Seamounts, and slow slip, and hydrates, Oh my! Marine electromagnetic investigation of the Hikurangi Margin, New Zealand

Christine Chesley, Samer Naif, Kerry Key, and Dan Bassett
Jacob Perez, Chris Armerding, and the science & ship crew of HT-RESIST

MTNet EMinar
15 June 2022

LAMONT-DOHERTY EARTH OBSERVATORY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

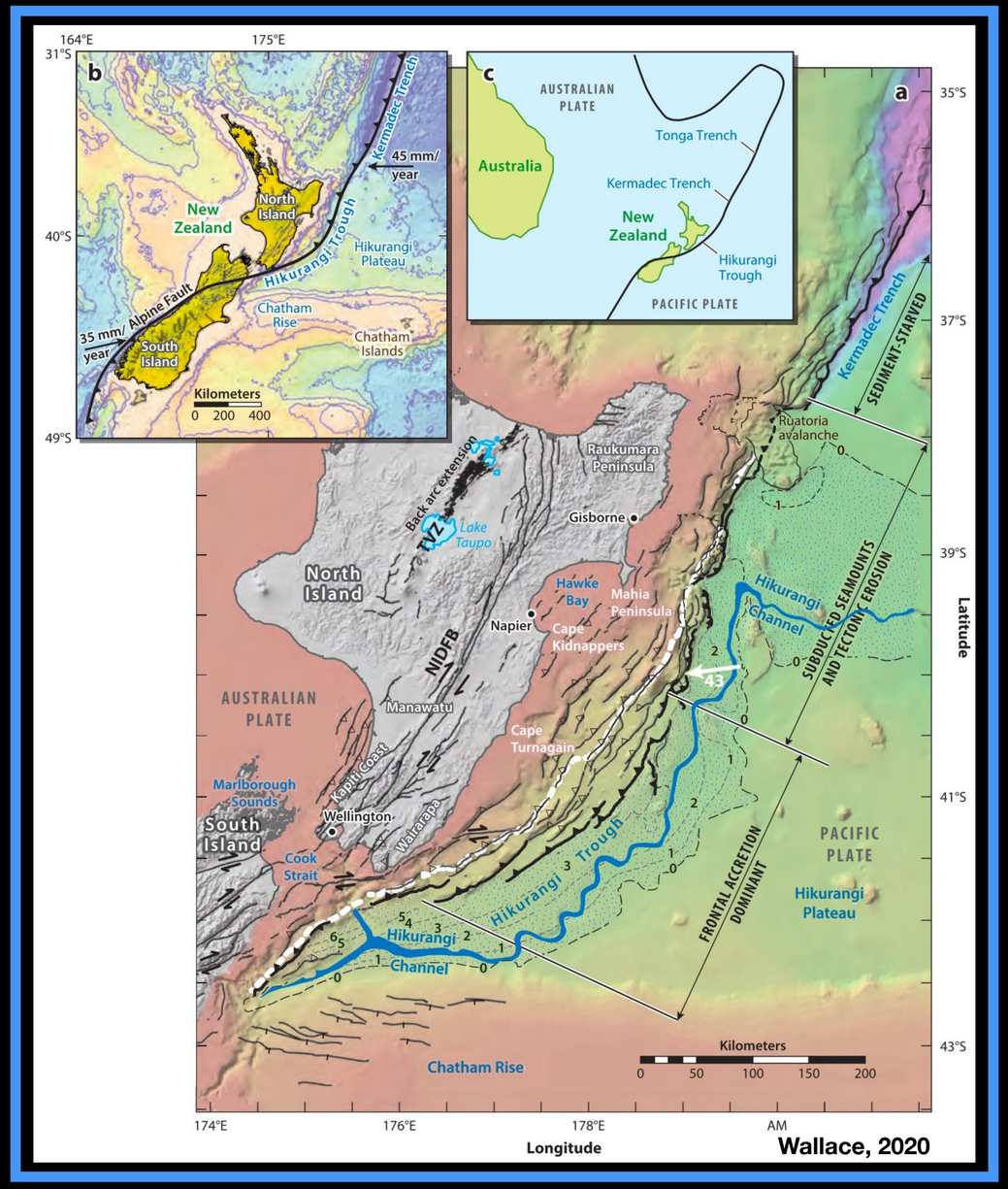
WOODS HOLE OCEANOGRAPHIC INSTITUTION

Geodynamic Processes at Rifting and Subducting Margins
GeoPRISMS

Overview

1. Tectonic Background of the Hikurangi Margin
2. Controversy of Subducting Topography
3. Seamounts in N. Hikurangi Margin
4. Resistivity in the C. and S. Hikurangi Margin
5. Concluding Remarks

Hikurangi Margin Tectonics



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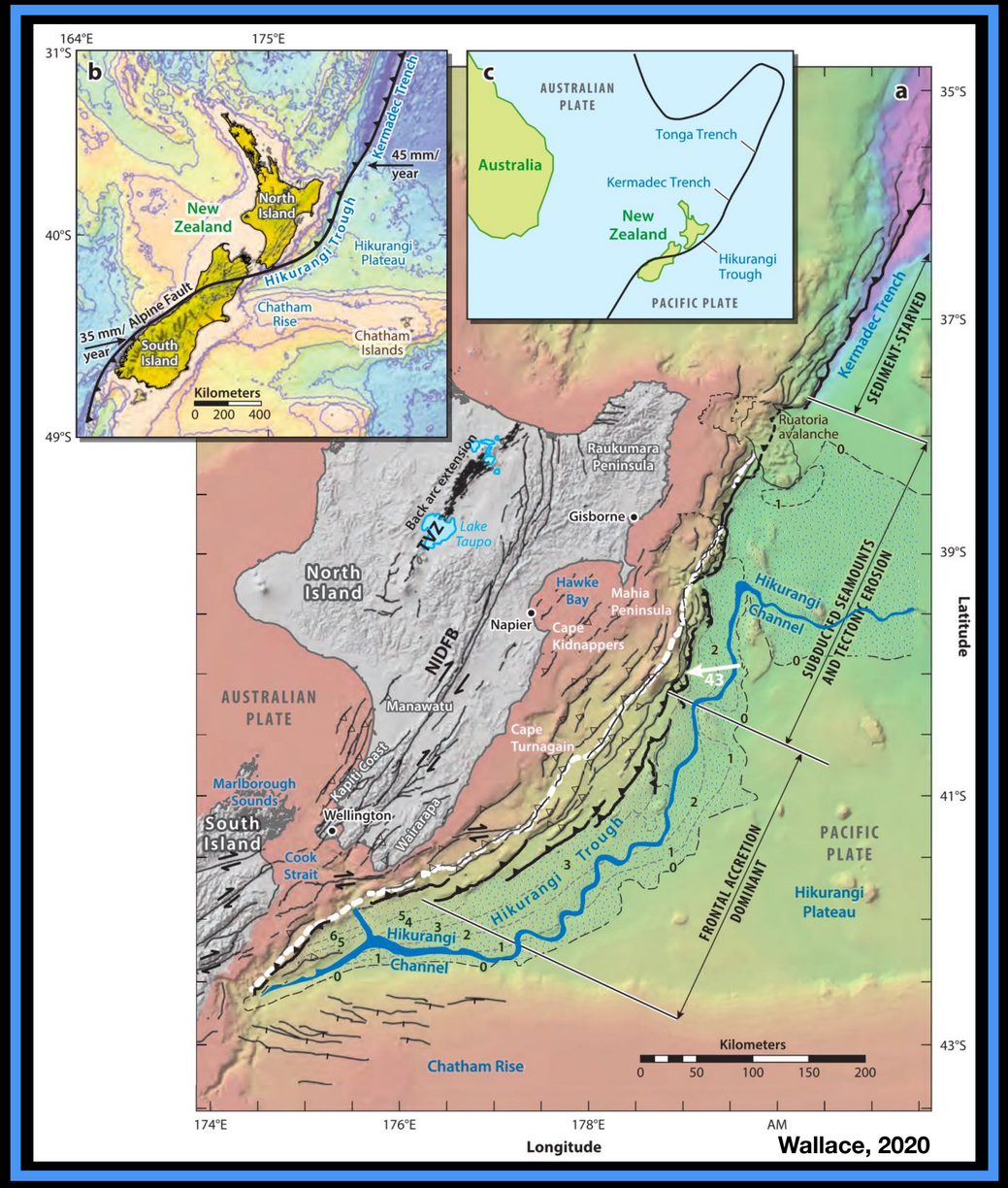
Hikurangi Margin Tectonics

