The geophysical contributions to the Metal Earth project

Richard Smith, Mostafa Naghizadeh, Saeid Cheraghi, Ademola Adetunji, Rajesh Vayavur, Esmaeil Eshaghi, Graham Hill, David Synder, Eric Roots, Fabiano Della Justina, Hossein Jodeiri Akbari Fam, Christopher Mancuso, William McNeice, Amir Maleki, Rasmus Haugaard, Taus Jørgensen, Phil Wannamaker, Virginie Maris

Metal Earth project

- Multidisciplinary project to understand the controls on mineralization in Precambrian terranes

    - Geology
    - Geochemistry
    - Geochronology
    - Geophysics
        - Seismic (active and passive)
        - Magnetotelluric
        - Gravity
        - Magnetics
        - Borehole logging (no published results yet)
    - Primarily focussed on the crust down to the core-mantle boundary

- Geology/Geochem/Geochron is primarily from surface rocks
- The geophysics has been the primary tool in the shallow, mid and deeper crust.

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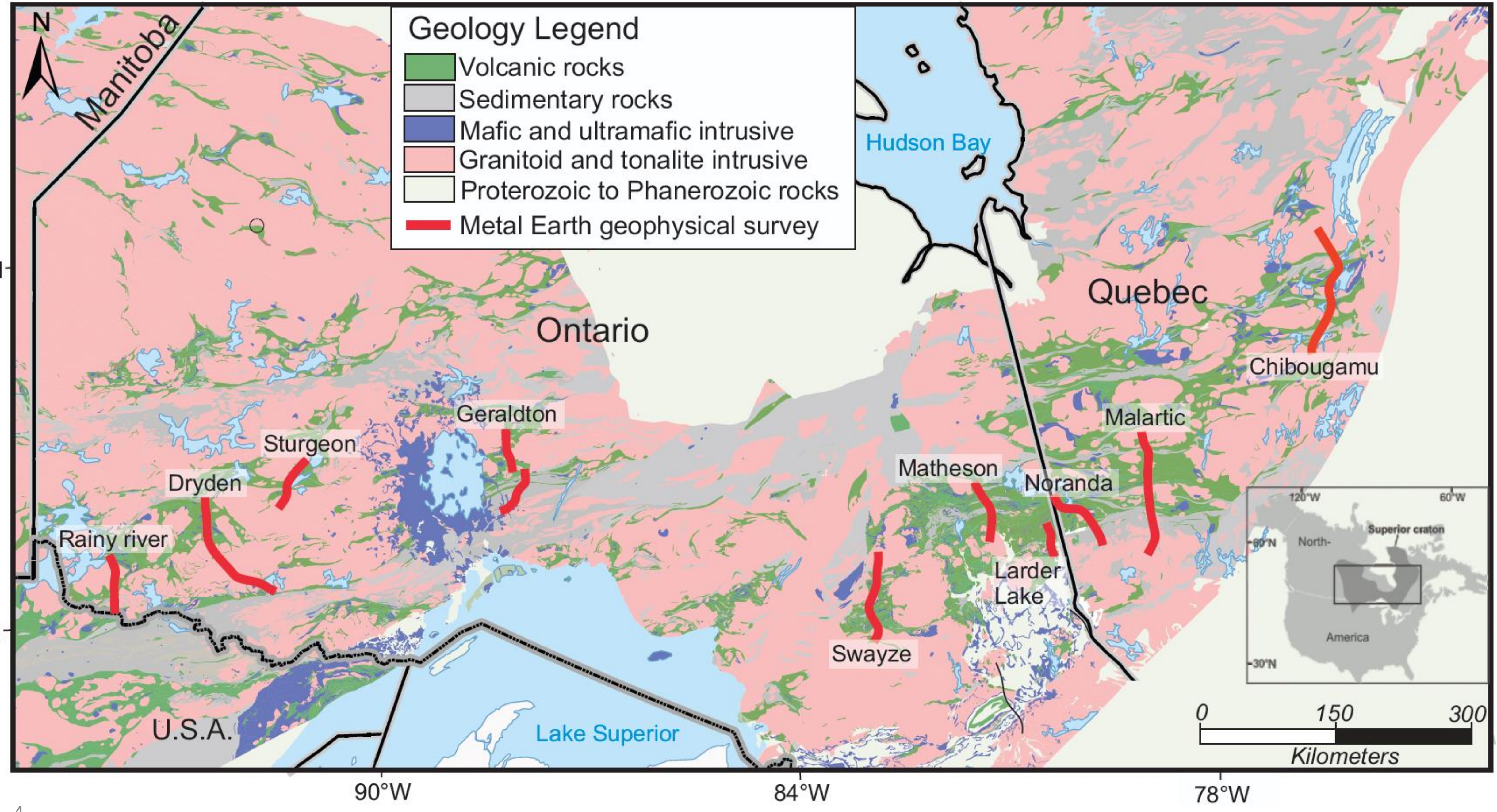
Metal Earth Ultimate Goals

- Tell the difference between endowed and un-endowed areas
- Devise exploration strategies for finding the endowed areas

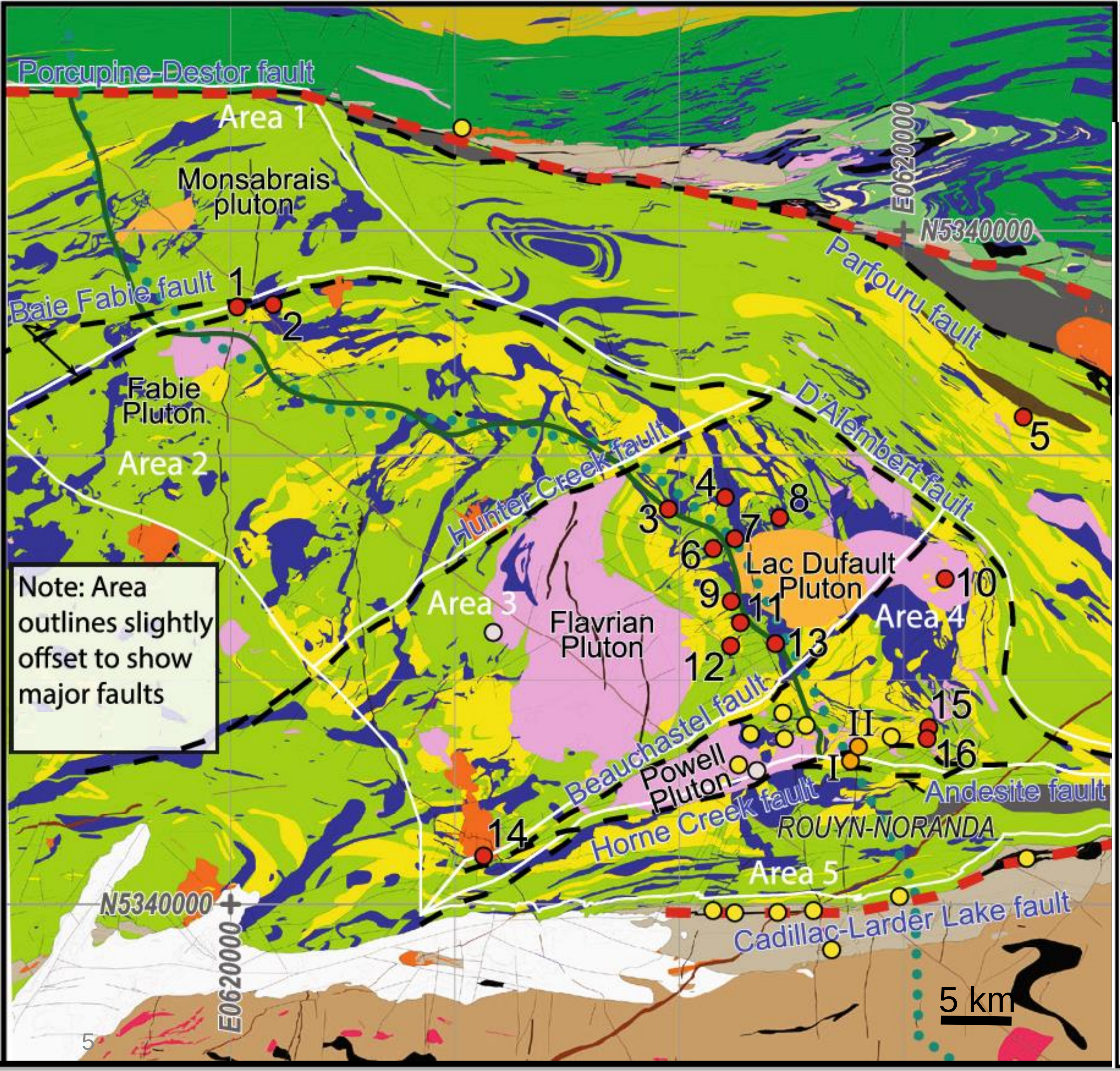

Geology Legend
Volcanic rocks
Sedimentary rocks
Mafic and ultramafic intrusive
Granitoid and tonalite intrusive
Proterozoic to Phanerozoic rocks
Metal Earth geophysical survey
N
Manitoba
Hudson Bay
Ontario
Quebec
Chibougamu
Malartic
Geraldton
Sturgeon
Dryden
Rainy river
Matheson
Noranda
Larder
Lake
Swayze
U.S.A.
Lake Superior
52°N
48°N
90°W
84°W
78°W
0
150
300
Kilometers
120°W
60°W
Superior craton
60°N
North-
America
30°N

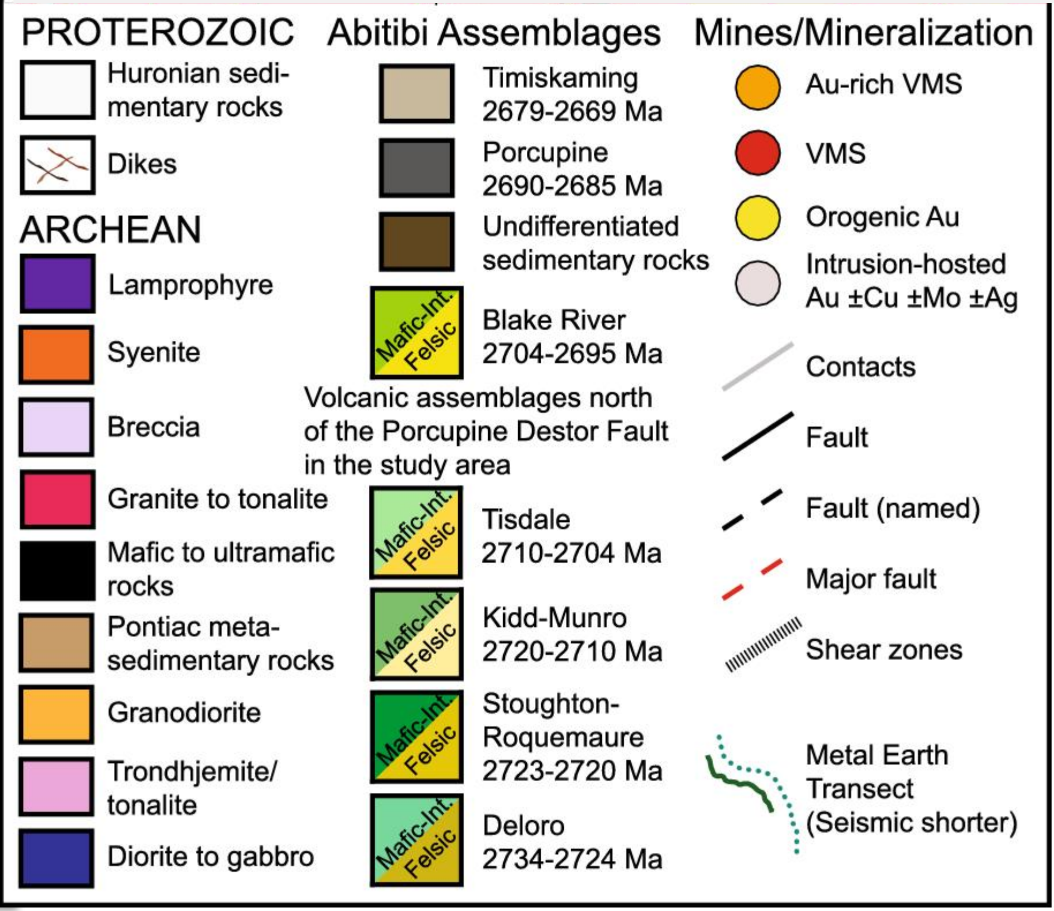
Noranda Transect

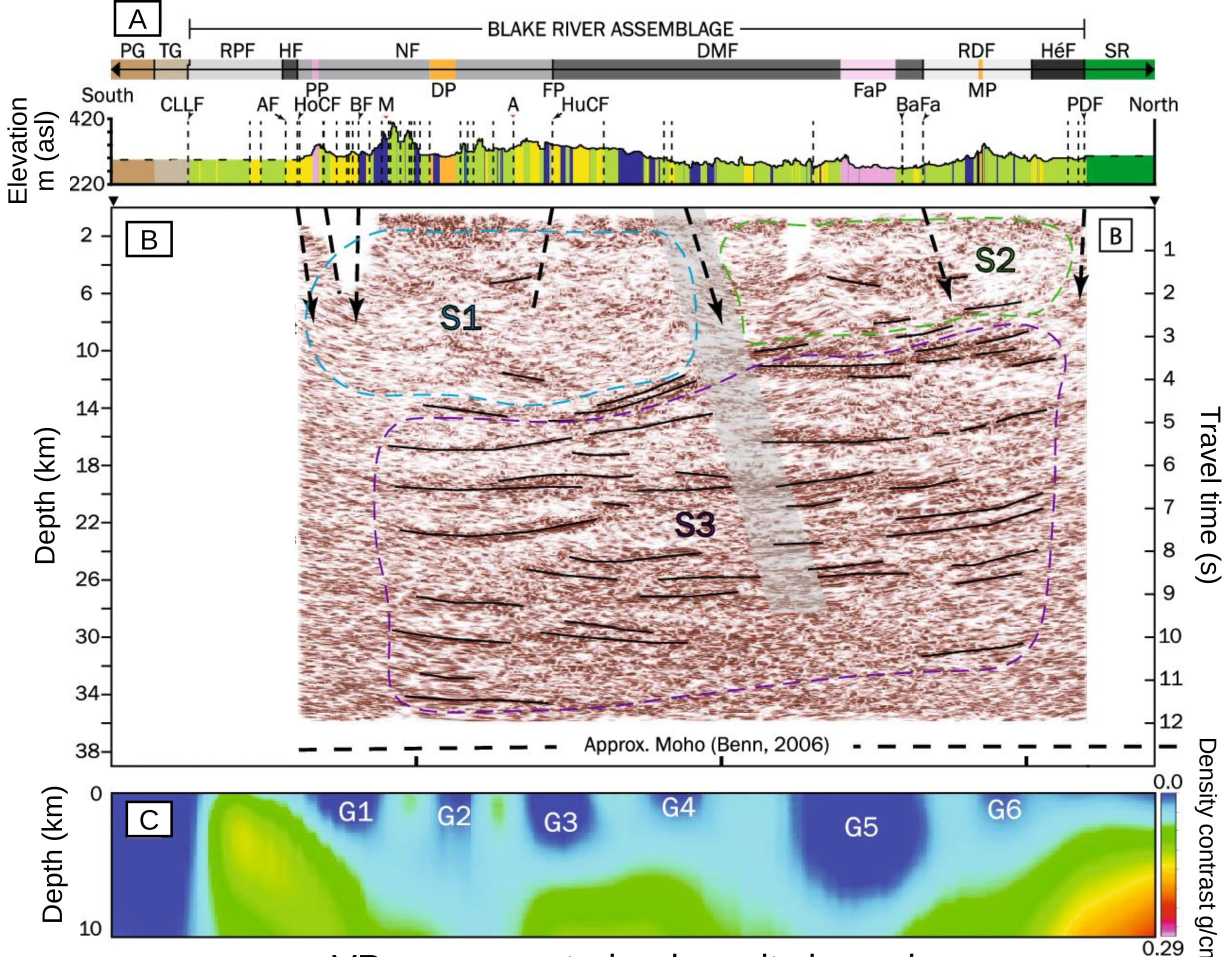
Jørgensen et al., 2022, Sci. Reports.

