake where large structures bring gold to surface

1

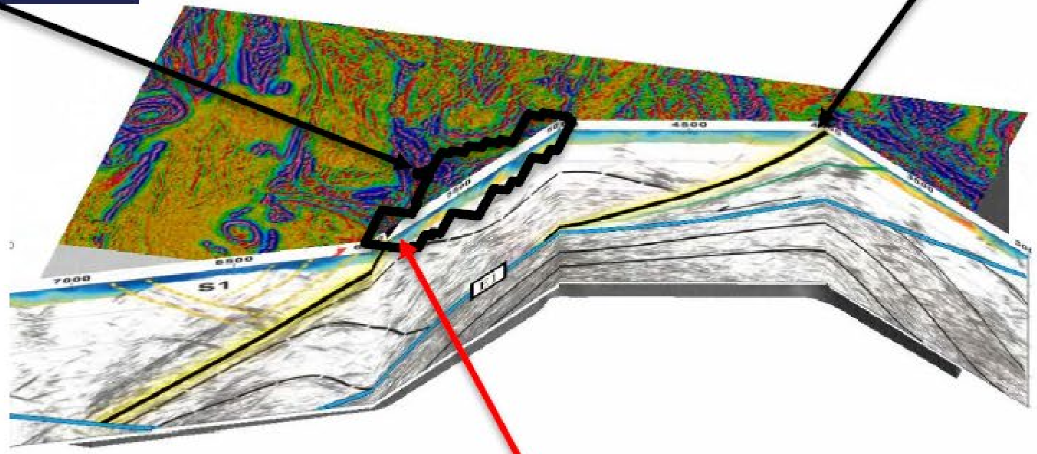
Red Lake Mine Complex
Cumulative gold production of 25 million ounces

2

LP Fault
Four gold zones drilled to date with apparent continuity being drilled over 4km, within an 18km target