- Pacific - Australian Plate convergence



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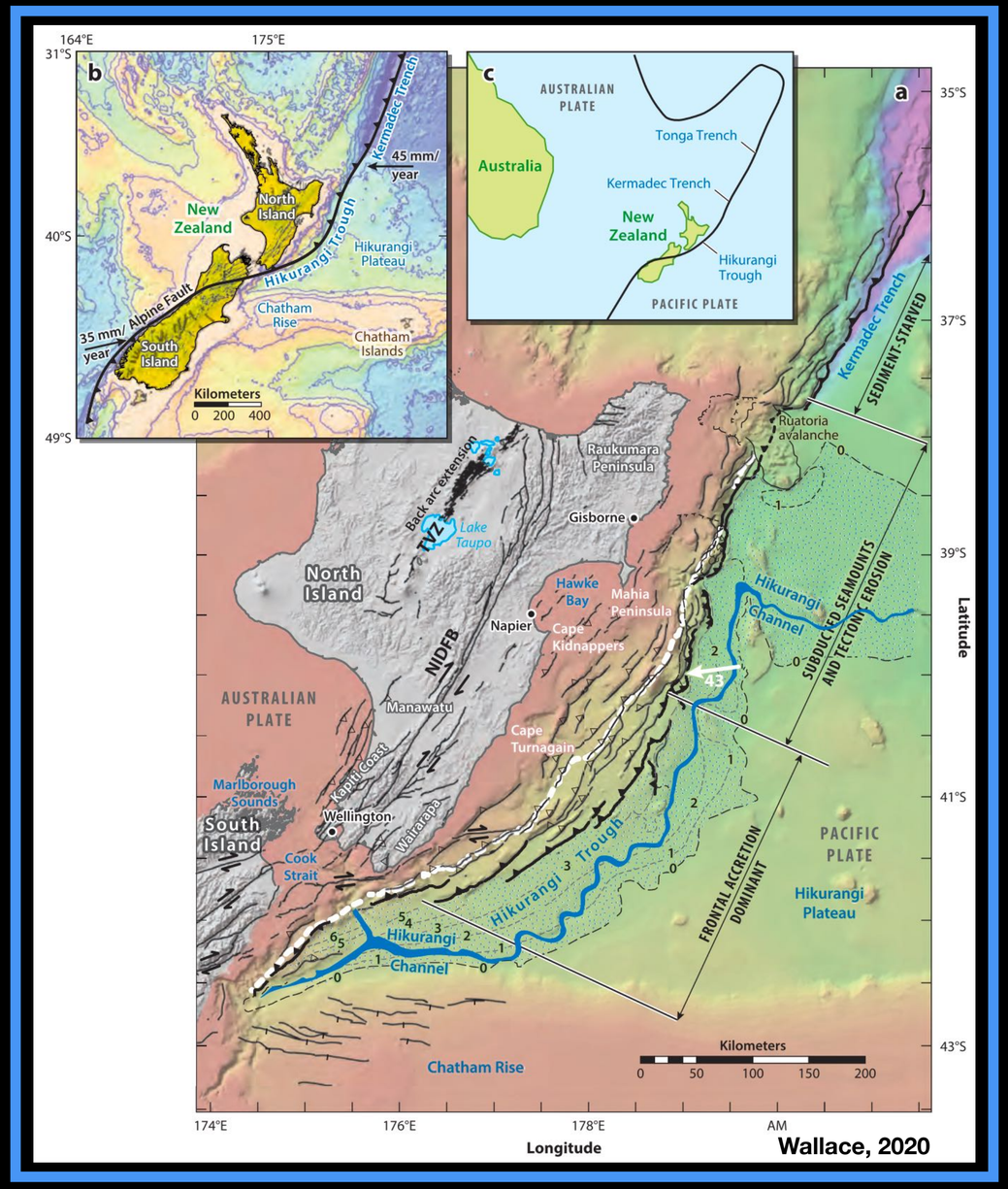
Hikurangi Margin Tectonics

- Pacific - Australian Plate convergence
- Hikurangi Plateau ~ 35 km thick



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Hikurangi Margin Tectonics

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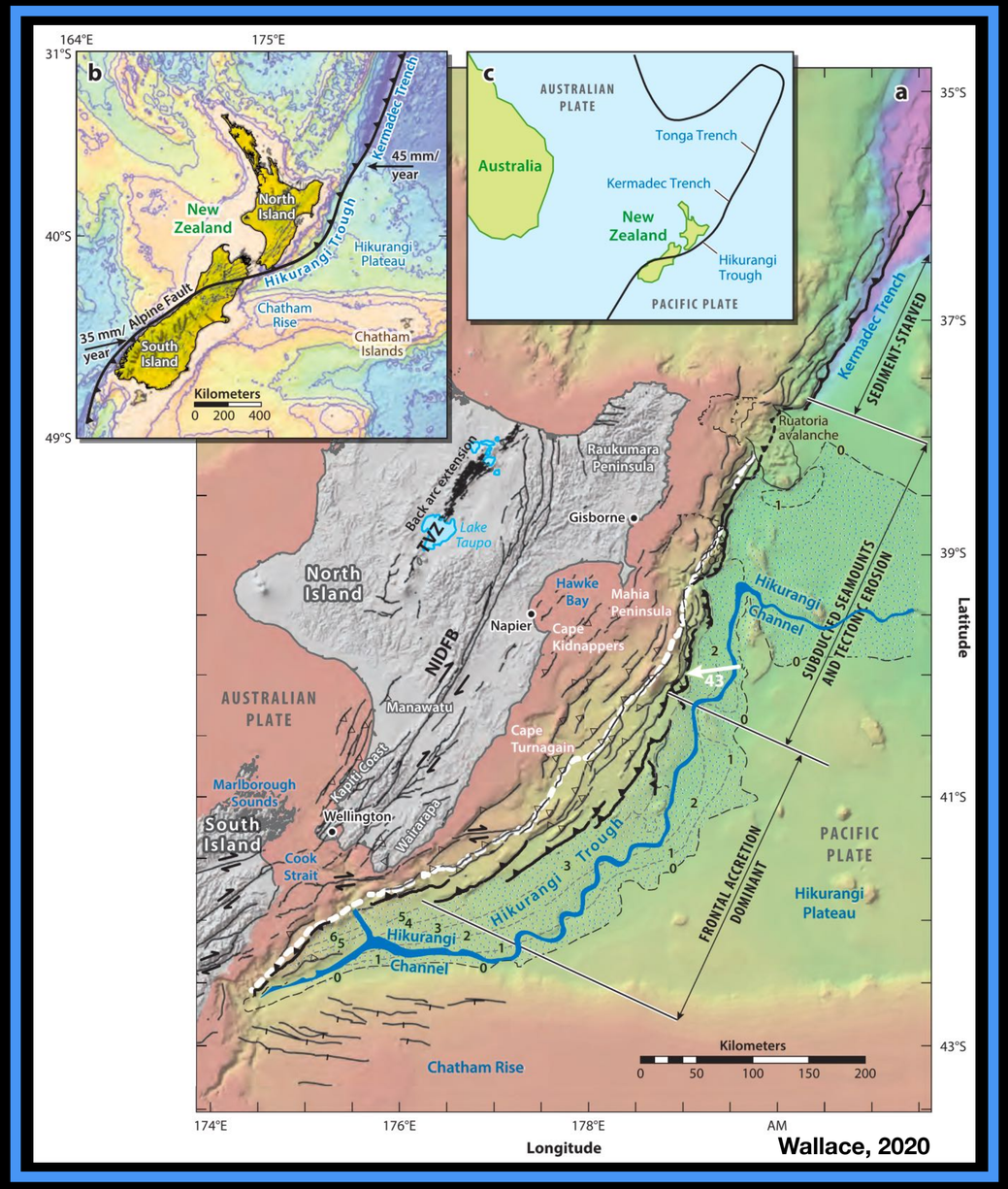
- Hikurangi Plateau ~ 35 km thick
- From convergence to strike slip N to S



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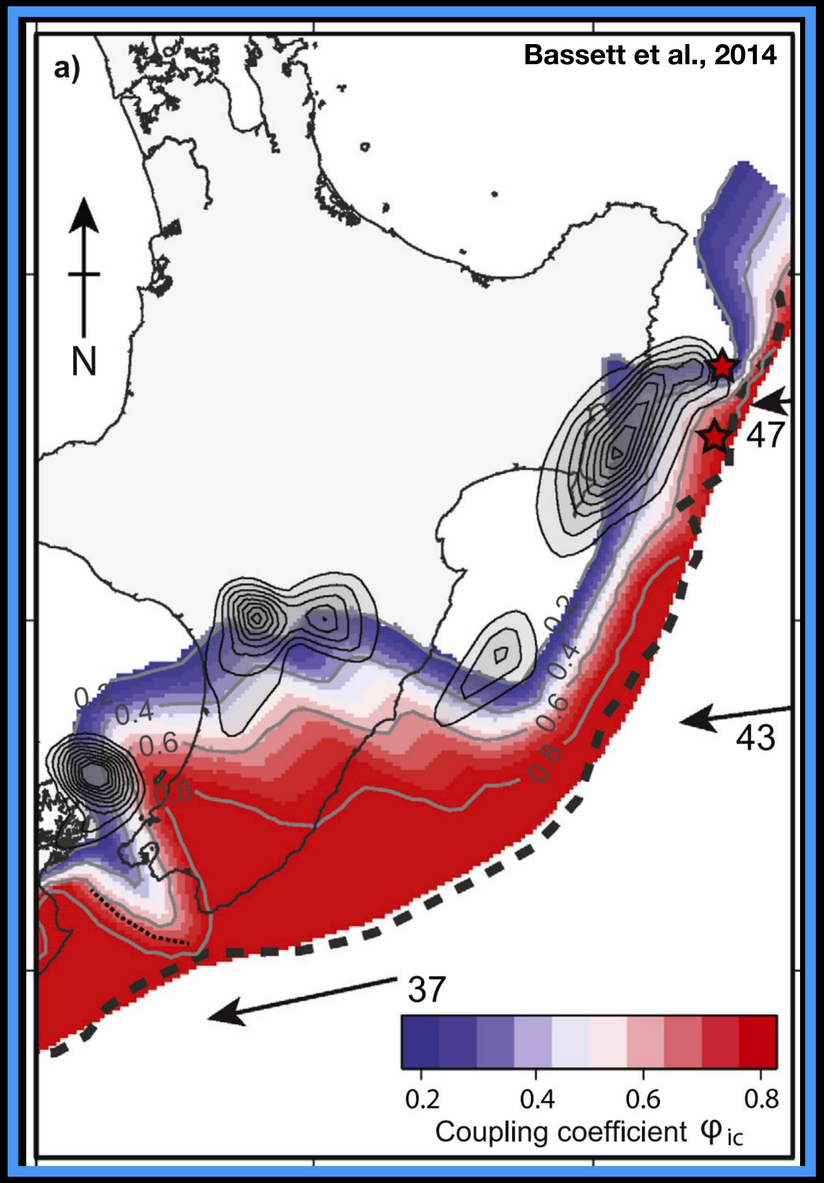
Along-Strike Variations