Key to Copper Mines with associated Au and Zn

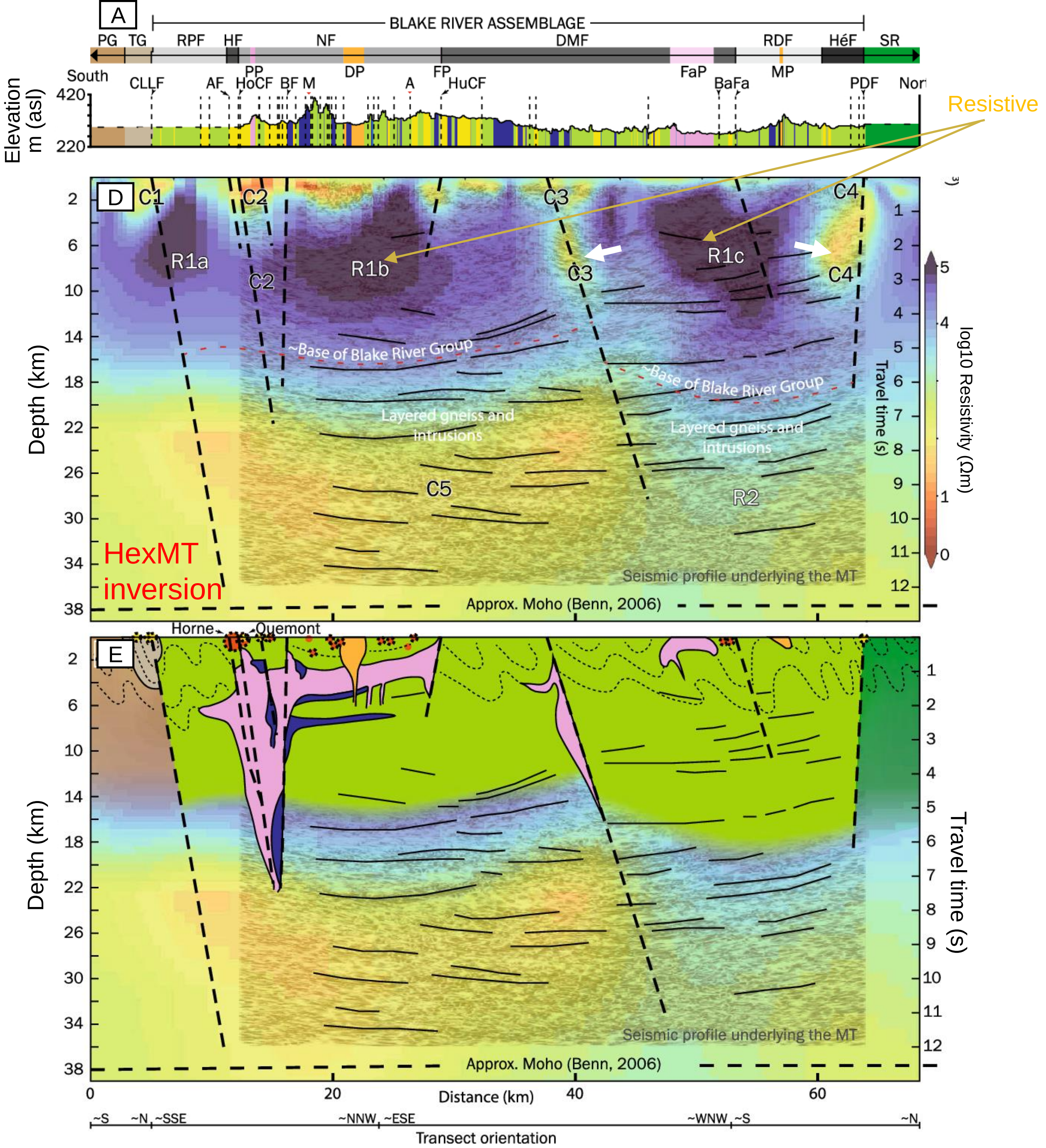
- I. Horne: 54 Mt
- II. Quémont: 17 Mt
- 1. Magusi River: 3.7 Mt
- 2. Fable Bay: 0.89 Mt
- 3. Ansil: 1.6 Mt
- 4. Vauze: 0.35 Mt
- 5. Bouchard-Hebert 20 Mt
- 6. East Waite 1,5 Mt
- 7. Waite: 1.1 Mt
- 8. Norbec 4.5 Mt
- 9. Amulet F: 0.27 Mt
- 10. Gallen: 8.1 Mt
- 11. Amulet A & C: 5.9 Mt
- 12. Corbet: 2.8 Mt
- 13. Millenbach: 3.6 Mt
- 14. Aldermac: 2.9 Mt
- 15. Deldona: 0.09 Mt
- 16. Delbridge: 0.36 Mt







VPmg unconstrained gravity inversion



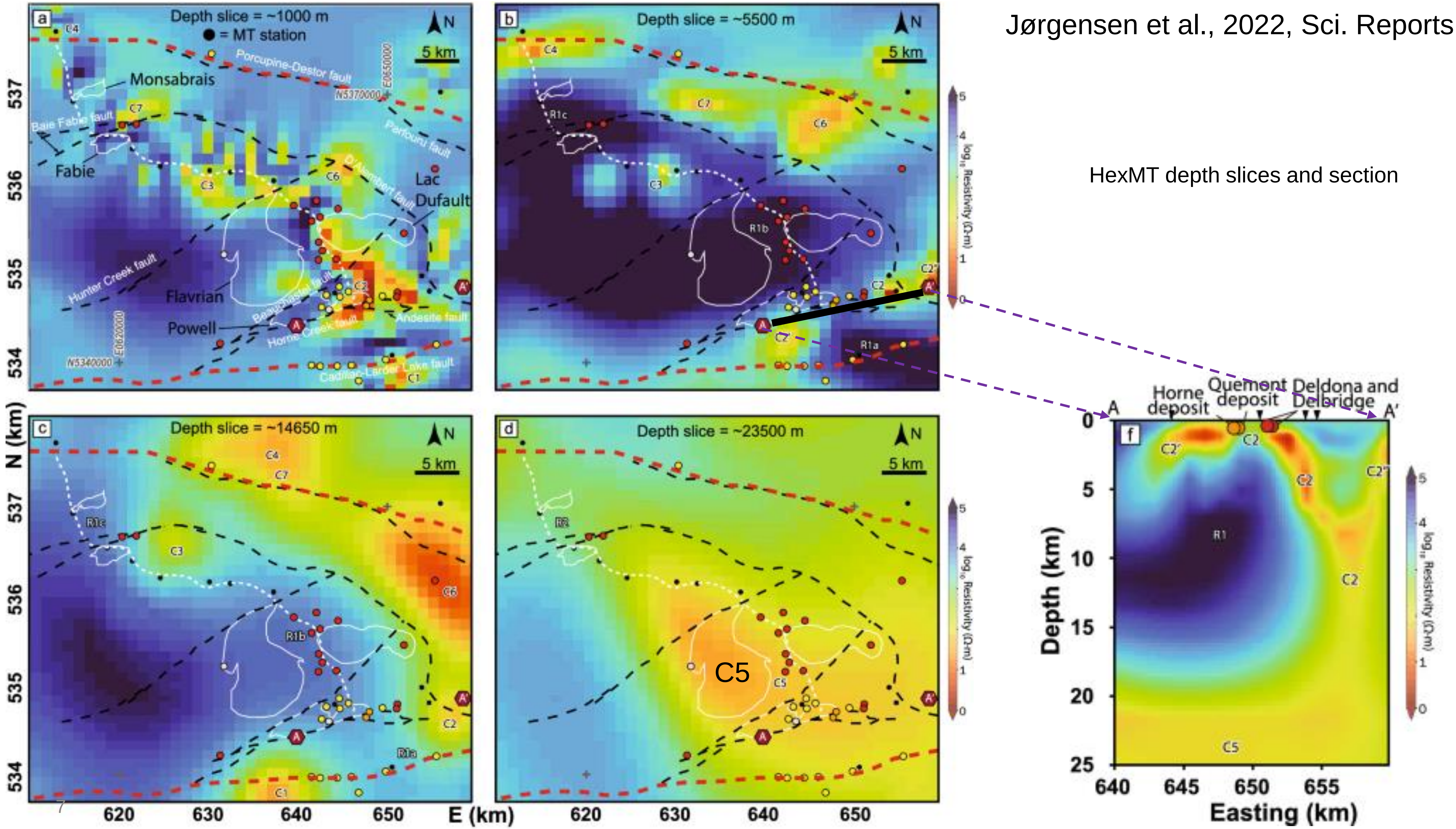
Key to labels on geological sections:

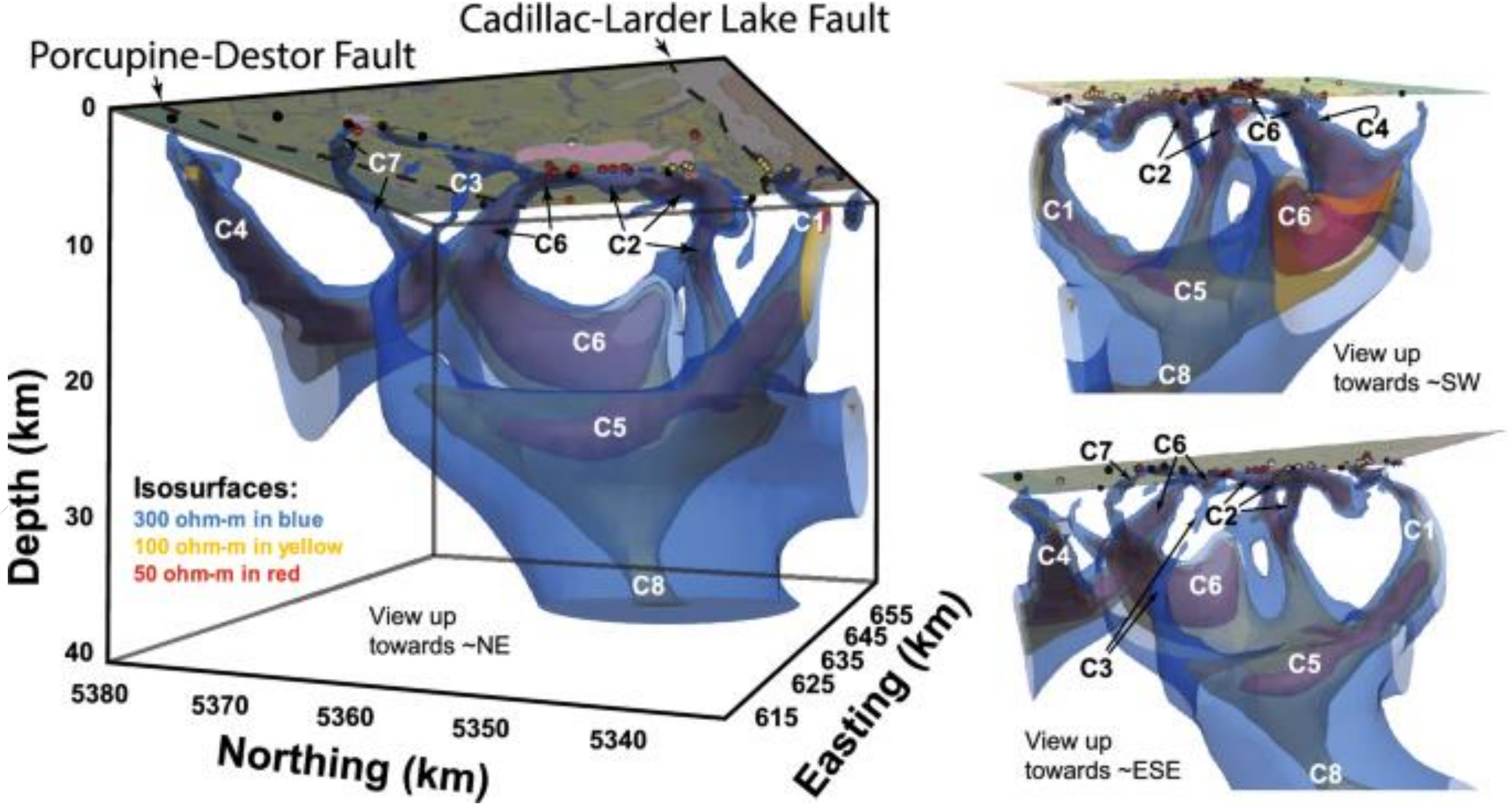
PG: Pontiac Group; **TG**: Timiskaming Group; **RPF**: Rouyn-Pelletier formation; **HF**: Horne formation; **NF**: Noranda formation; **DMF**: Duprat Montbray formation; **RDF**: Reneault-Dufresnoy formation; **HéF**: Hébecourt formation; **SR**: Stoughton-Roquemaure; **PP**: Powell pluton; **DP**: Lac Dufault pluton; **FP**: Flavrian pluton; **FaP**: Fabie pluton; **MP**: Monsabrais pluton; **CLLF**: Cadillac-Larder Lake fault; **AF**: Andesite fault; **HoCF**: Horne Creek fault; **BF**: Beauchastel fault; **HuCF**: Hunter Creek fault; **BaFa**: Baie Fabie fault; **PDF**: Porcupine-Destor fault.

Jørgensen et al., 2022, Sci. Reports.

Jørgensen et al., 2022, Sci. Reports.