Dixie Project

1 Red Lake Mine Complex (Evolution Mining)

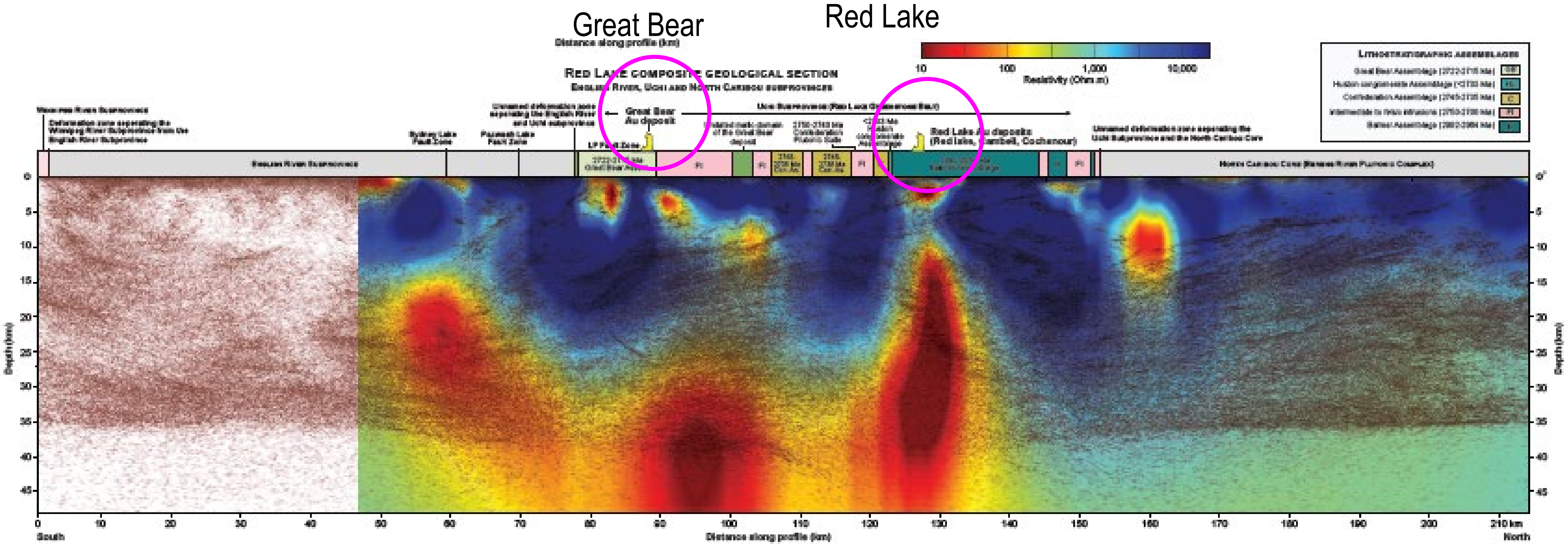


2 Great Bear's LP Fault Zone

Seismic cross section after Zeng & Calvert, 2006

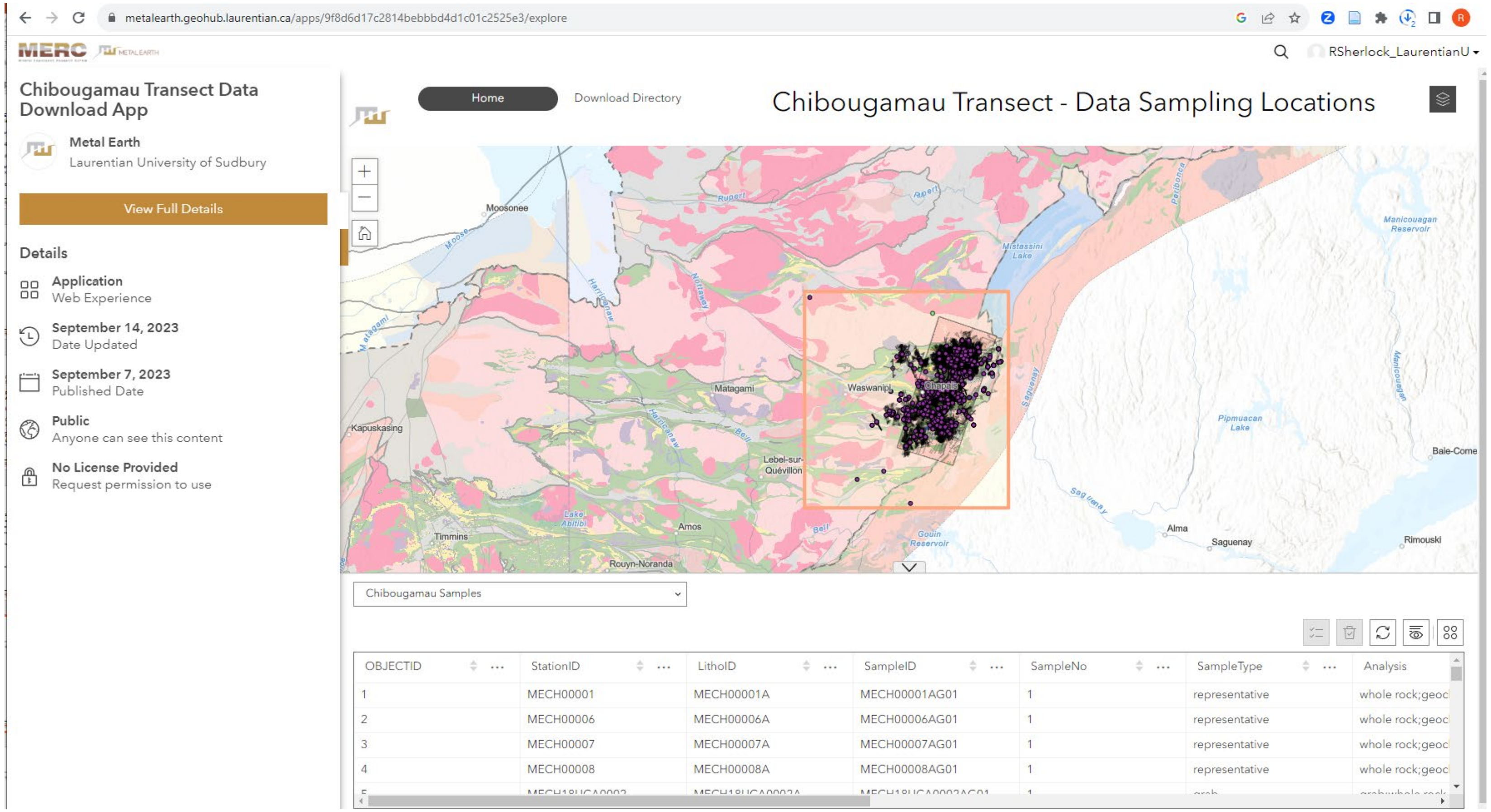
Lithoprobe dataset

Metal Earth MT over Lithoprobe seismic



Lithoprobe dataset

Metal Earth Data online now



Geology
Geochemistry
Gravity
MT
Seismic

Geochron database (separate)

Superior Map

New Abitibi Map across jurisdictions

All open source

https://metalearth.geohub.laurentian.ca/

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