- Interseismic coupling decreases to the north



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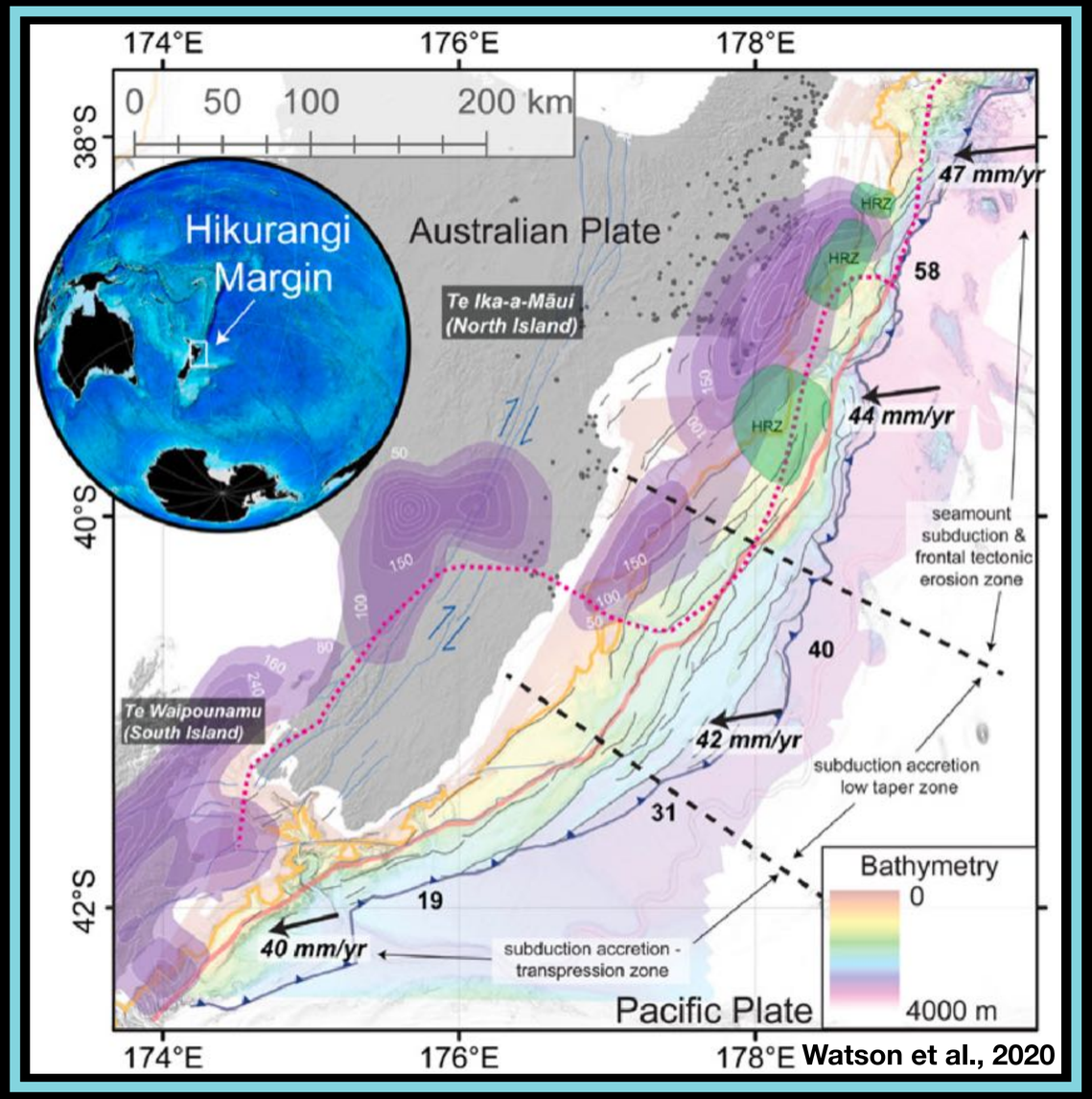

- Slow slip events are shallower & more frequent to the north

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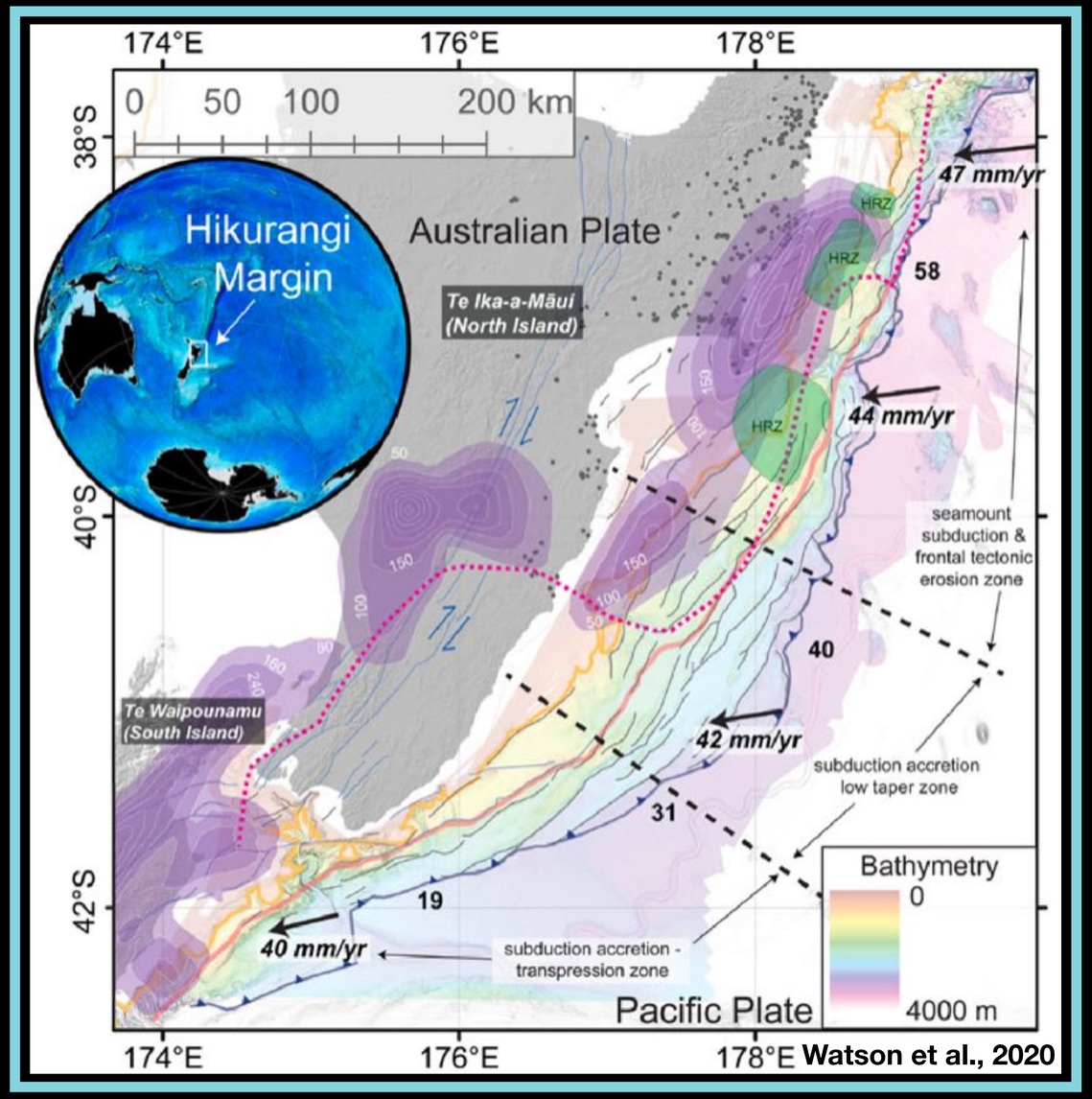
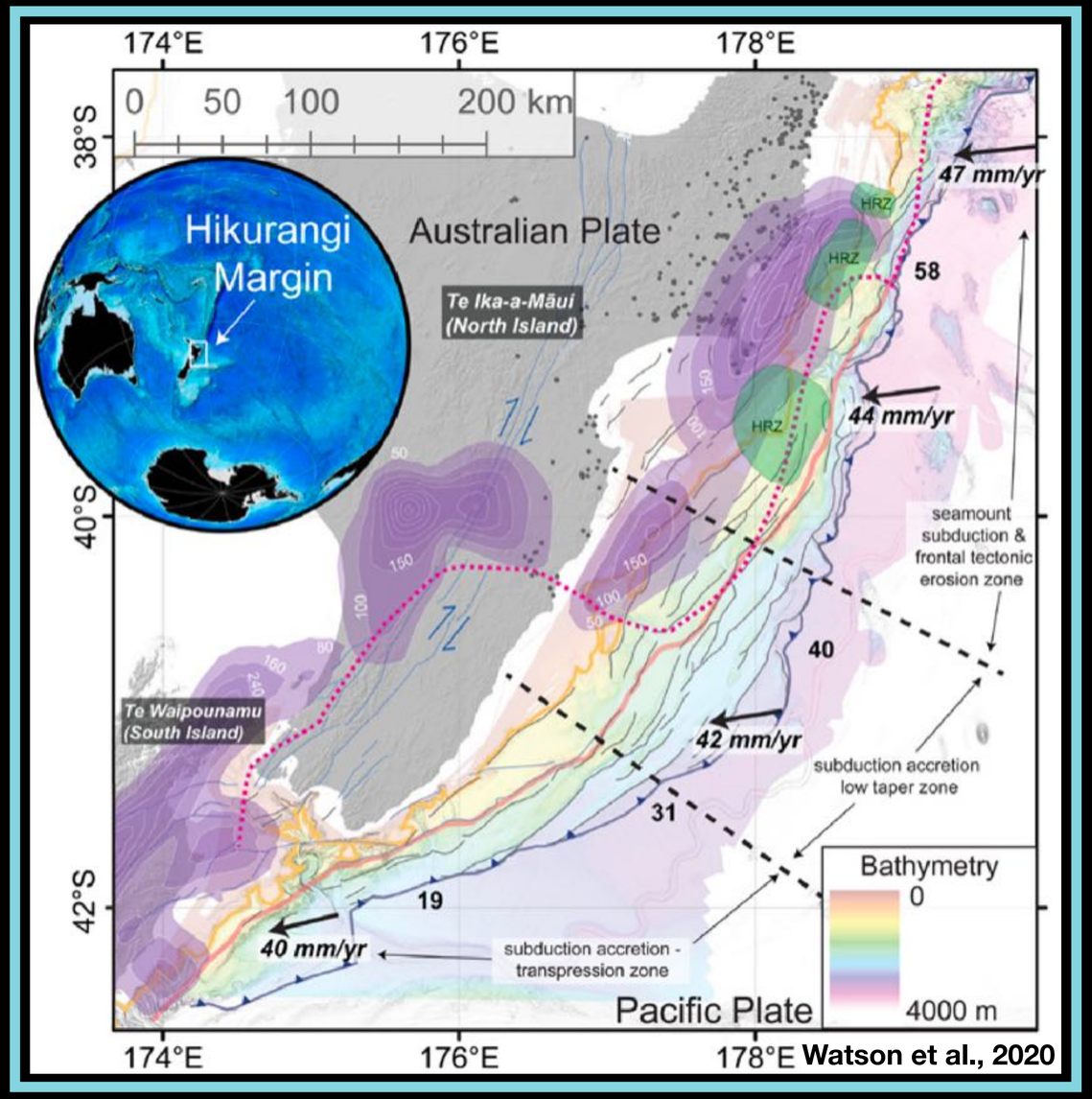
Along-Strike Variations