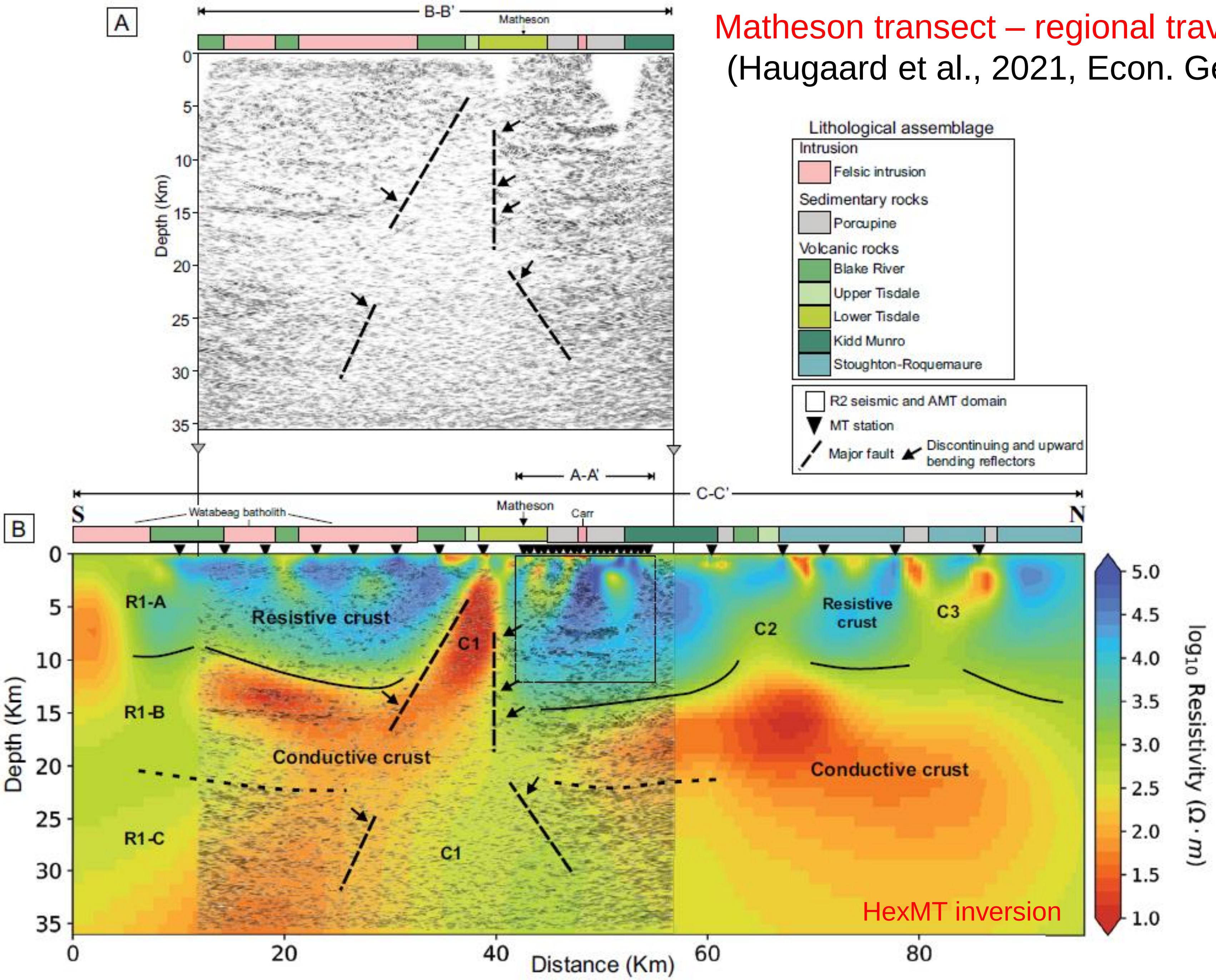
HexMT depth slices and section

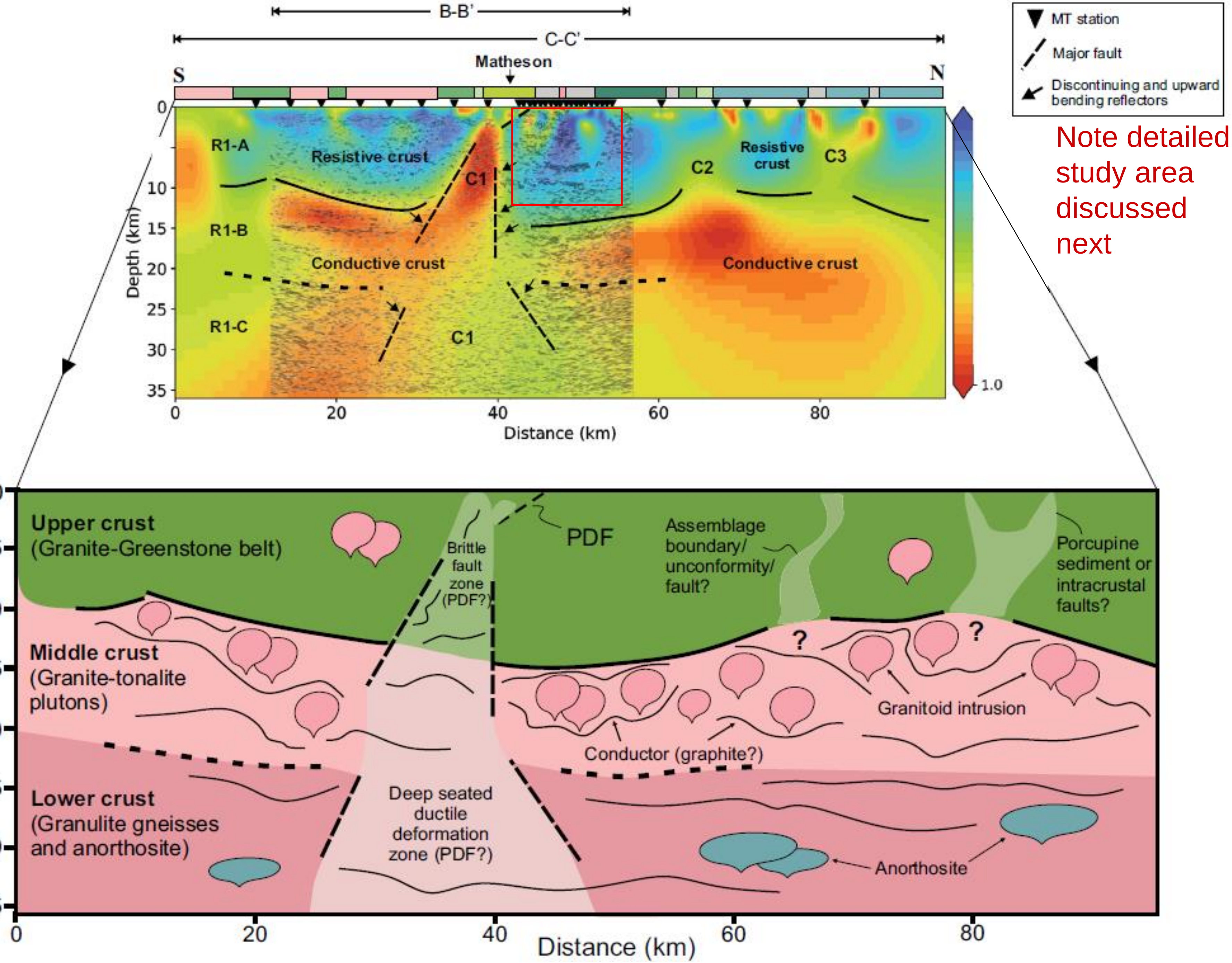




Jørgensen et al., 2022, Sci. Reports.

Matheson transect – regional traverse
(Haugaard et al., 2021, Econ. Geol.)

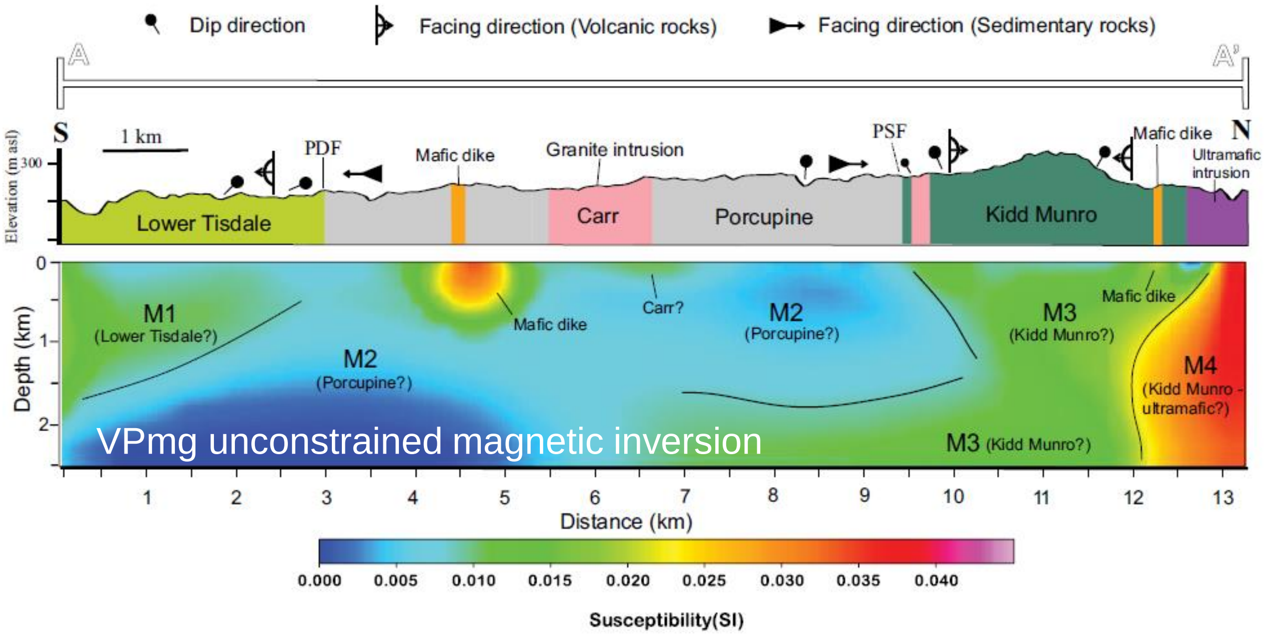


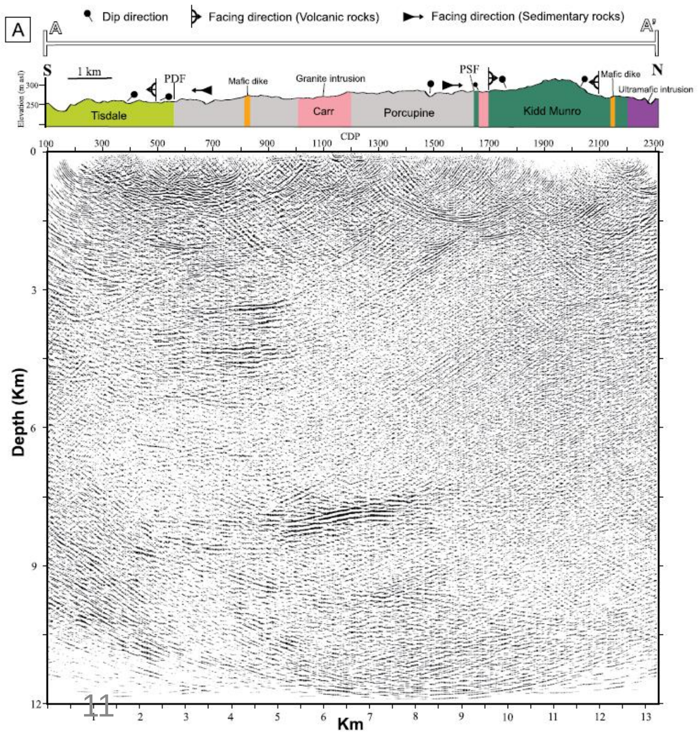


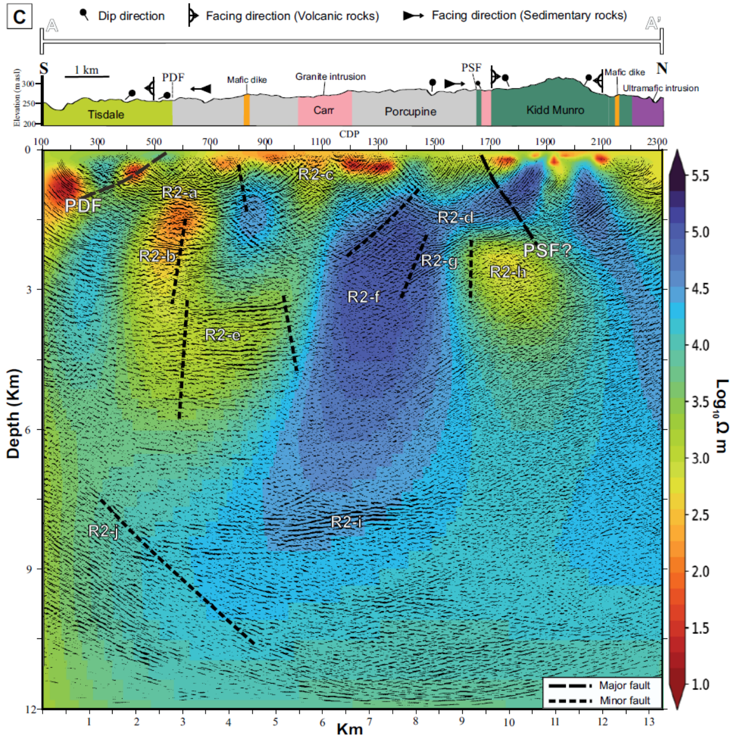
Note detailed study area discussed next

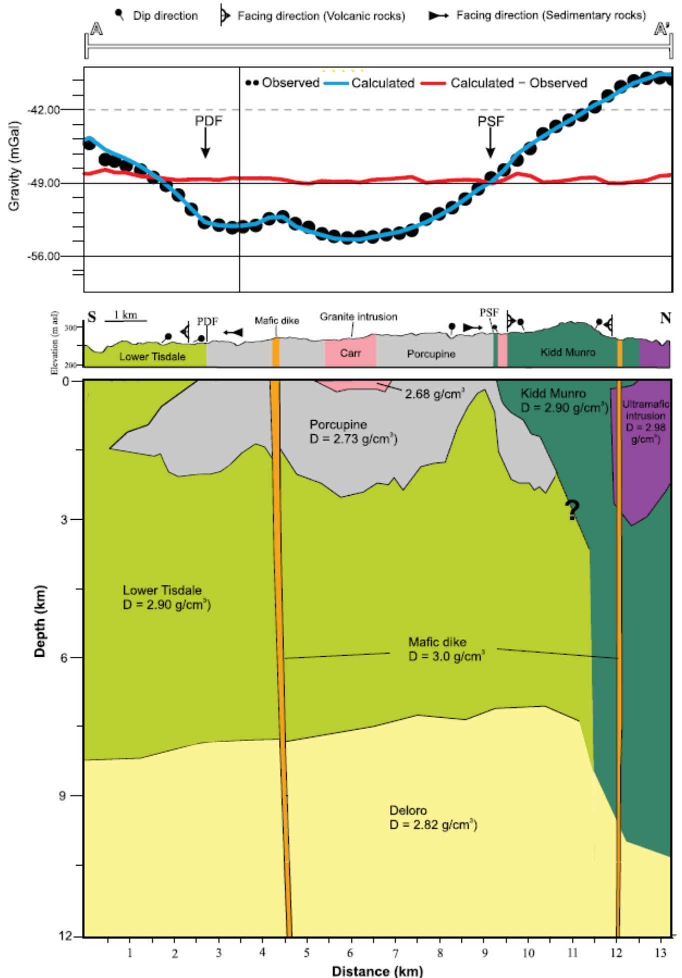
Haugaard et al., 2021, Econ. Geol.

Matheson transect – local traverse (Haugaard et al., 2021, Econ. Geol.

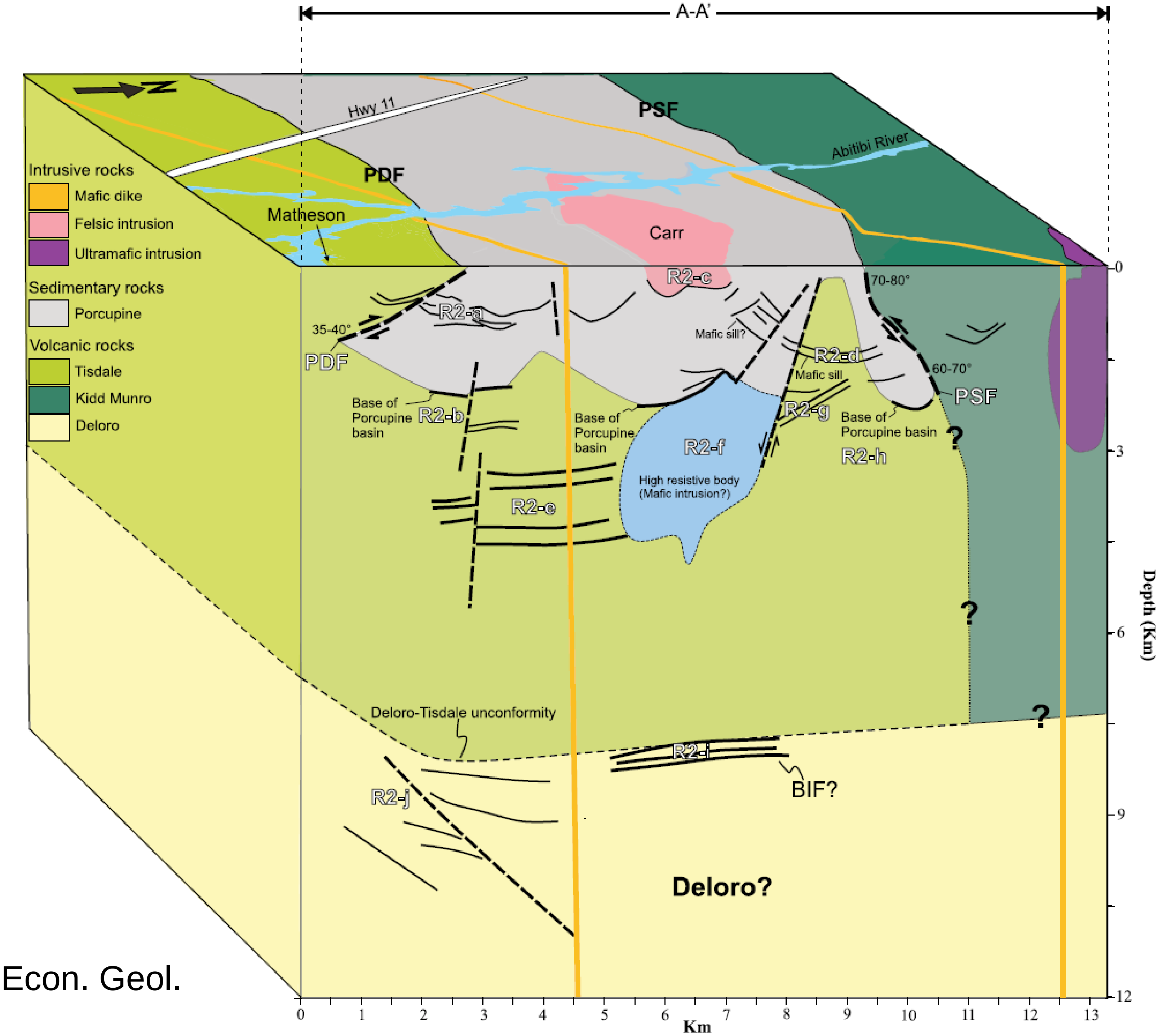






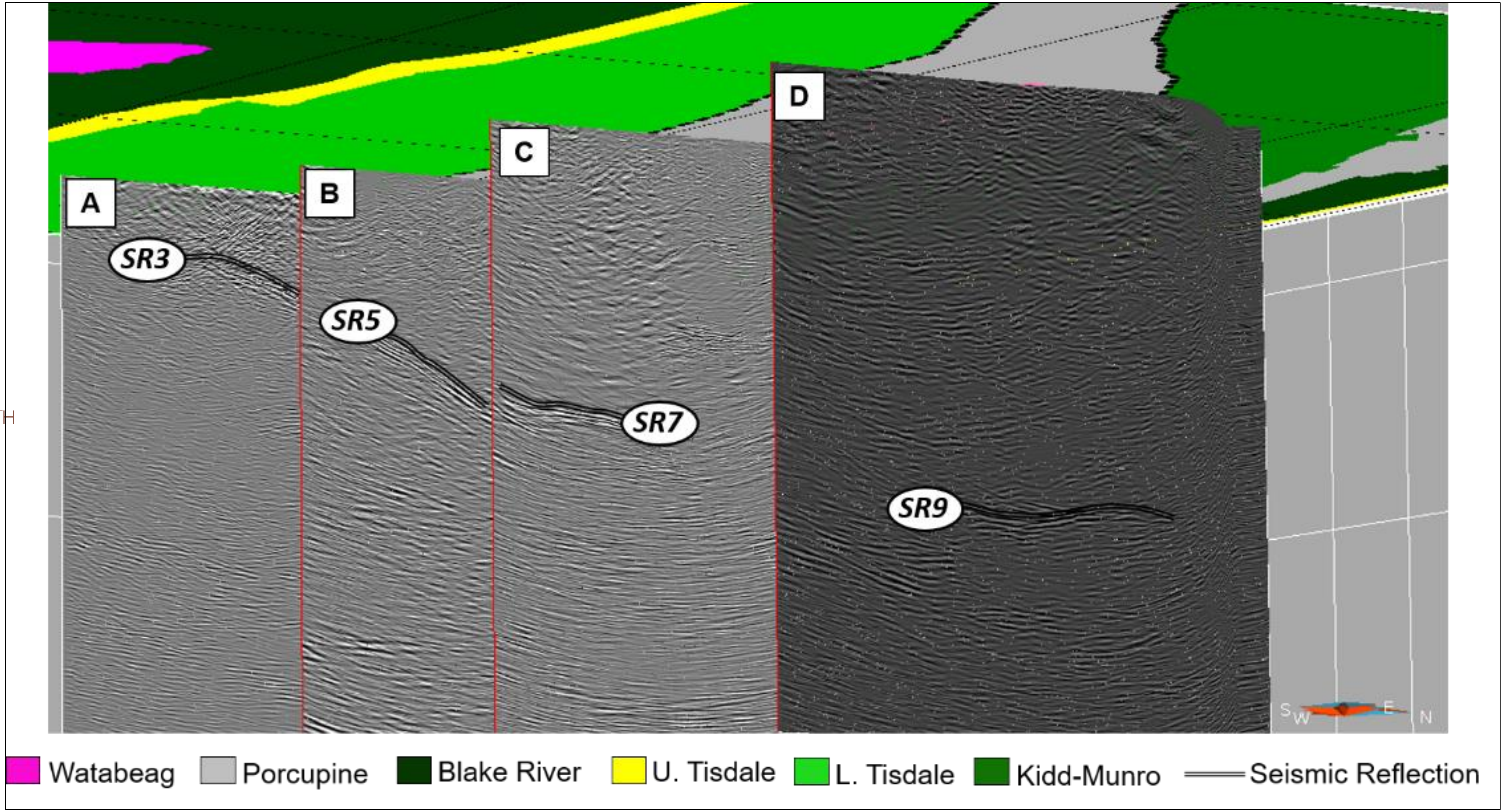


Geological interpretation



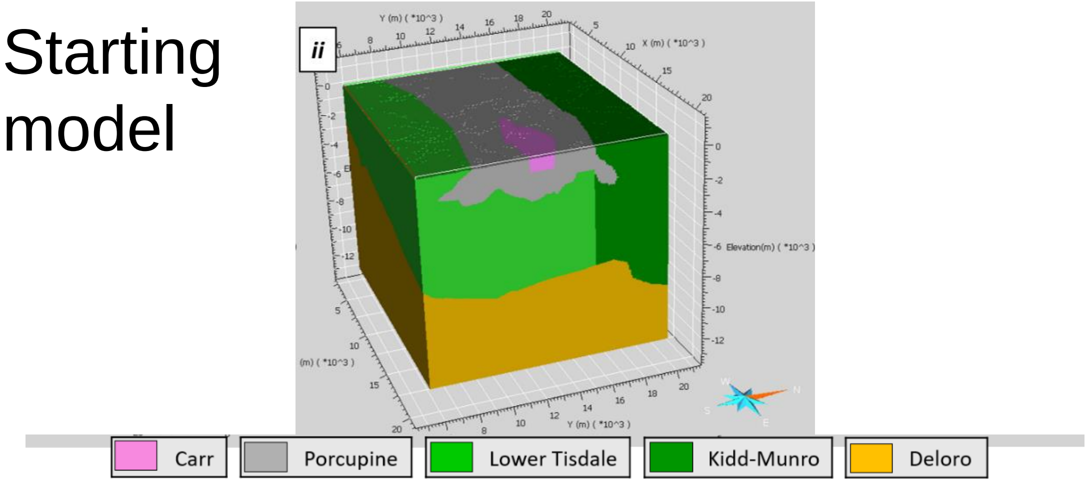
Haugaard et al., 2021, Econ. Geol.

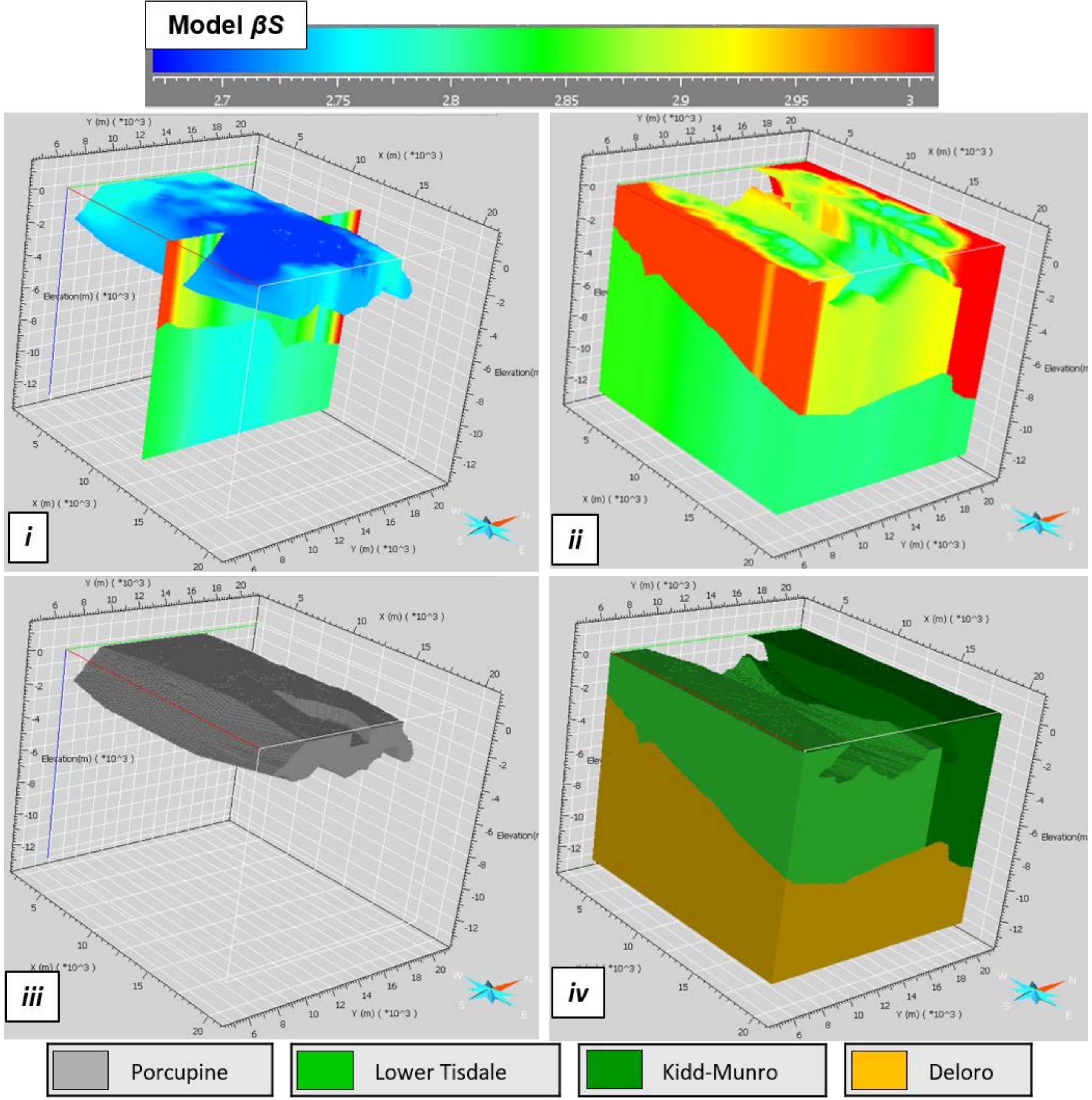
Three additional seismic lines, with a shallowing reflector. Could the Deloro be getting shallower?



Fabiano Della Justina, 2022

Starting model





Final inversion model

$\chi \sim 1$

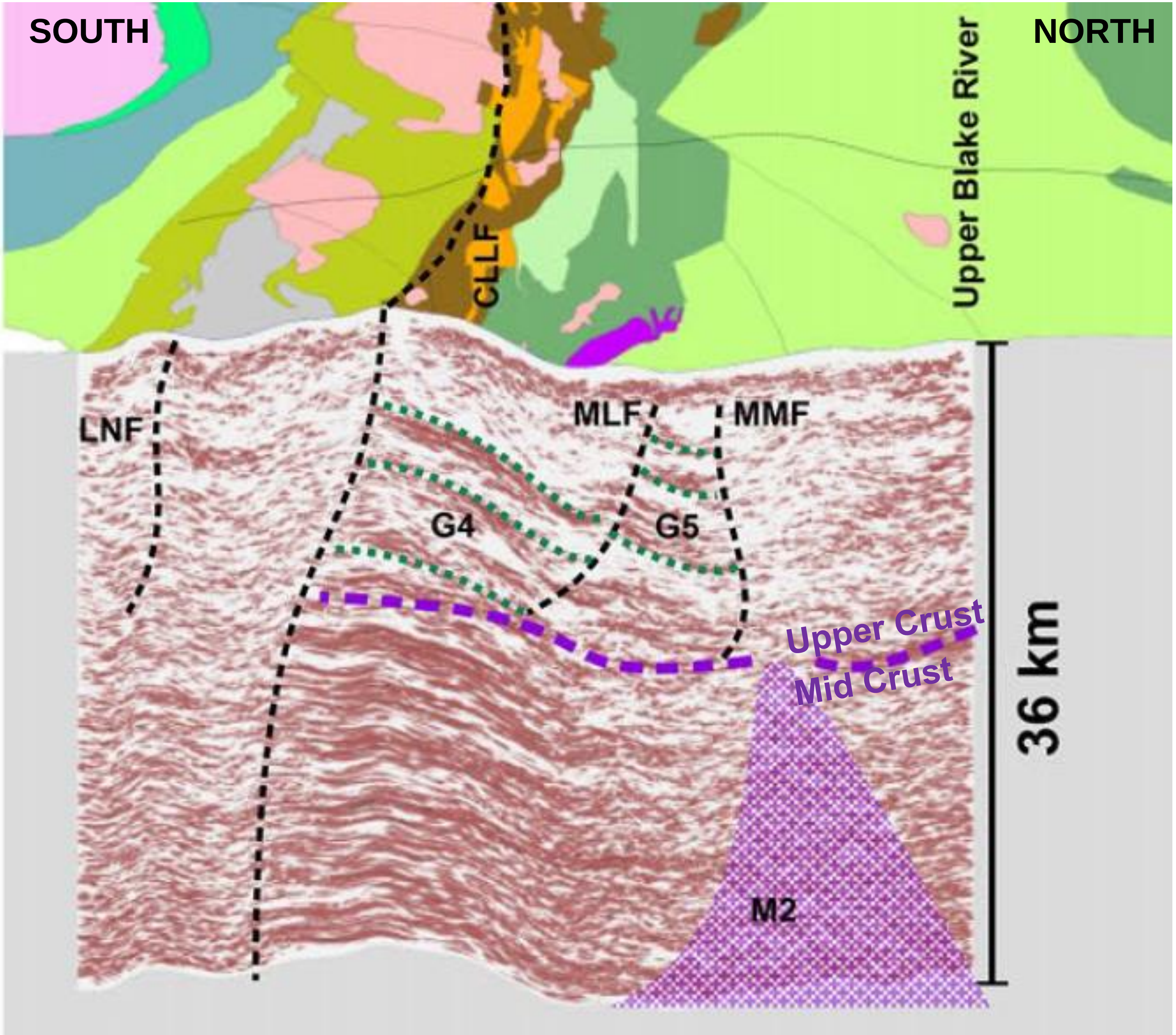
Deloro hypothesis is feasible!