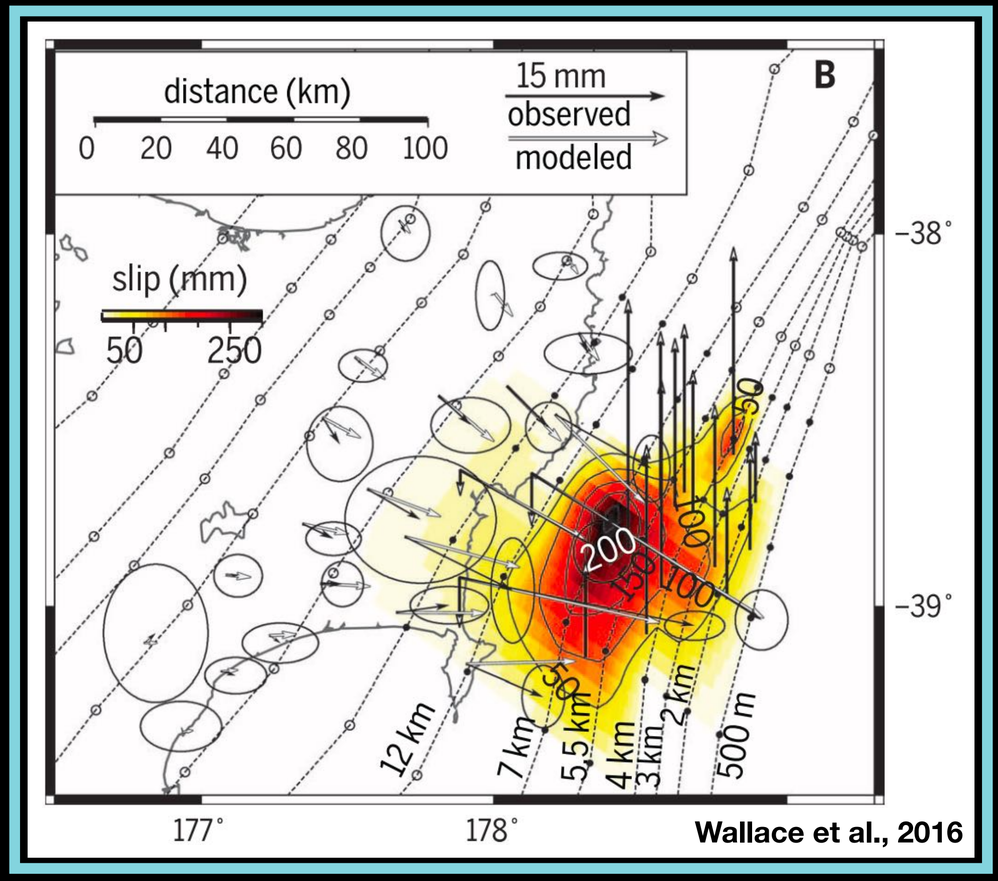
- Slow slip events are shallower & more frequent to the north
- Related to amount of fluid available?

Along-Strike Variations



Watson et al., 2020

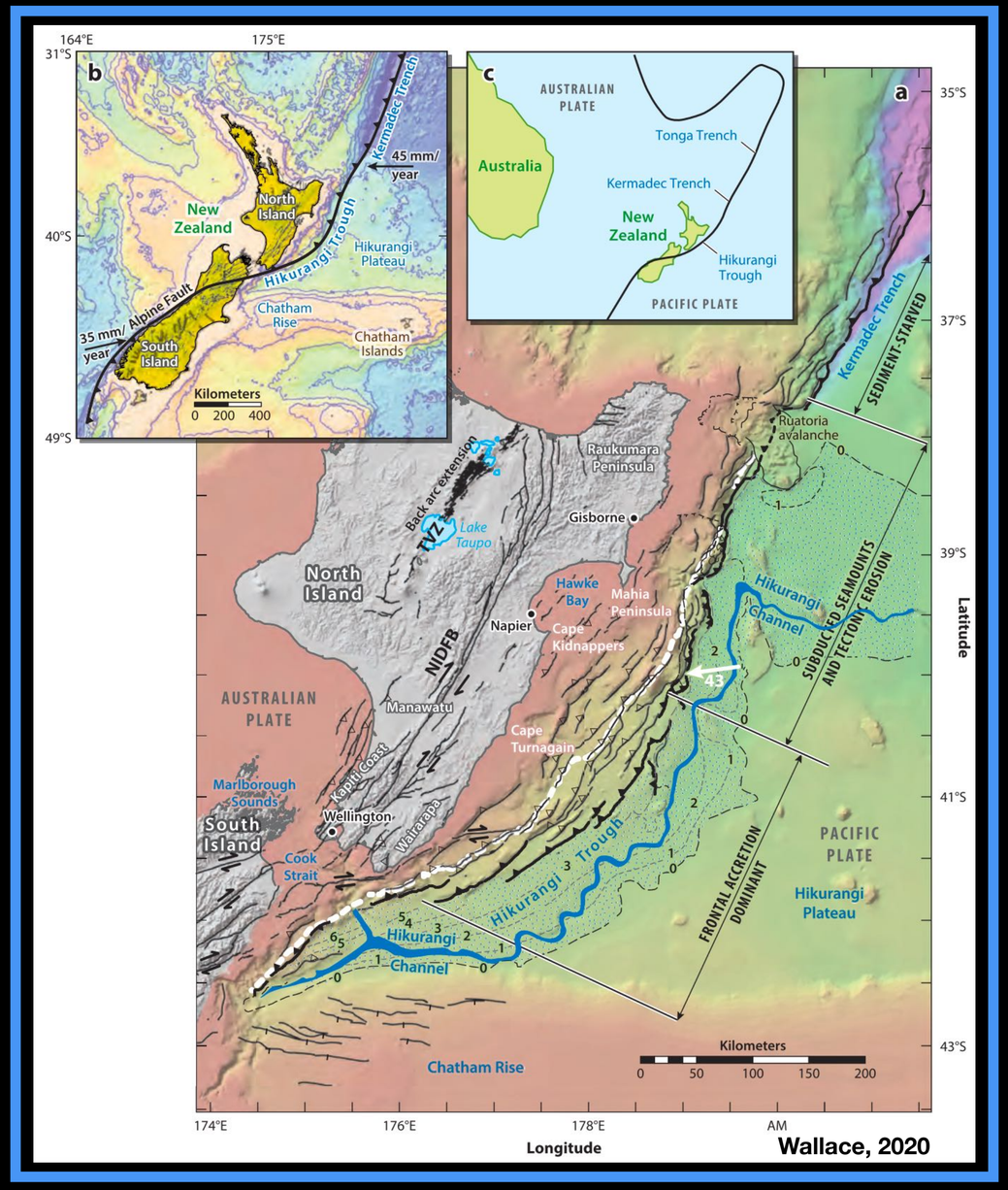
- Slow slip events are shallower & more frequent to the north