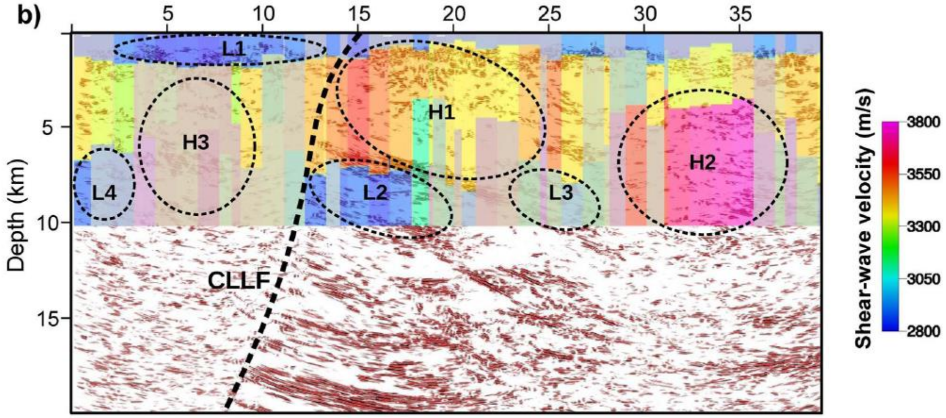
Fabiano Della Justina, 2022

Larder Lake transect

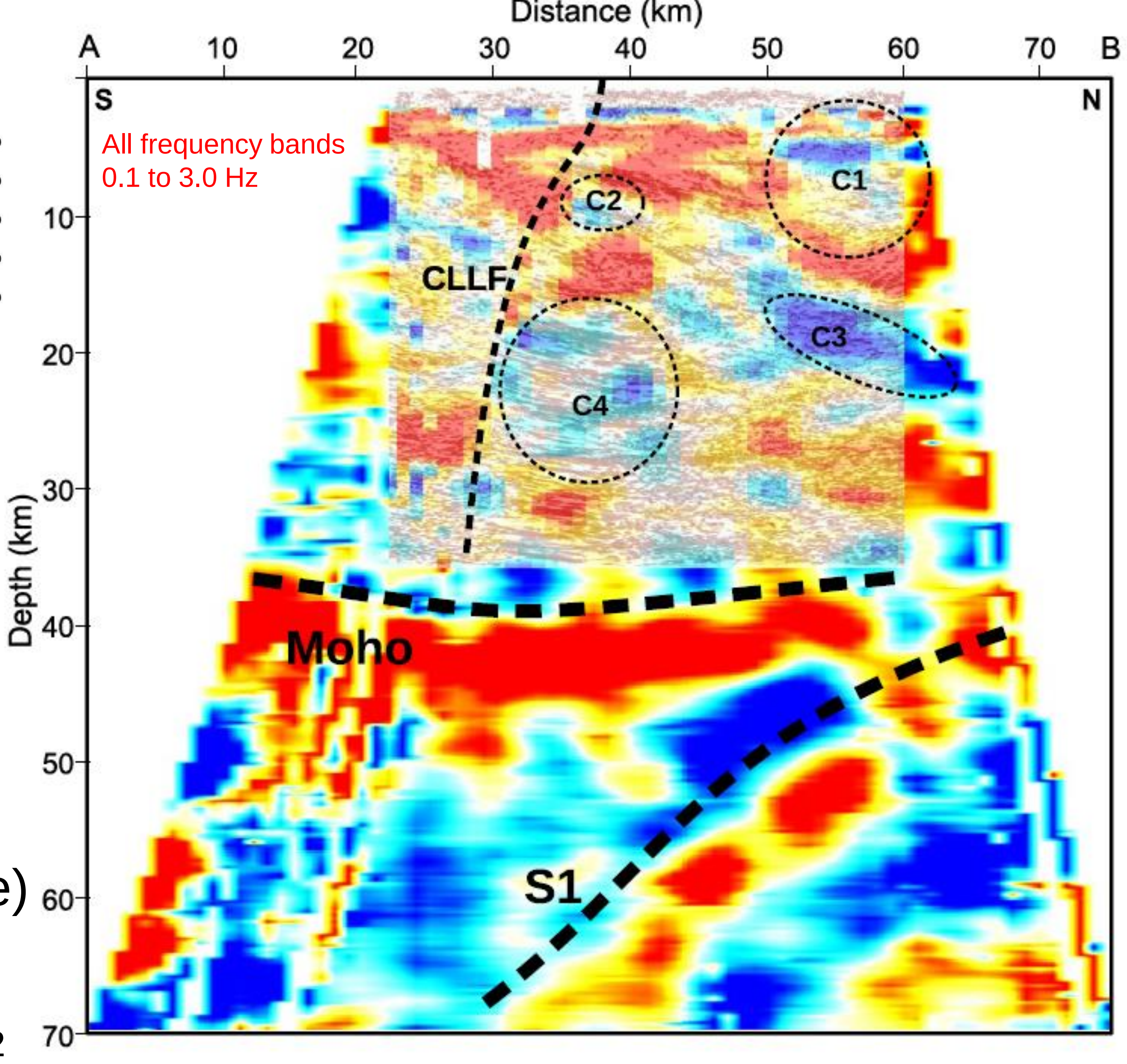
Reflection seismic

Naghizadeh et al., 2022



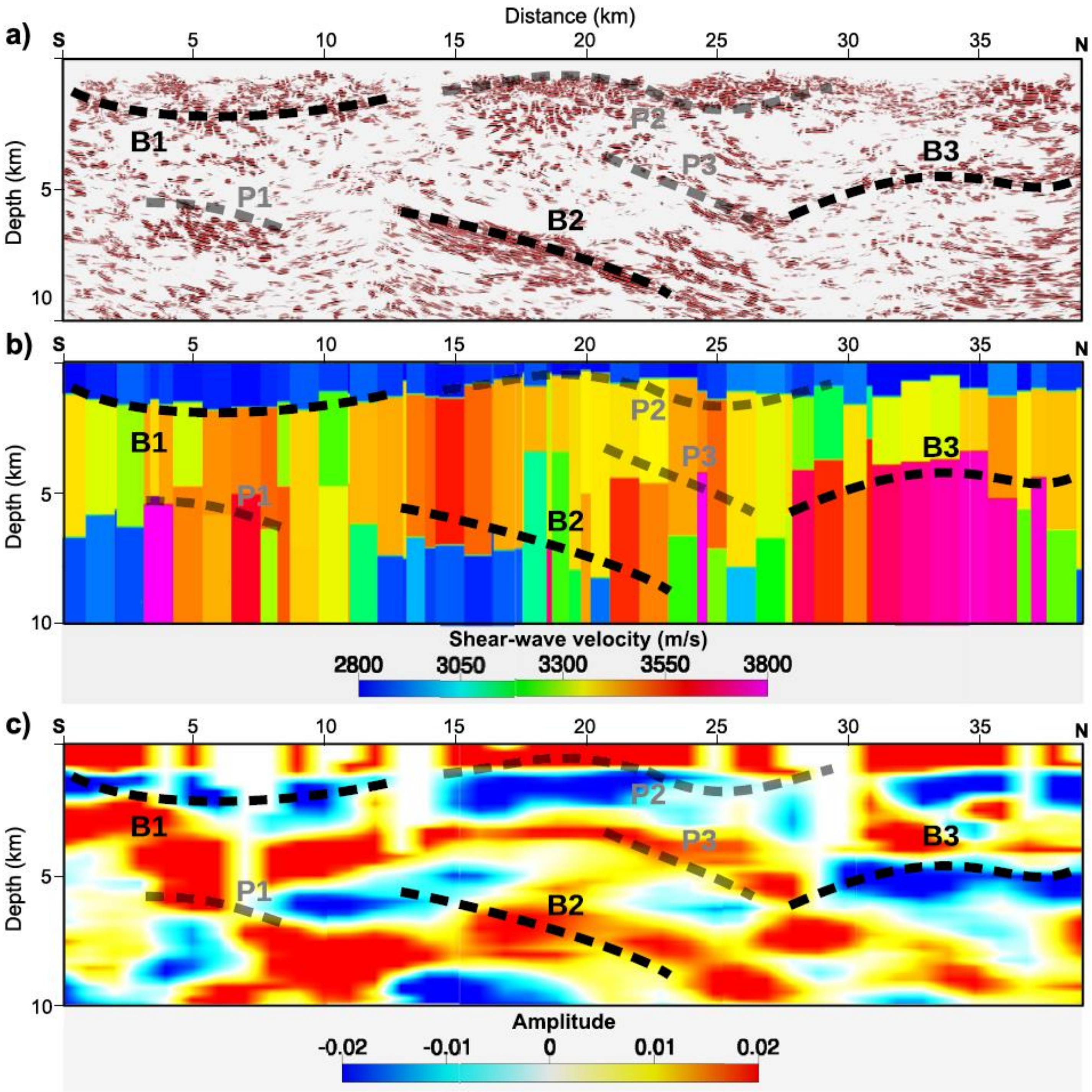


Ambient noise surface wave tomography (Sisprobe)



Receiver function analysis: P-S convertability (Sisprobe)

Naghizadeh et al., 2022



Reflection section

Ambient-noise shear-wave tomography

P-S convertability

VHF band
0.8 to 3.0 Hz

Naghizadeh et al., 2022

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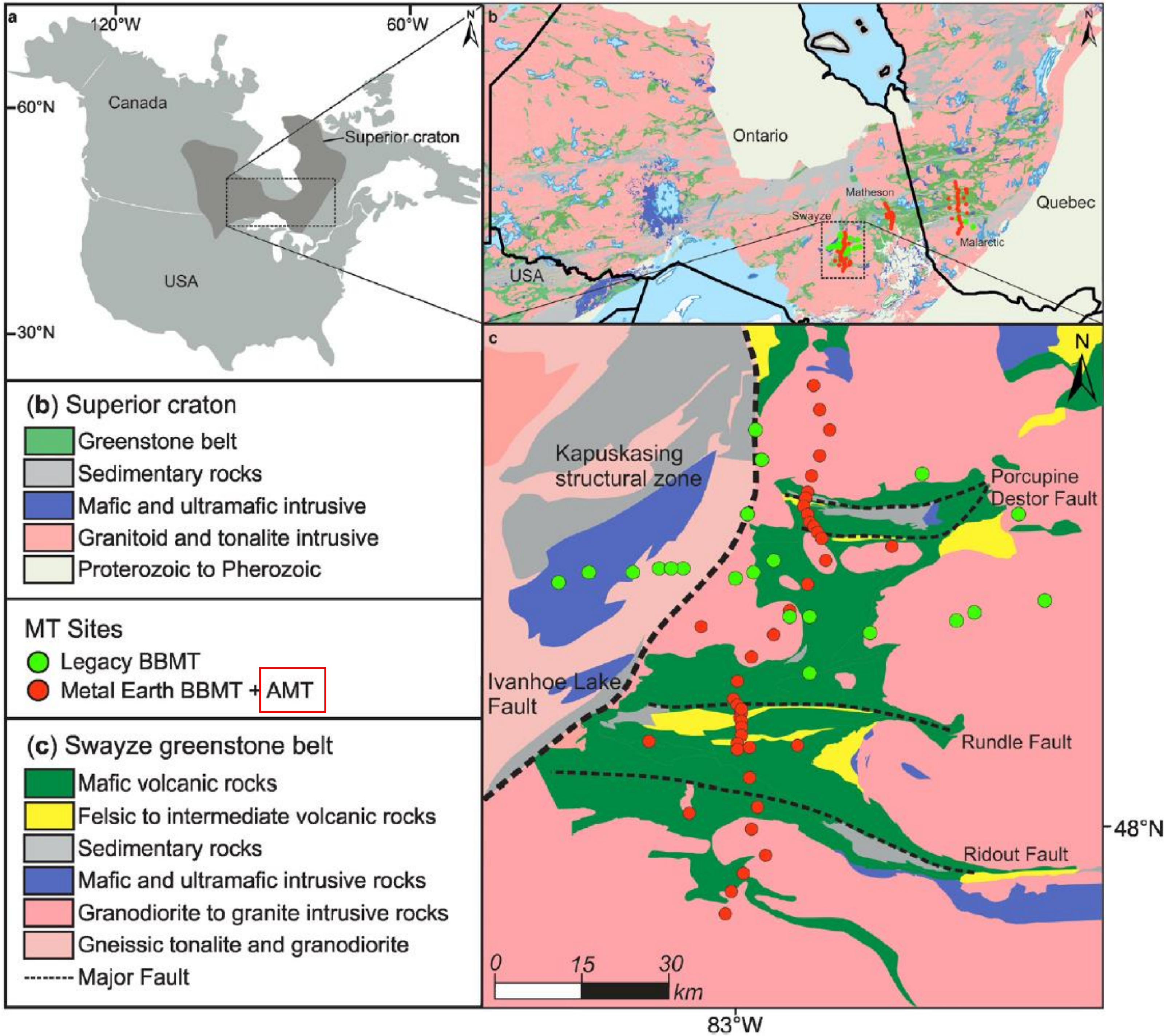
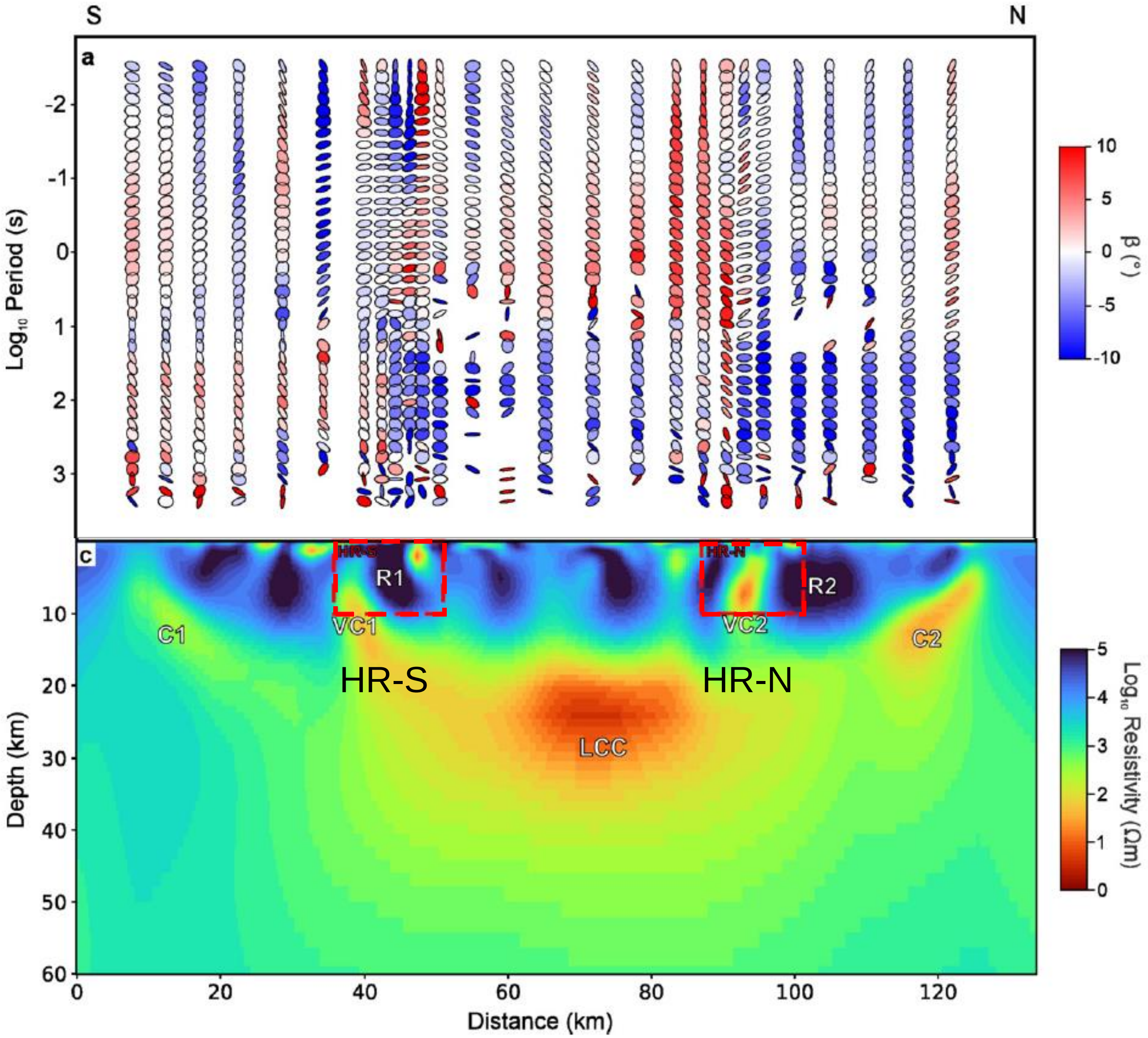


Hill et al. 2021, EPSL

Phase tensor ellipses coloured by skew.
Data is clearly 3D



ModEM Regional tensor and induction vector (Z+K) inversion, using Z then K models as reference and a-priori models

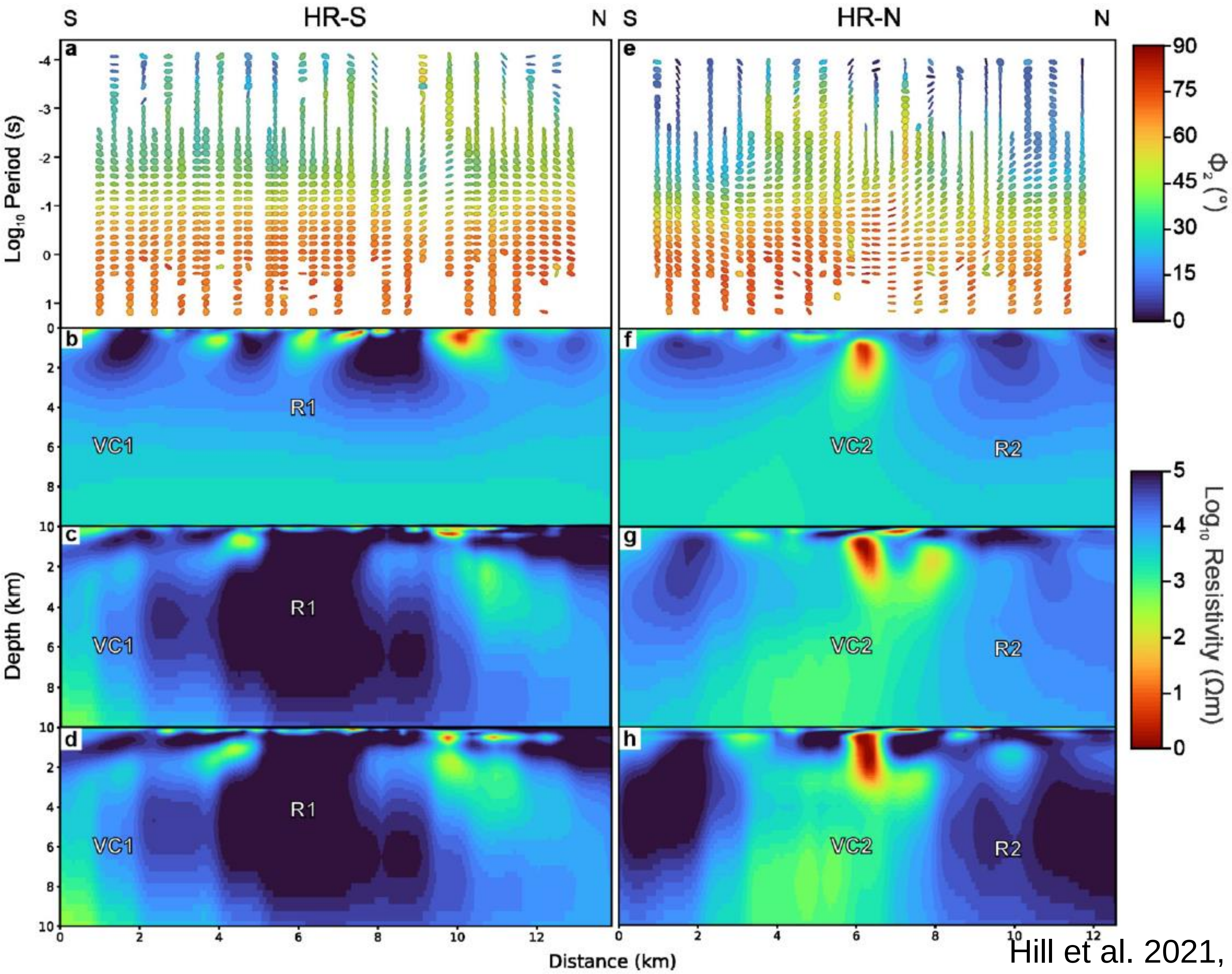
Hill et al. 2021, EPSL

Phase data

Starting: half-space
A--priori: half-space

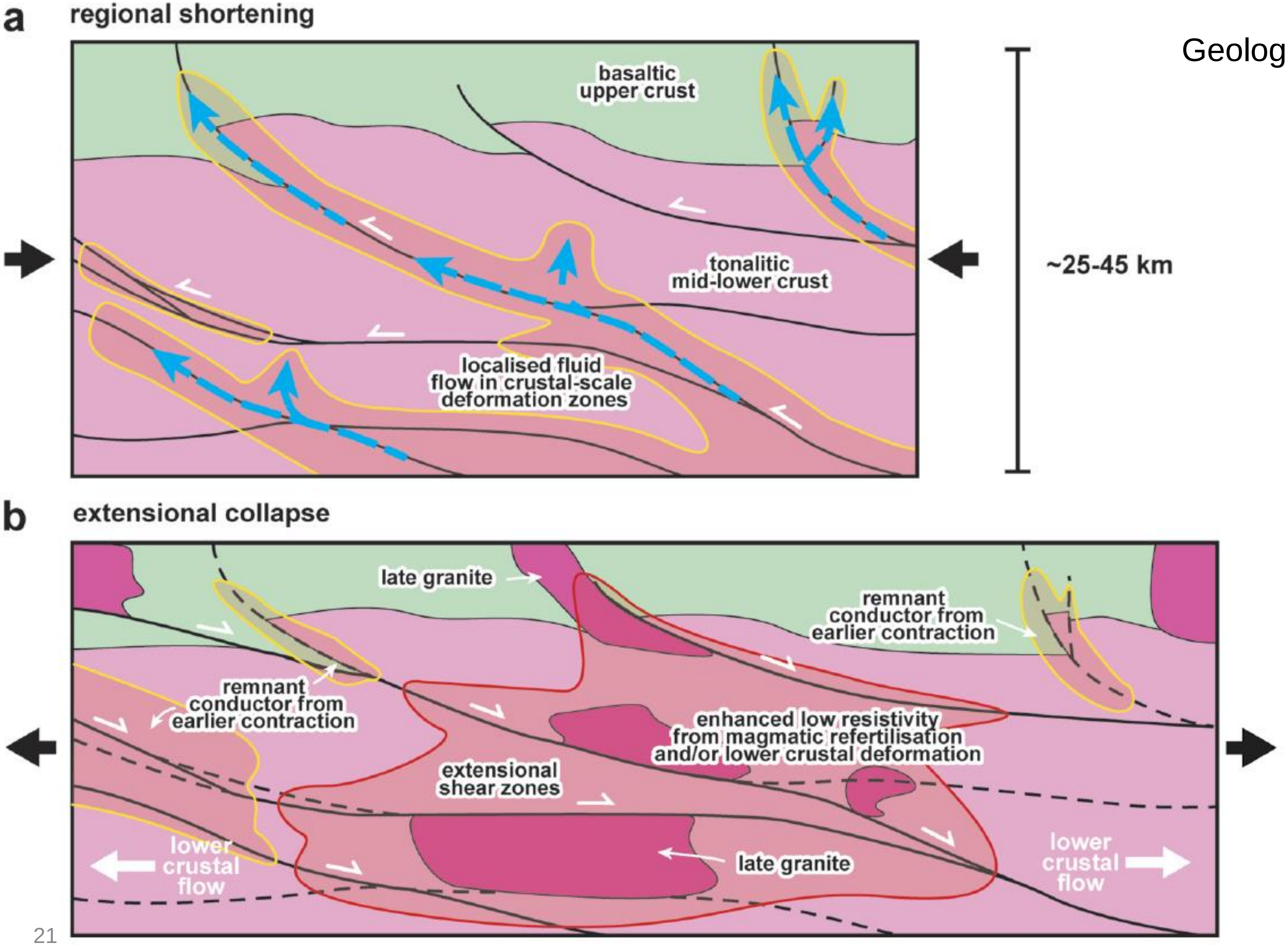
Starting: regional
A--priori: half-space

Starting: regional
A--priori: regional



Hill et al. 2021, EPSL

Geological interpretation



Hill et al. 2021, EPSL

Geophysical Conclusions

- Reflectivity low in upper crust; stronger in mid/lower crust
- Sub horizontal conductive zones in mid crust and sub vertical ones through an otherwise resistive upper crust sometimes associated with low-reflectivity zones
- Passive seismic consistent with other data
- Receiver function analysis can explore deeper than our reflection seismic
- Gravity can model features in the top ~10 km and confirm geological hypotheses
- Regional and local scale MT and AMT can be combined

Exploration Conclusions

- Interpretations are different on different section
- Interpretations done by different groups with different styles
- Uniform interpretations required to tell the difference between the endowed and un-endowed
- This is the current focus of the project

Project Research & Funding Partners

Government	Acquisition and Processing	Software
Canada First Research Excellence Fund	SAExploration	Mira Geoscience ...modelling the earth
Canada	Absolute Imaging	aspentech
	Complete MT Solutions	Seequent
	Moombarriga Geoscience	Adobe
	Sisprobe by egis	esri

A review of results from Metal Oceans: A project of Metal Earth

Richard Smith

Drawing on work from researchers in the Metal Oceans project. An outcome from discussions with Mark Hannington

Metal Ocean project

- Uniformitarianism (Hutton and Lyell): The modern ocean is the key to the ancient ocean

- Archean crust
  - Volcanic: mafic, andesitic, felsic.
  - Pillow structures and sedimentary basins suggest a marine environment.
  - There are a number of time periods where continental crust was created from seafloor crust and preserved.
  - Mineral deposits are associated with many of these

- The Lau Basin is where current oceanic crust could potentially become continental

- The Lau basin is endowed with metals

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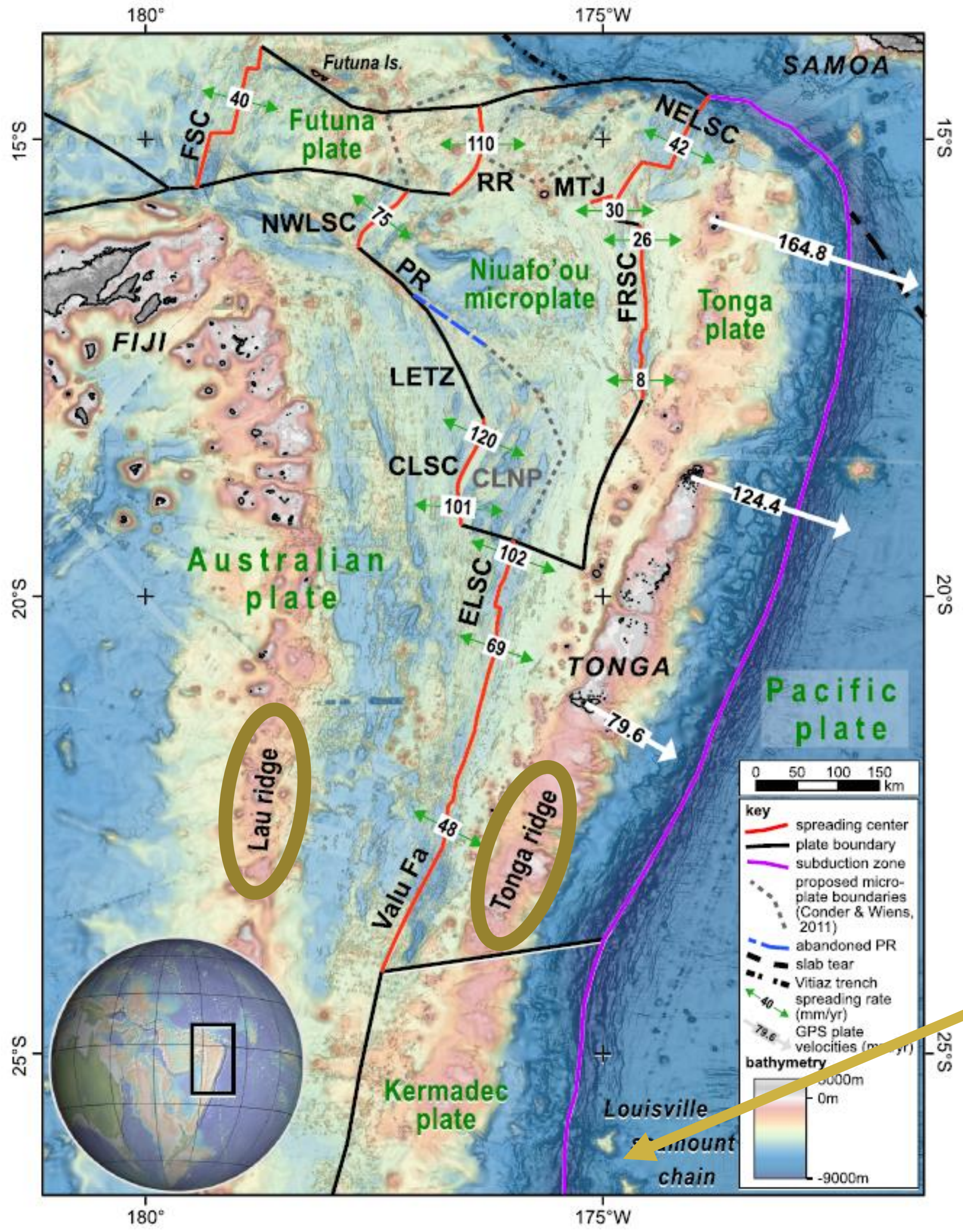
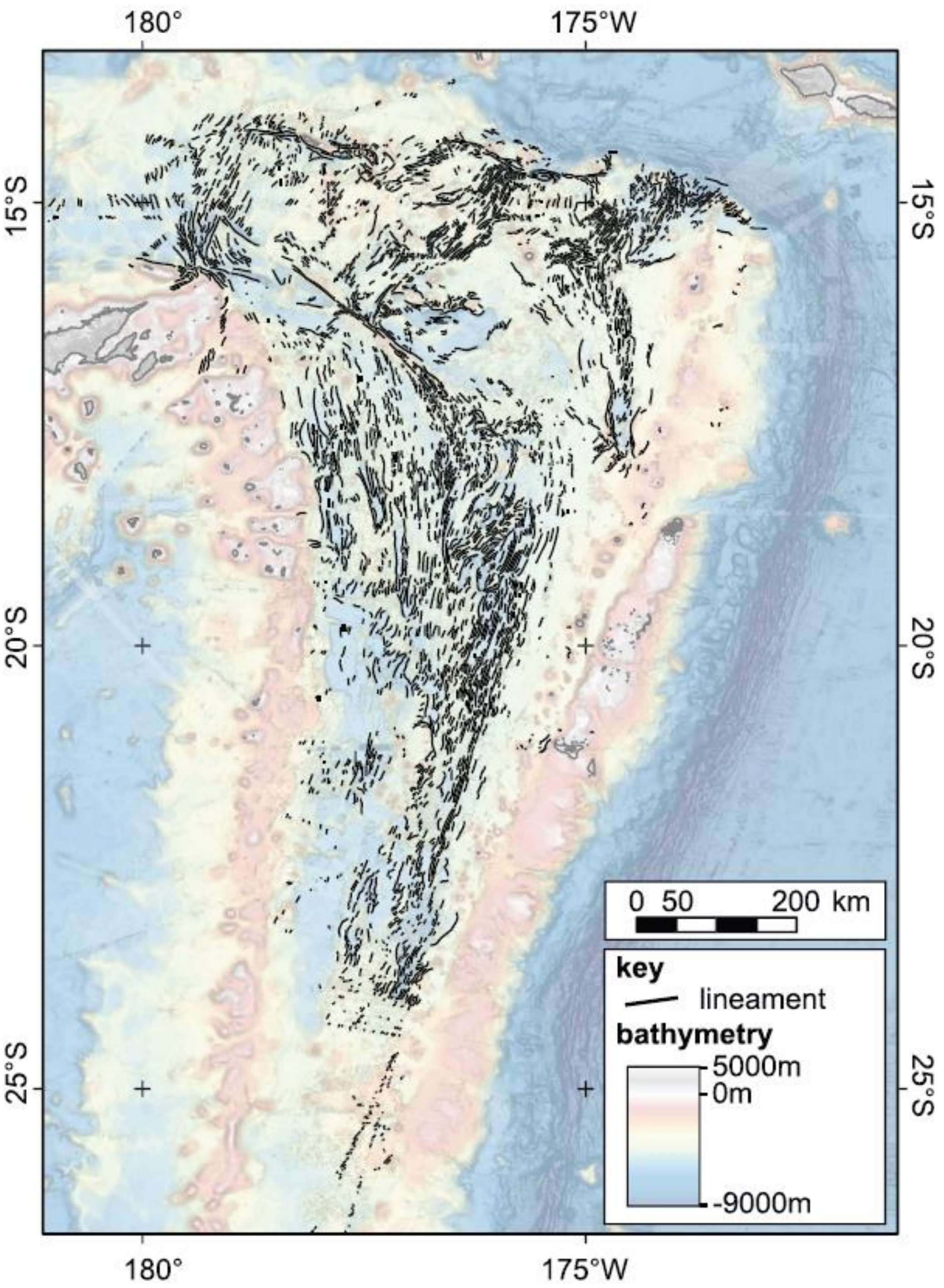
Study Area



Bathymetry

Note Louisville seamount chain about to be subducted.
Perhaps already subducted to the north.