Wallace et al., 2016

Along-Strike Variations

- Seafloor roughness increases to the north



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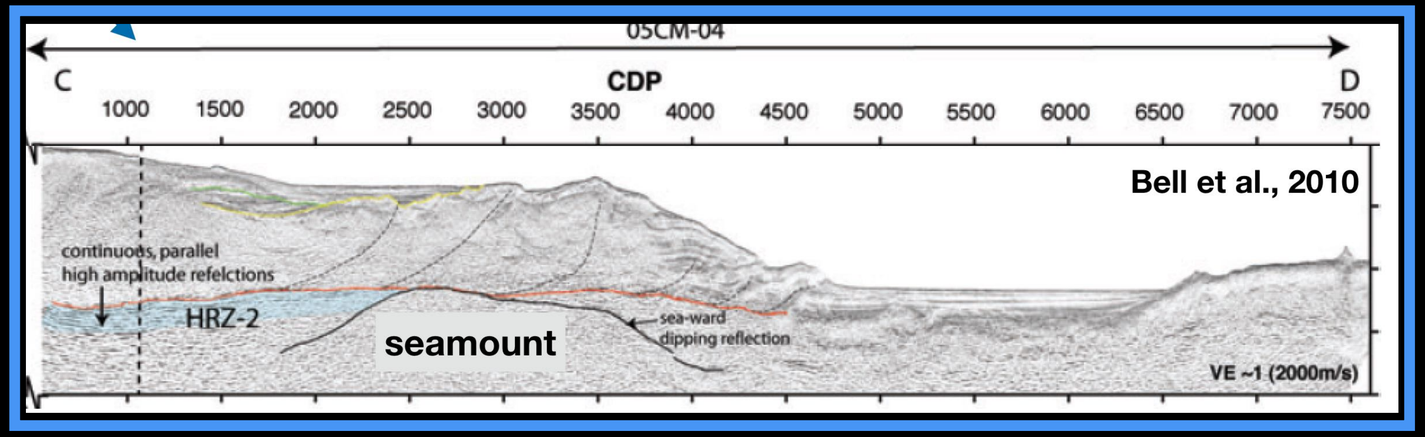
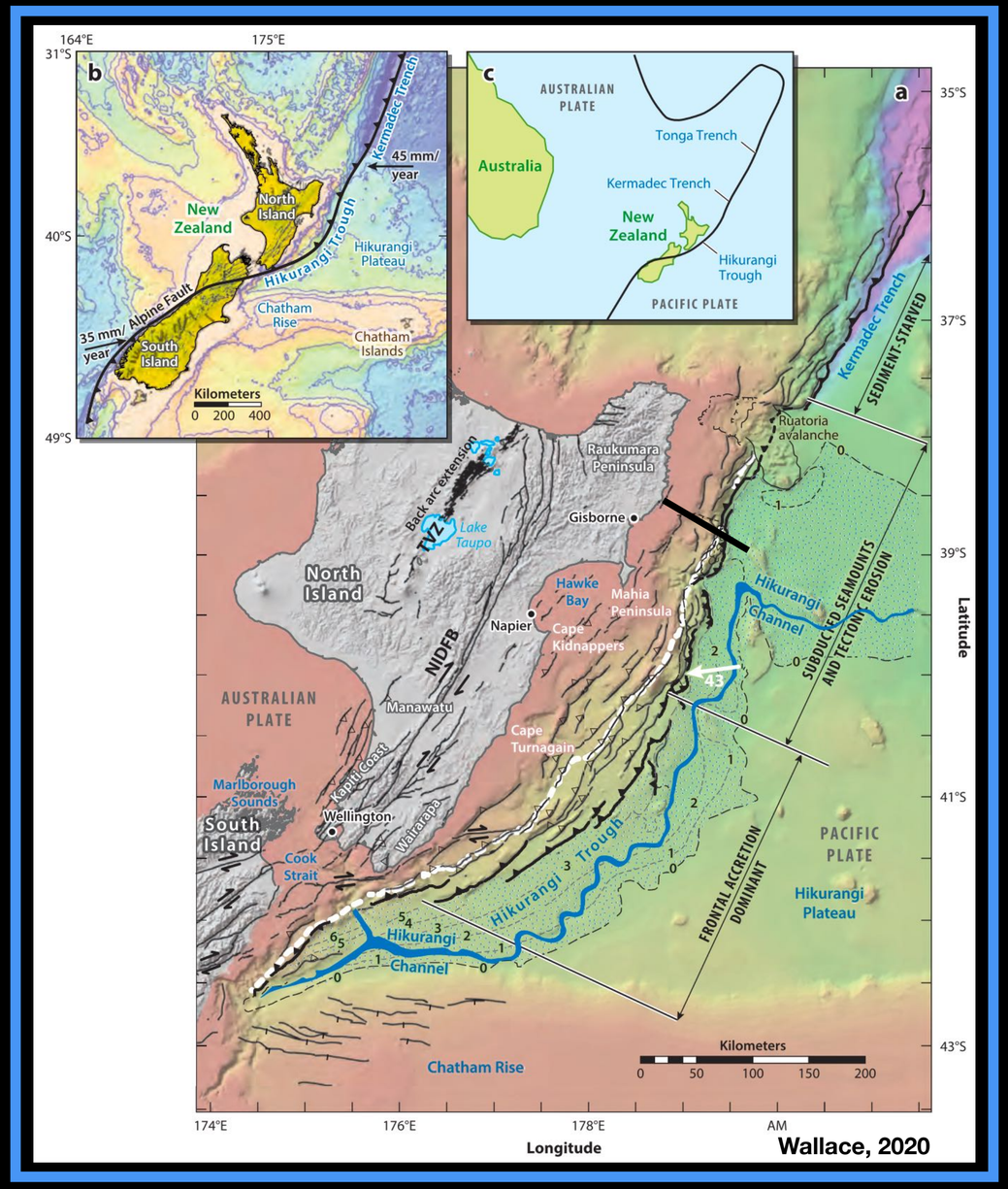
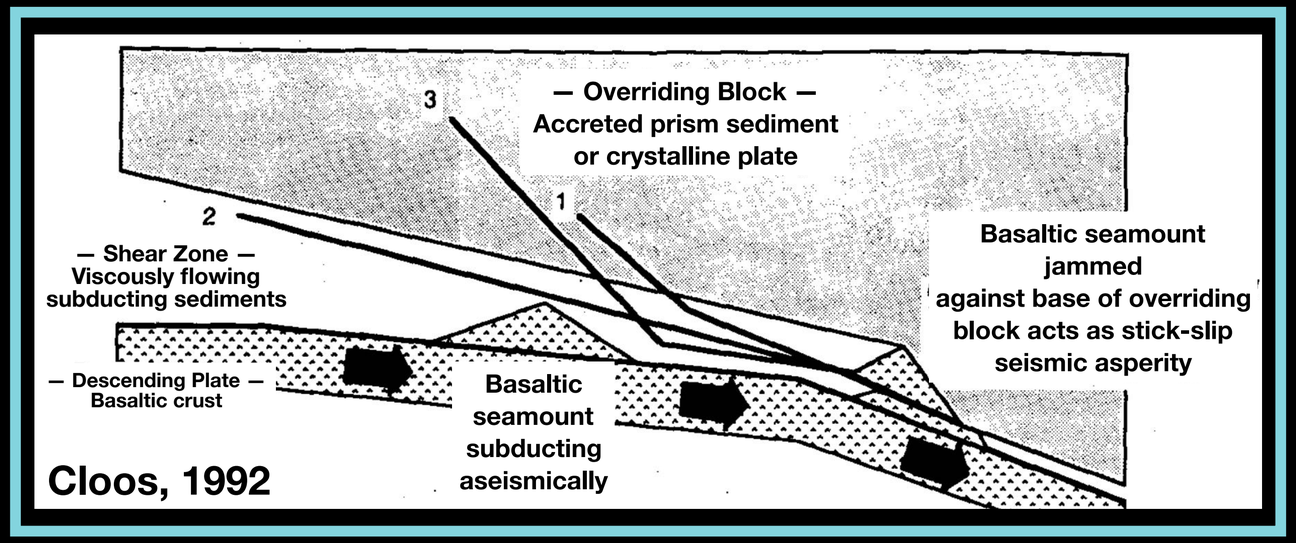




Subducting Topography and Fault Slip

Subducting Topography and Fault Slip

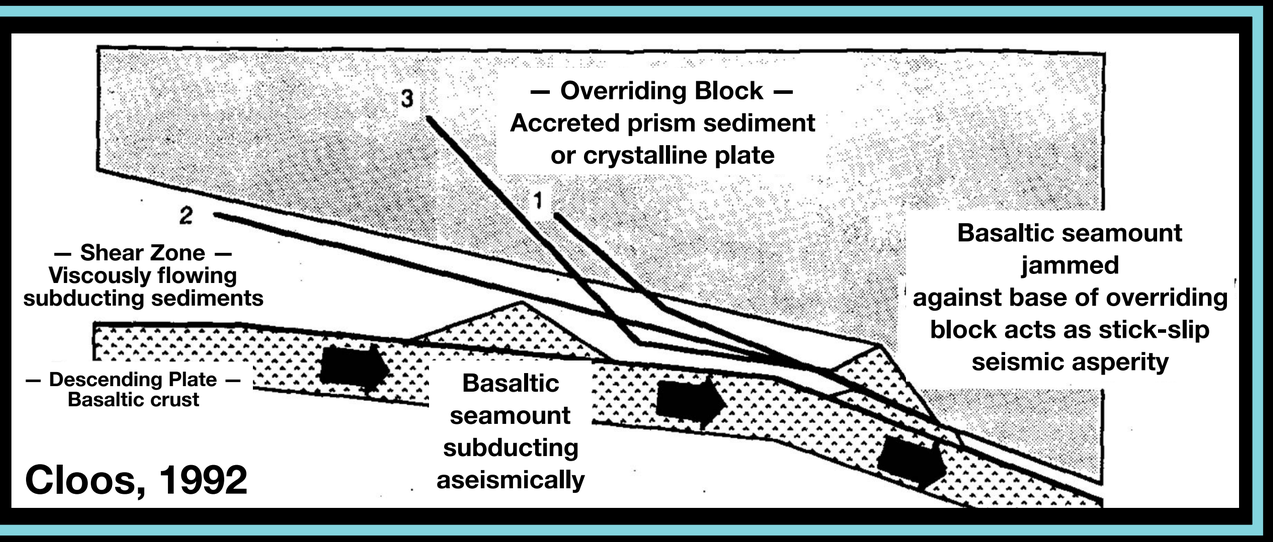
- **Camp A:**
  Subducting seamounts promote large EQs

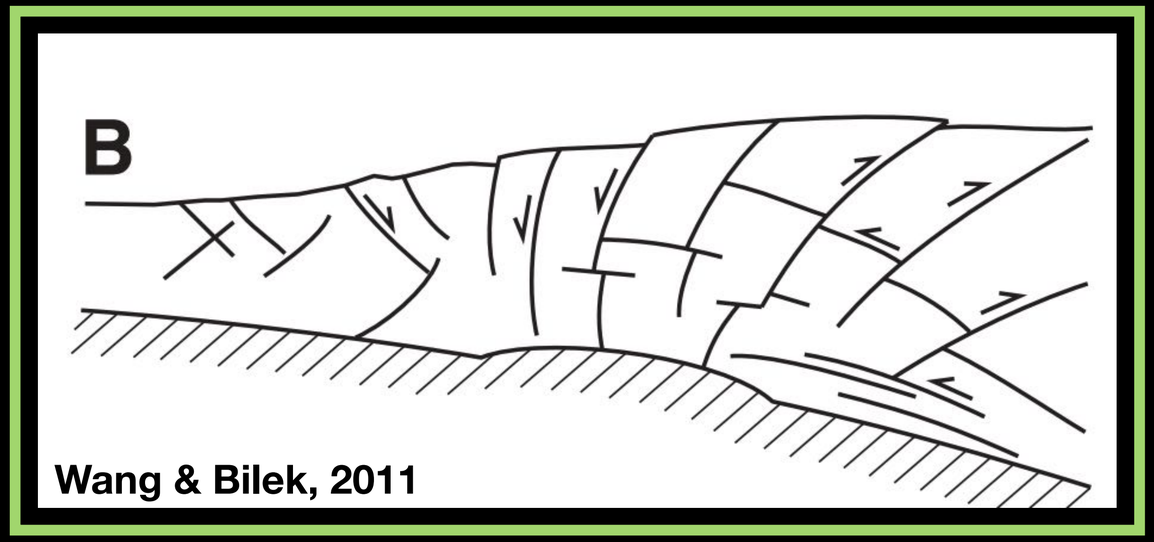


Subducting Topography and Fault Slip

- **Camp A:**
  Subducting seamounts promote large EQs

- **Camp B:**
  Subducting seamounts promote small EQs and aseismic creep





Subducting Topography and Fault Slip

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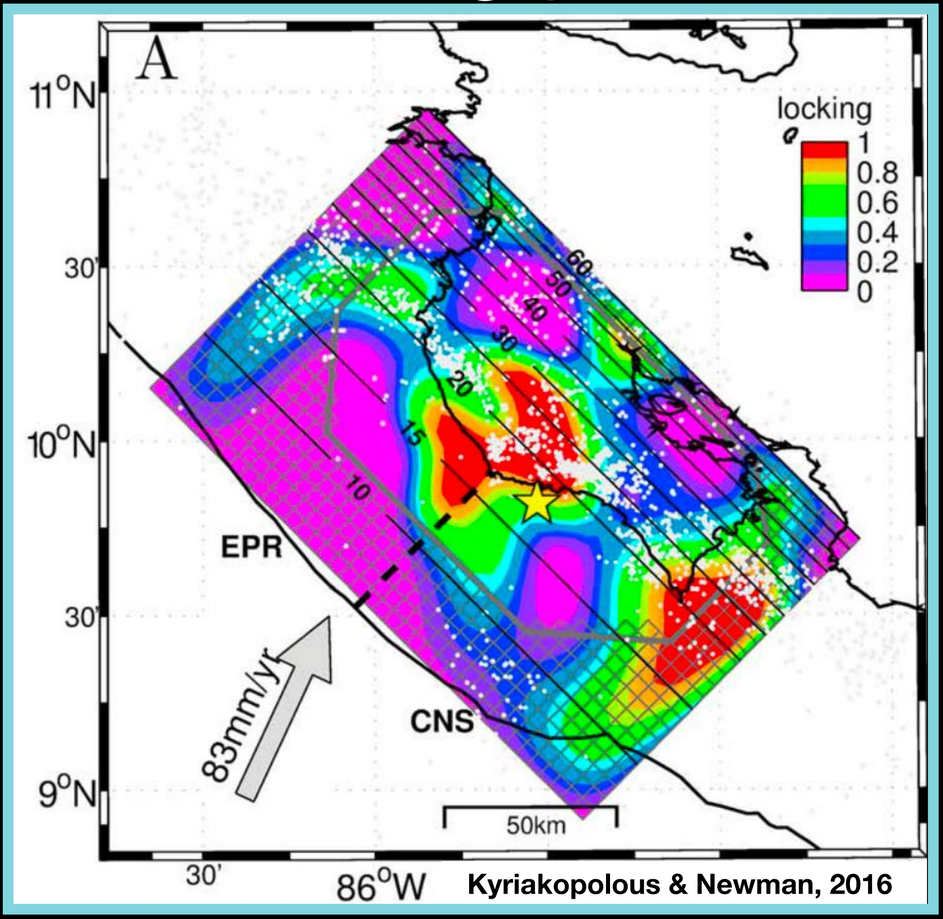

Kyriakopolous & Newman, 2016

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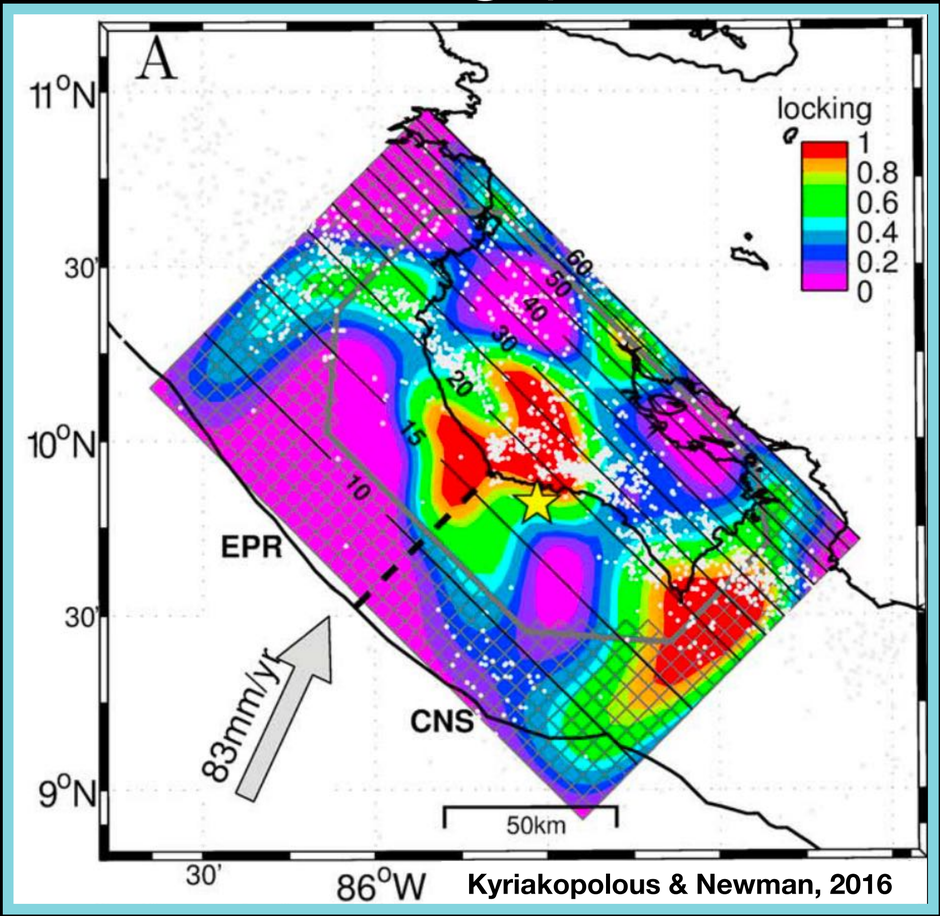
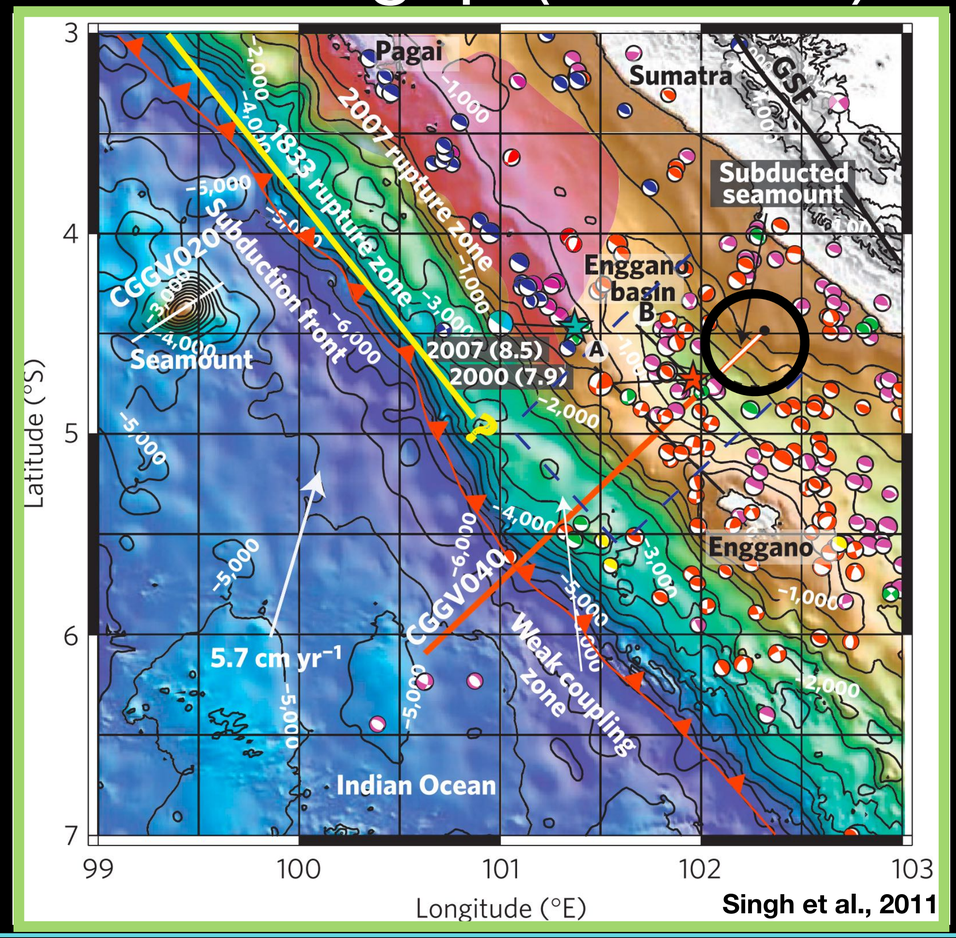


Kyriakopolous & Newman, 2016

- **Camp B:** Seamount—> seismic gap (Sumatra)