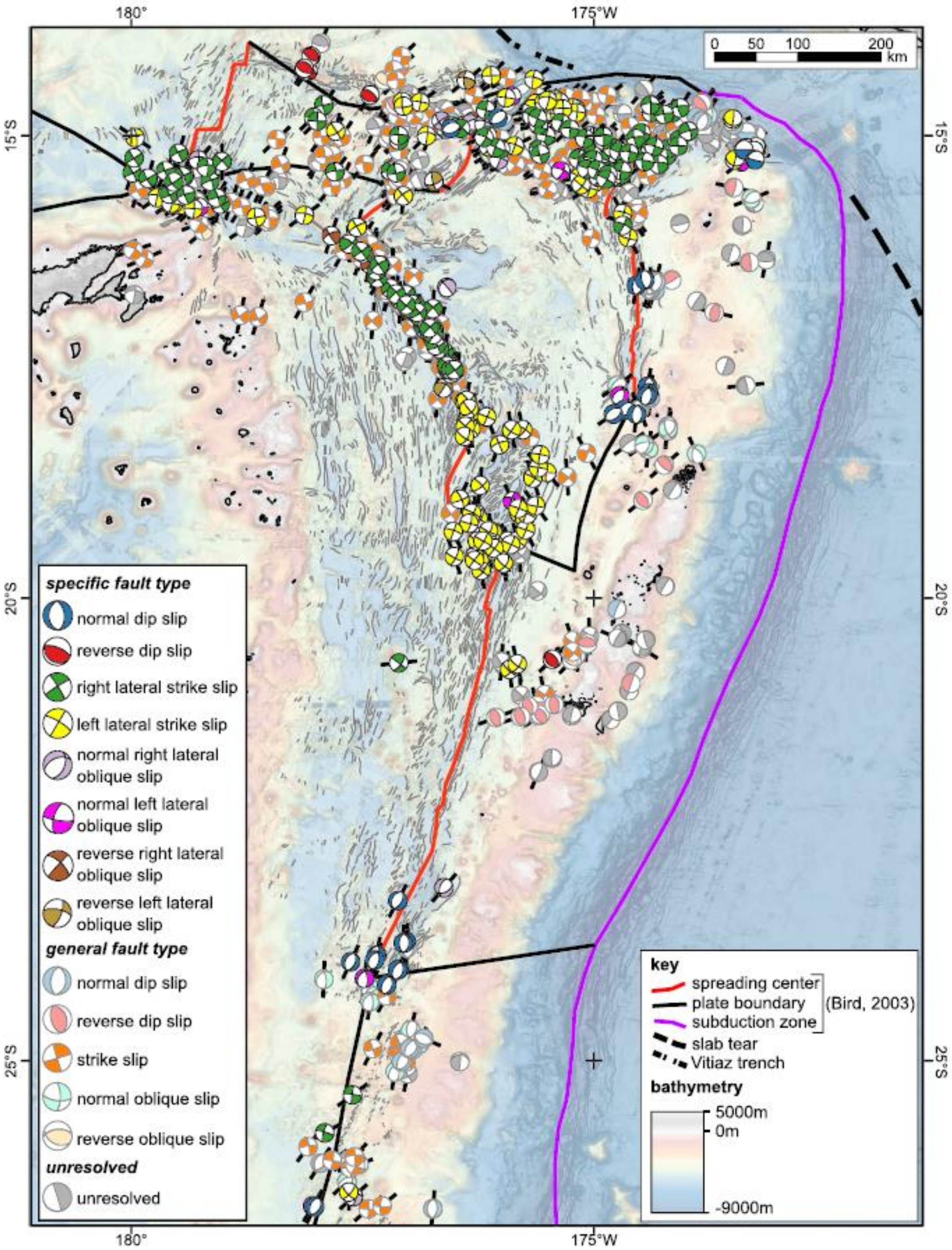
Baxter, et al. (2020). G^3, doi 10.1029/2020GC008924



Lineaments

- Derived from bathymetry, satellite altimetry and gravity gradient

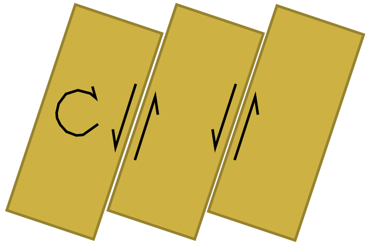
Baxter, et al. (2020). G³, doi 10.1029/2020GC008924



Earthquake centroid moments tensors depicting movement on fault planes

Dominated by strike-slip transform faults (green and yellow)

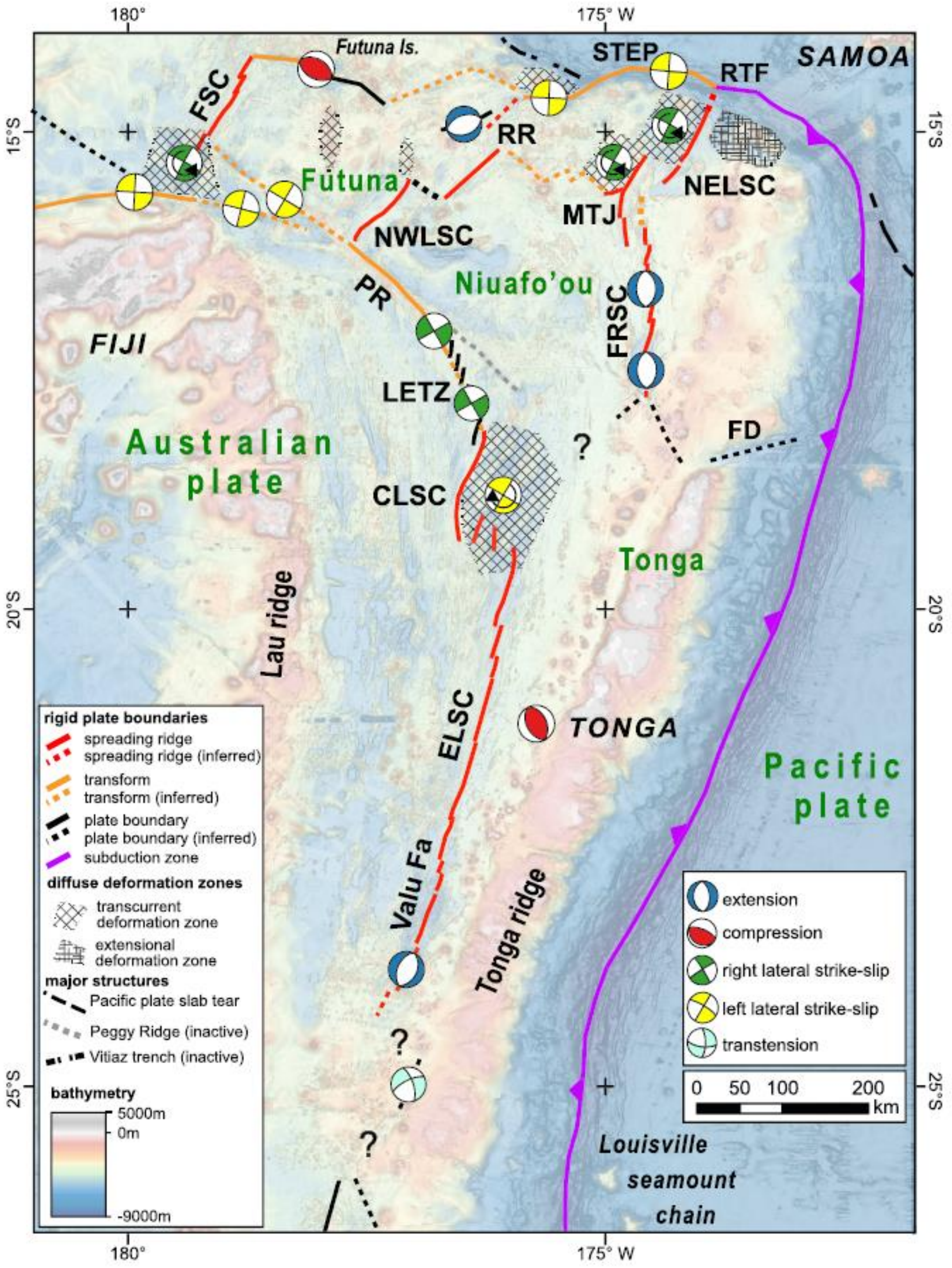
Analogous to books on a bookshelf



Left lateral = clockwise rotation
Right lateral = anticlockwise rotation

Many spreading centre later become transform faults like Peggy Ridge (PR)

Baxter, et al. (2020). G3, doi 10.1029/2020GC008924



Complex:

Growing spreading centres
Microplates, triple junction
Spreading centres merging into transform faults
Volcanos
Transcurrent deformation zones
Extensional deformation zones
Very slow spreading, but at many locations

Simple:

Subduction zone and back-arc spreading centre

No spreading at Louisville seamont chain

Baxter, et al. (2020). G³, doi 10.1029/2020GC008924

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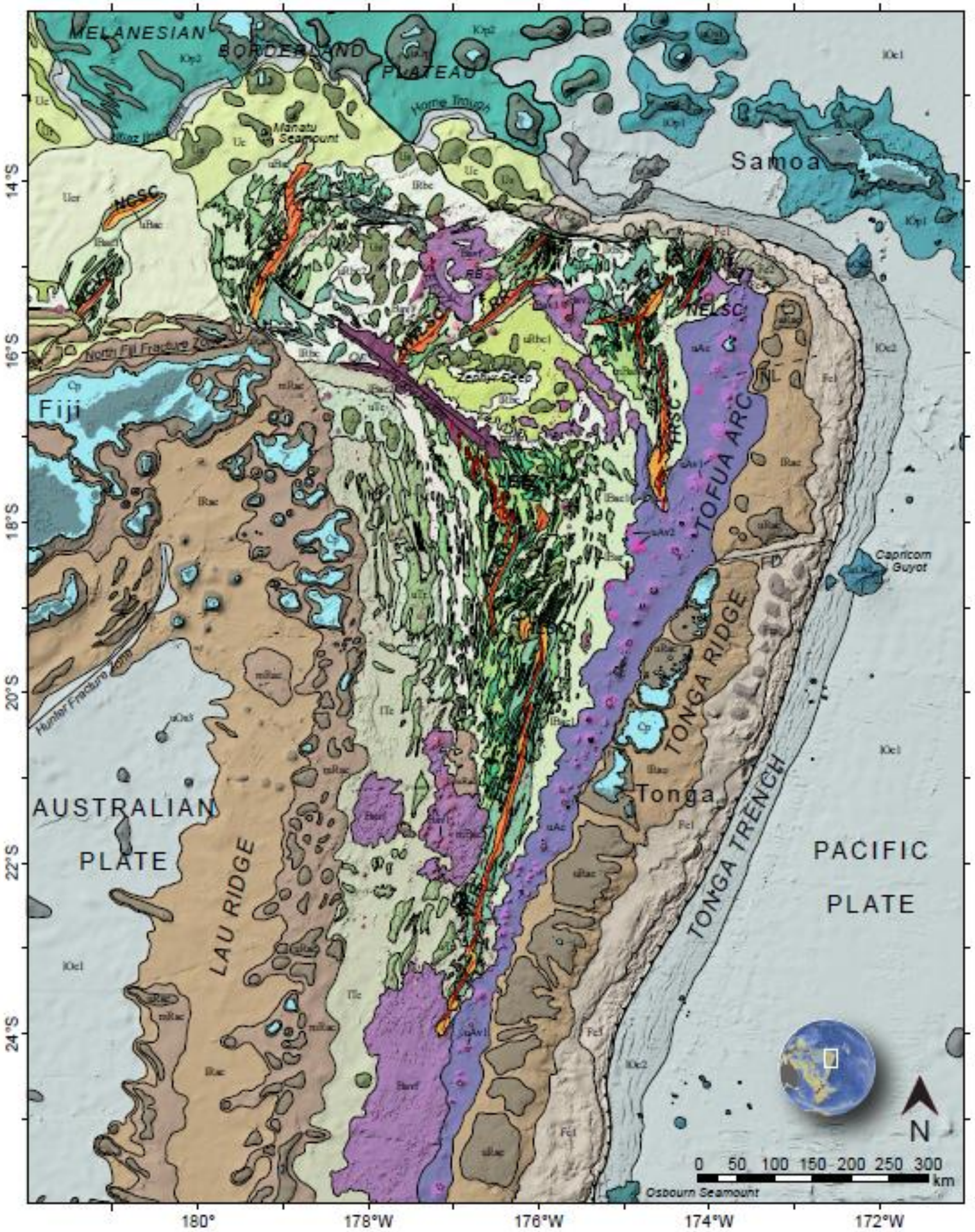
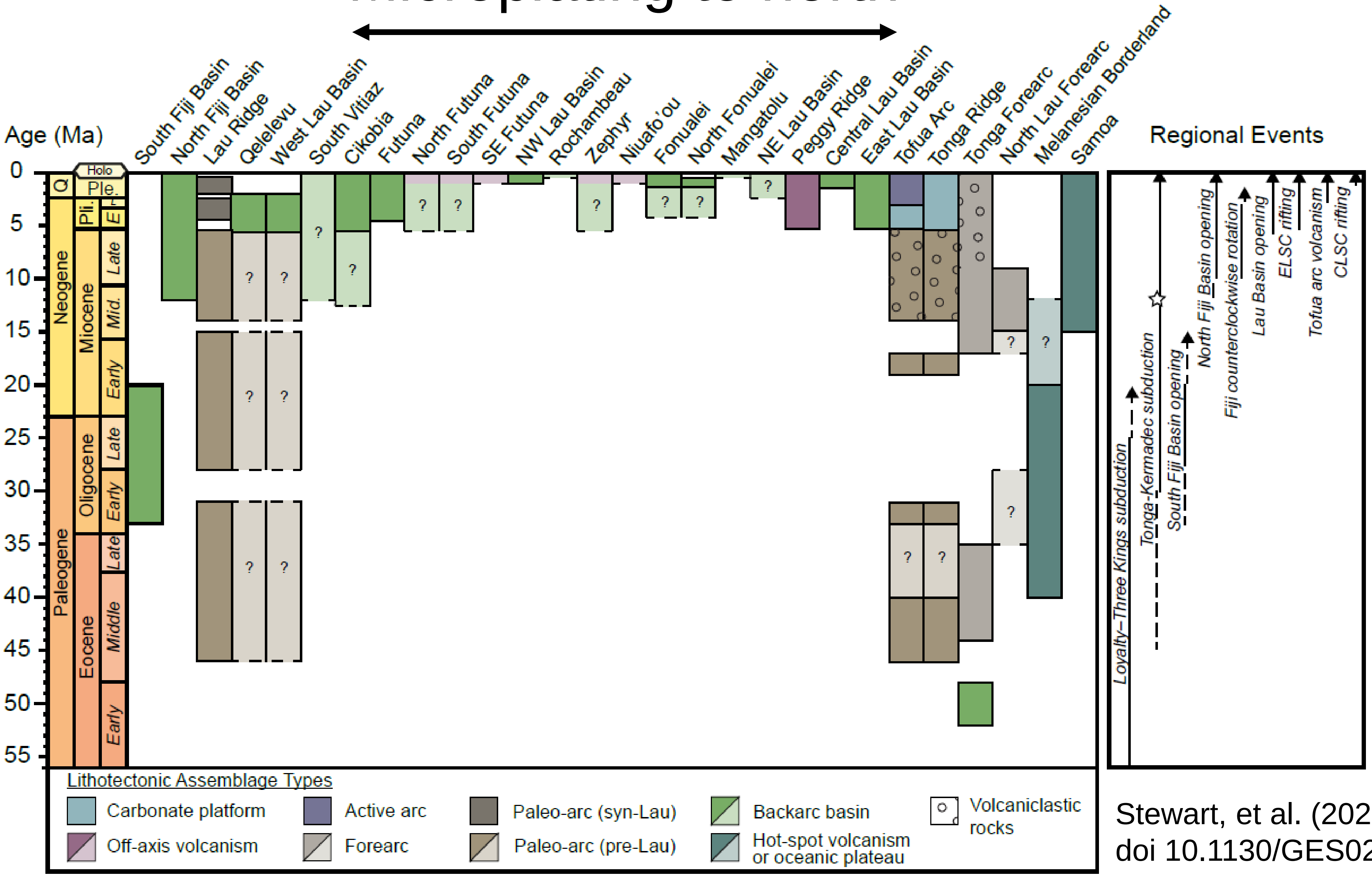