Singh et al., 2011

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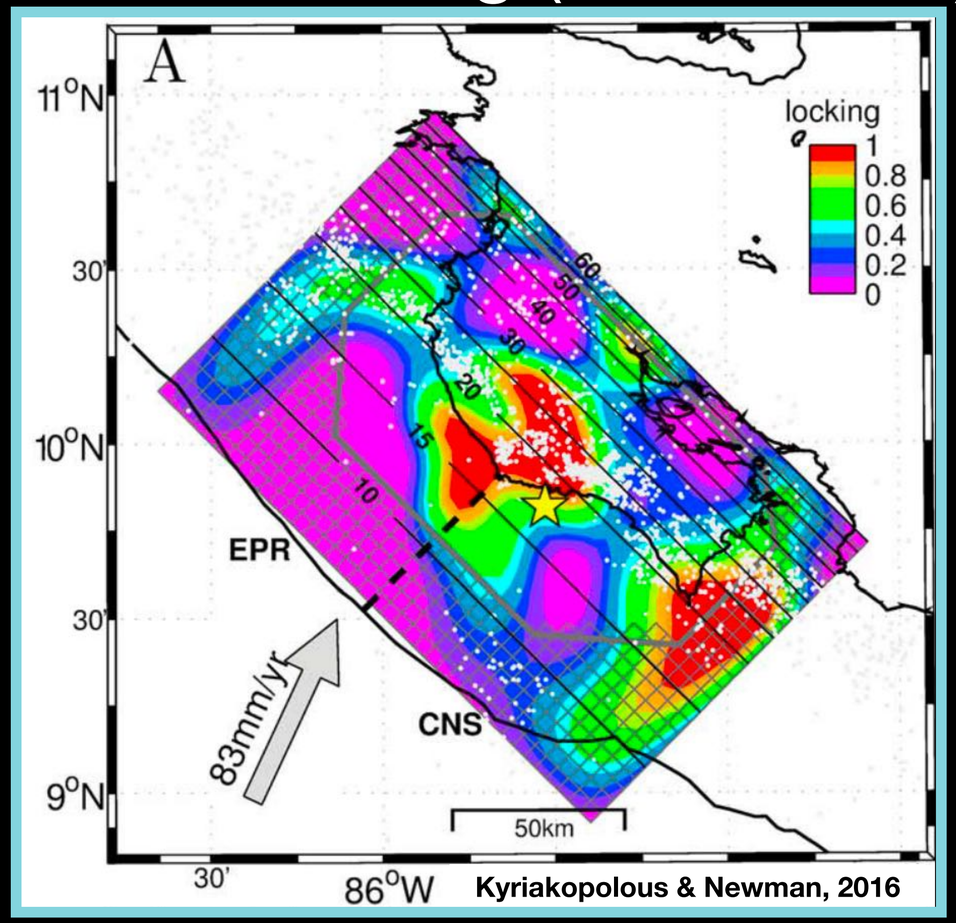

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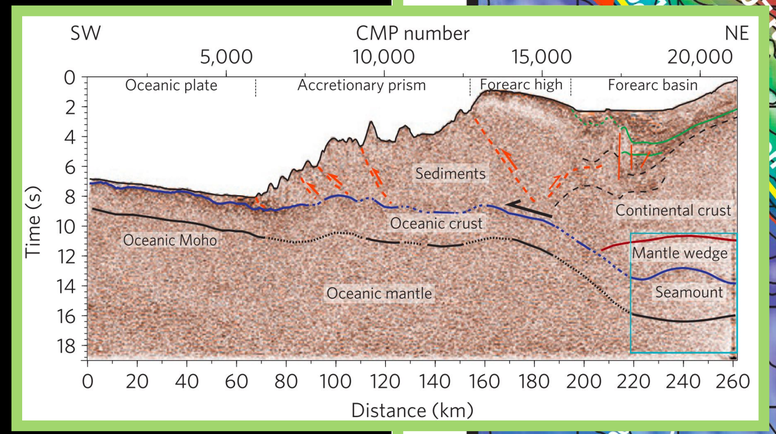
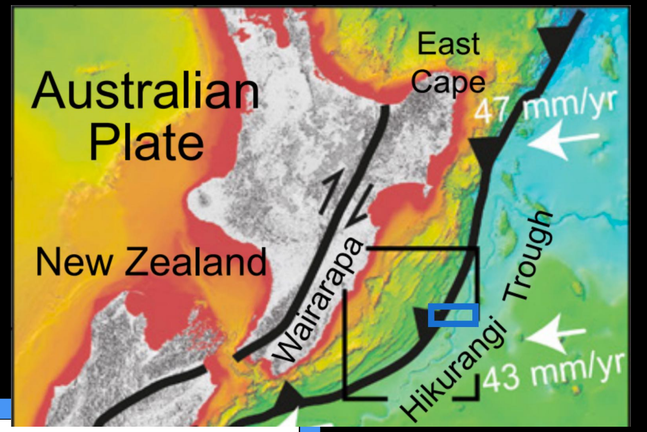
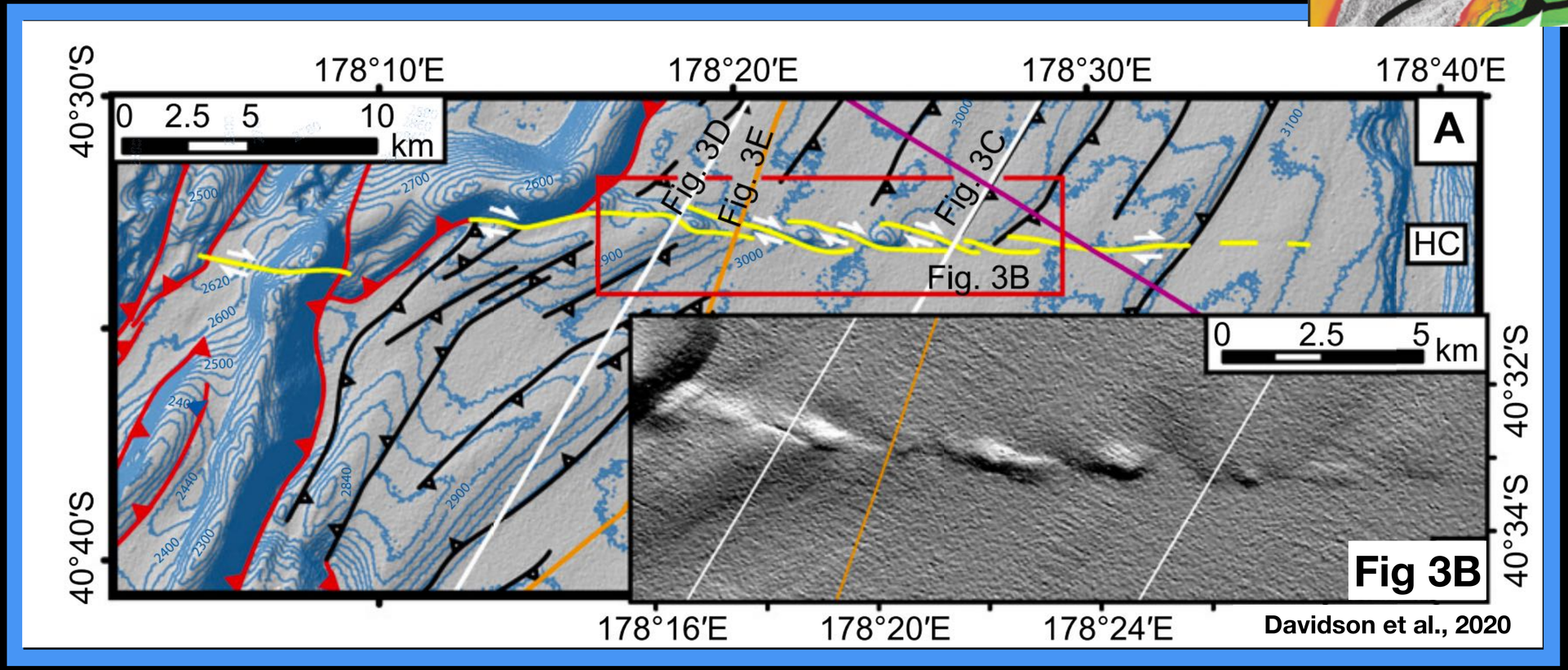


Singh et al., 2011

Imaging Subducting Topography

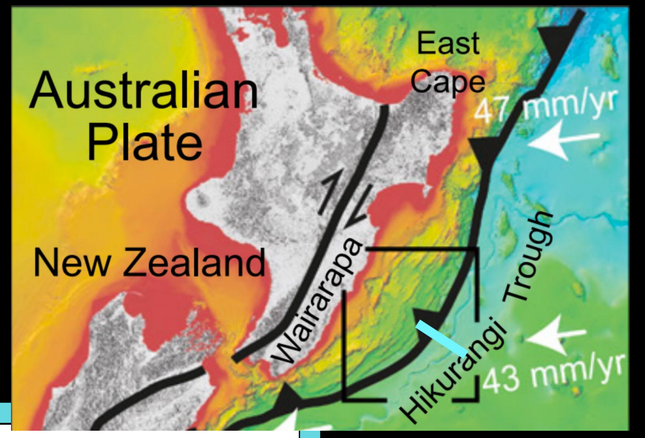
- Surficial strike-slip faults from incipient seamount subduction