Geological mapping

- Based on gravity, magnetics, bathymetry, dredge samples

Stewart, et al. (2022). Geophere, doi 10.1130/GES02340.1

Microplating to north



Stewart, et al. (2022). Geophere, doi 10.1130/GES02340.1

Geological conclusions

- A mix of active and relic arc and backarc crust
- Assigned to assemblages and ages assigned
- In last 3 m.y. failed rifts, ridge jumps, deformation zones and slow rates of accretion in many spreading centres
- Triple junctions are zones of weakness which mantle material can rise through
- The faster spreading to the north maybe because the Louisville seamount chain is no longer blocking the trench

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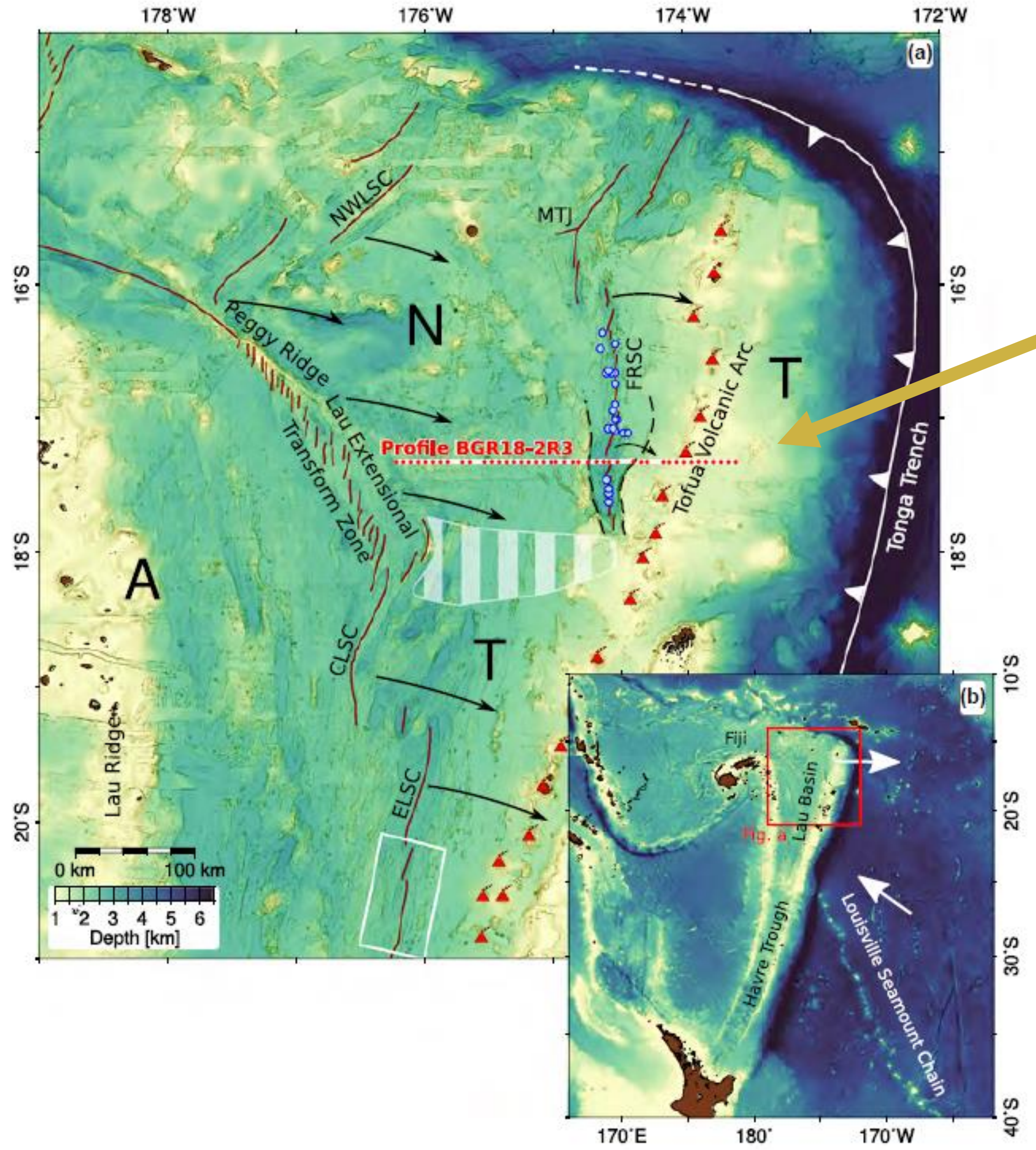
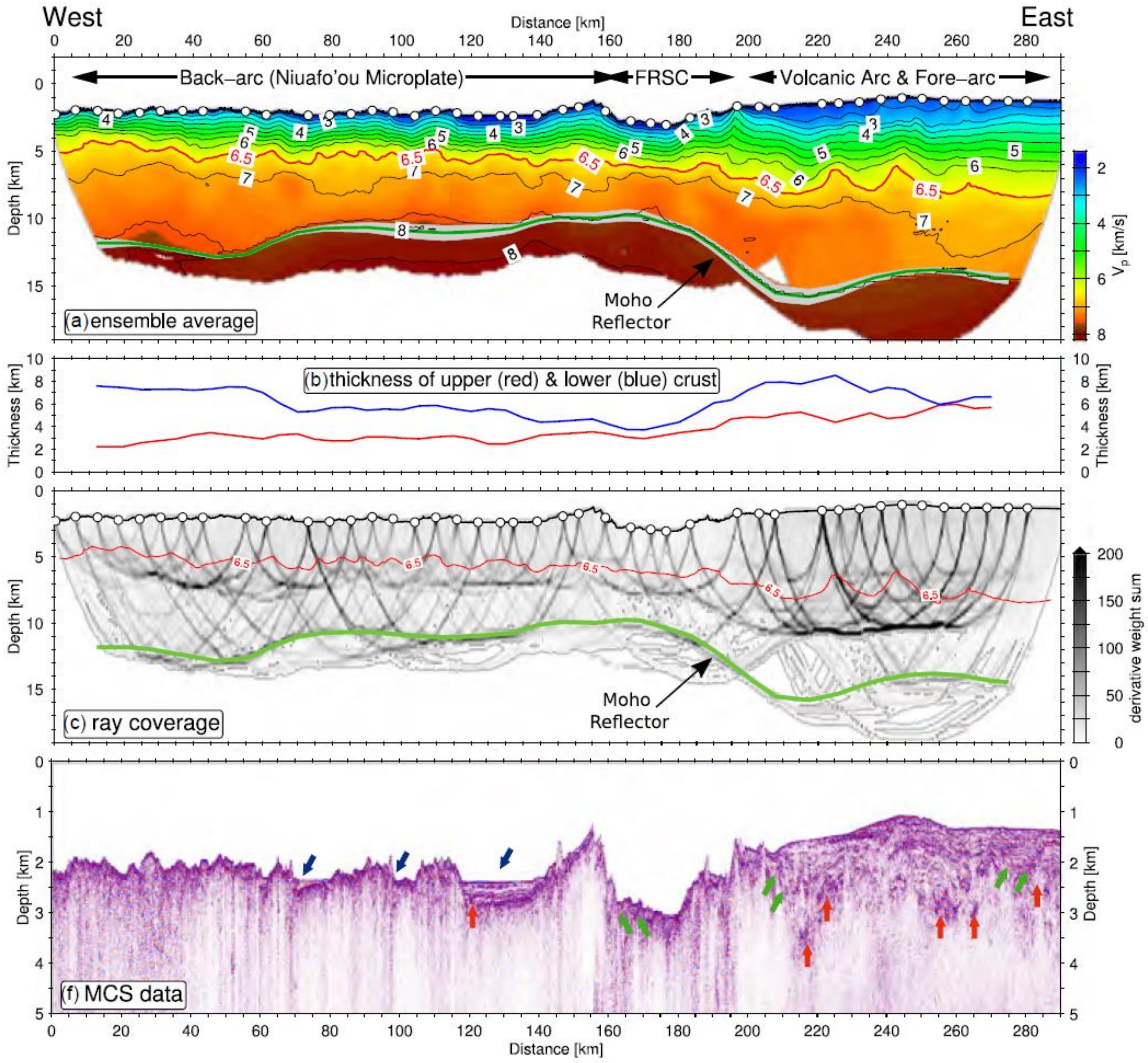


Geophysical profile location

Schmid et al., 2020, JGR Solid Earth, doi 10.1029/2019JB019184



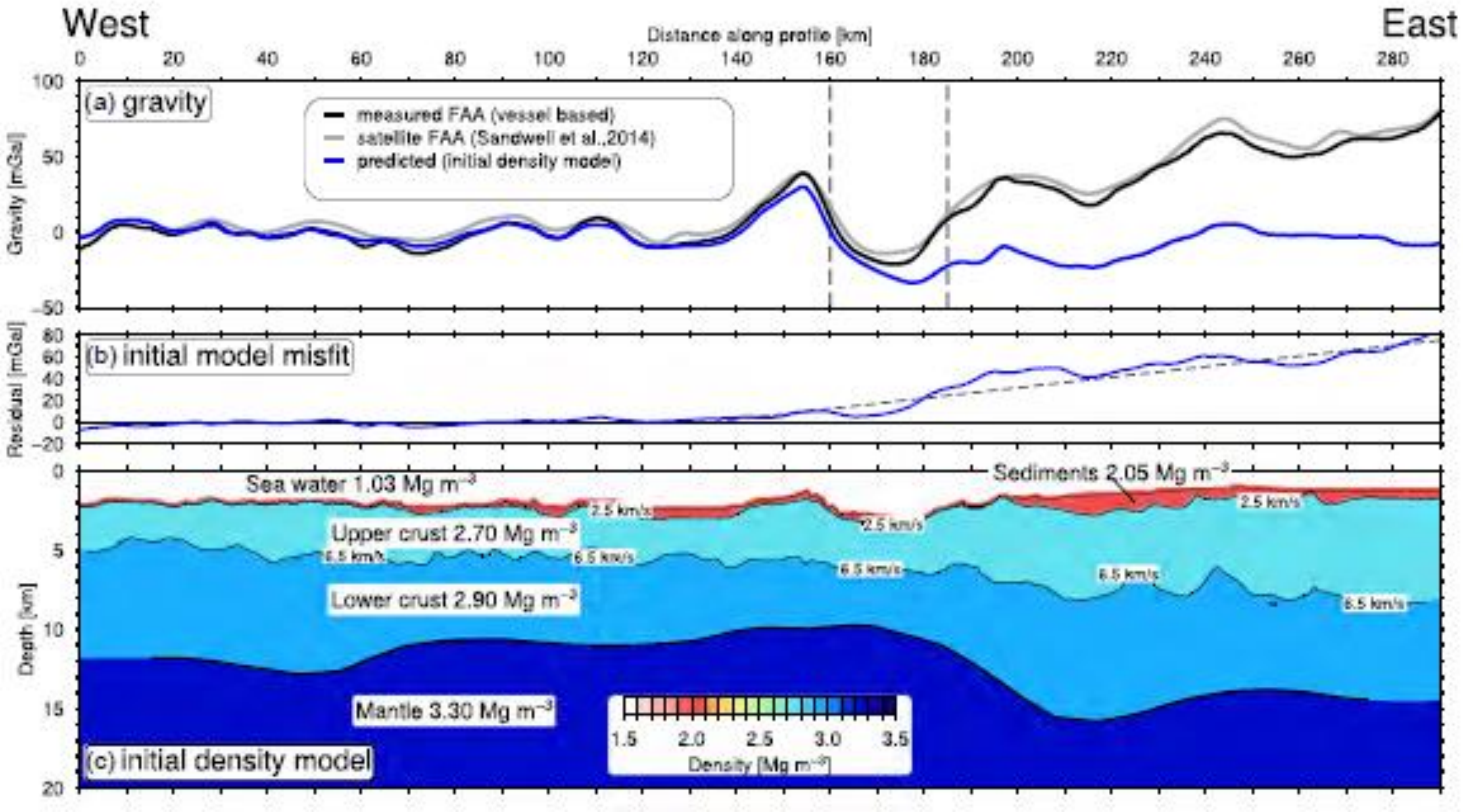
Seismic tomography

- Shows variable thickness of the crust (c.f. Abitibi)
- Shows two layers within the crust

Seismic reflection

- Shows variability on the upper crust
  - Black arrows sedimentary basins
  - Green arrows normal faults
  - Red arrows possible magmatic sills

Schmid et al., 2020, JGR Solid Earth,doi 10.1029/2019JB019184



Gravity modelling

- shows similar variability on the thickness of the upper crust (sky blue)

Schmid et al., 2020, JGR Solid Earth,doi 10.1029/2019JB019184

Conclusions

- Geophysical studies reveal the complex microplate structure of the northern Lau Basin
- The complex structure developed in the last 3 m.y.
  - Weaknesses at triple junctions could allow upwelling of mantle material which might be endowed with metals.
- The crust shows variable thickness similar to that seen in Archean upper crust.
- Sills are evident in the thicker crust of the arc. This might be similar to what is seen in the Archean.

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Academic and Government

uOttawa

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Dalhousie University

Memorial University

University of Toronto

Mount Royal

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