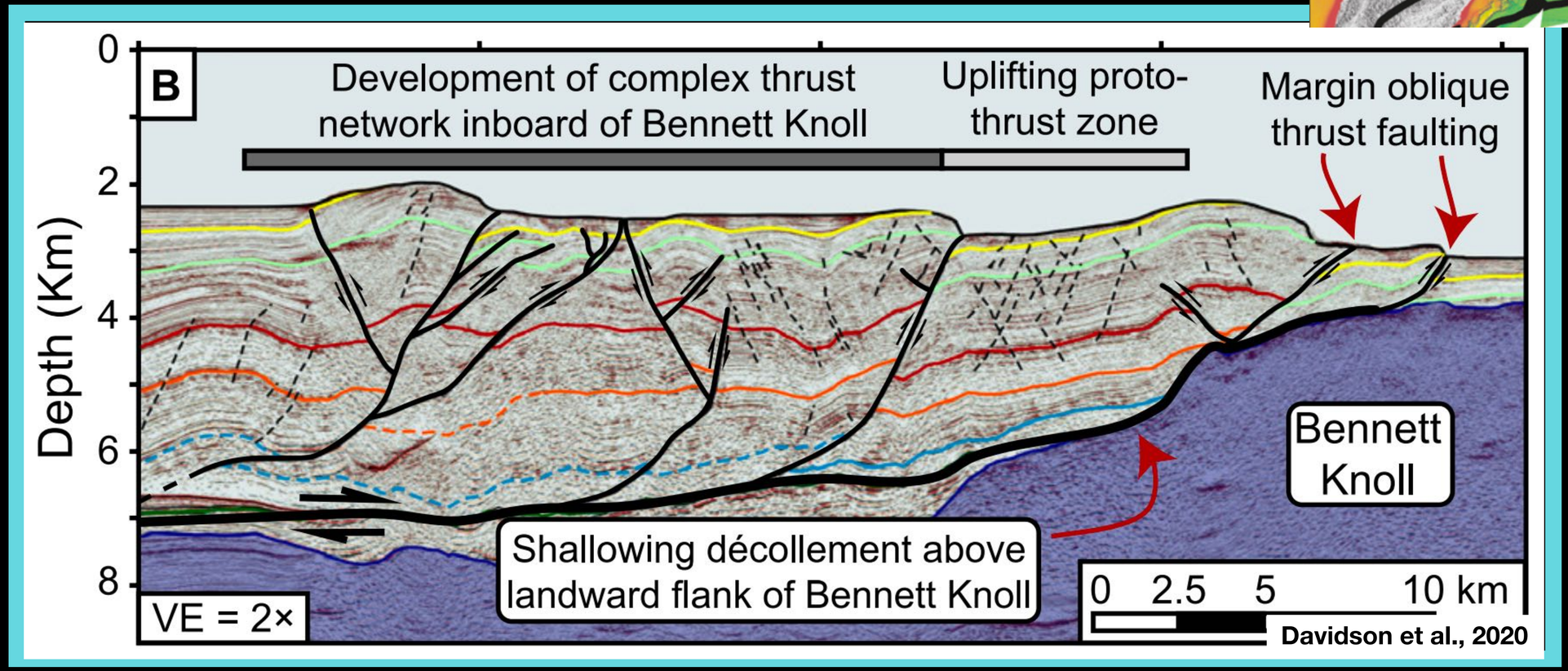




Imaging Subducting Topography

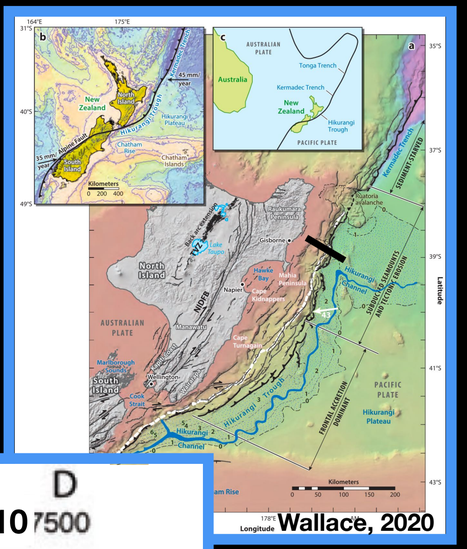
- High res images, but seamount still shallow

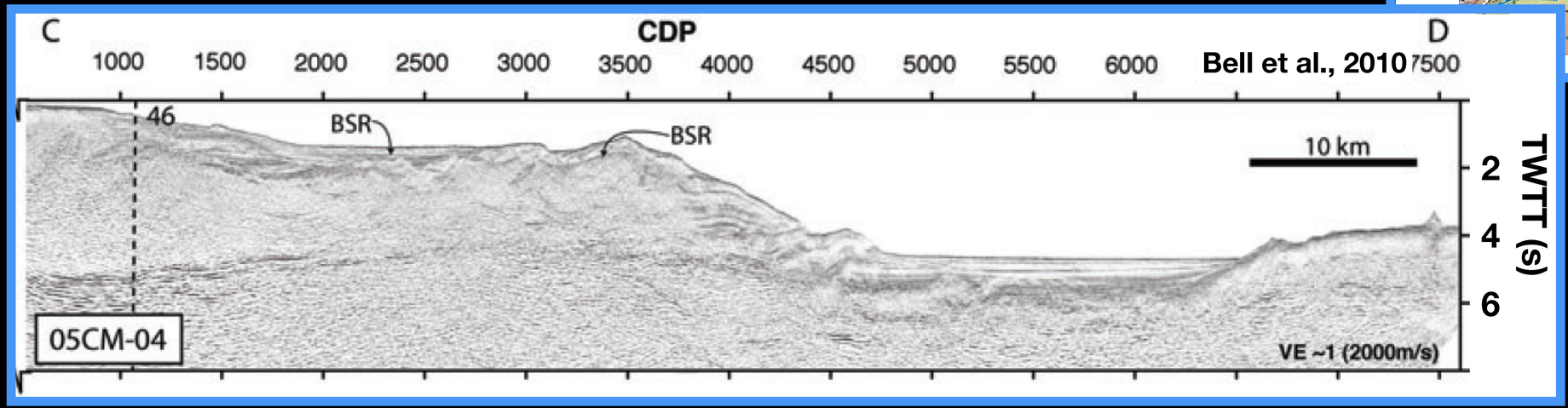




Imaging Subducting Topography

- More difficult to image once deeper





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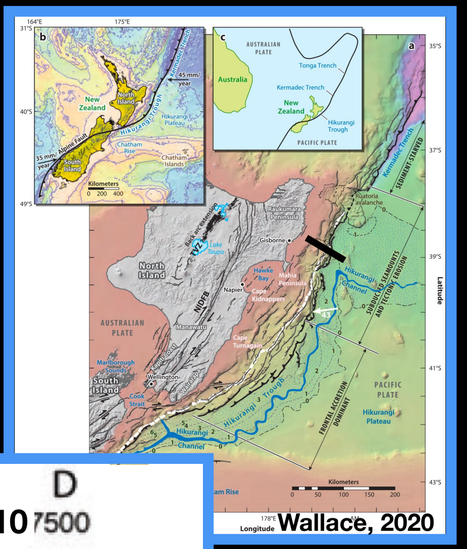

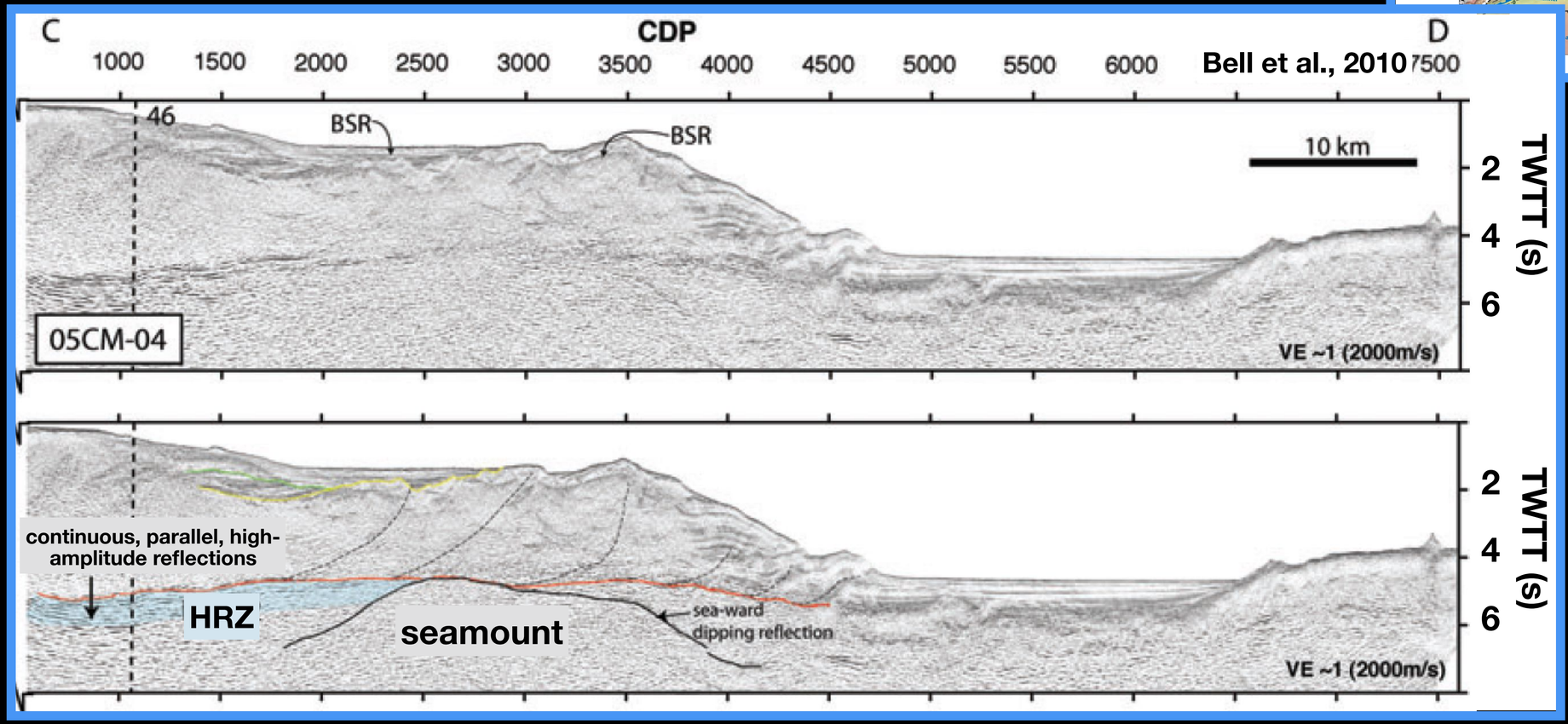

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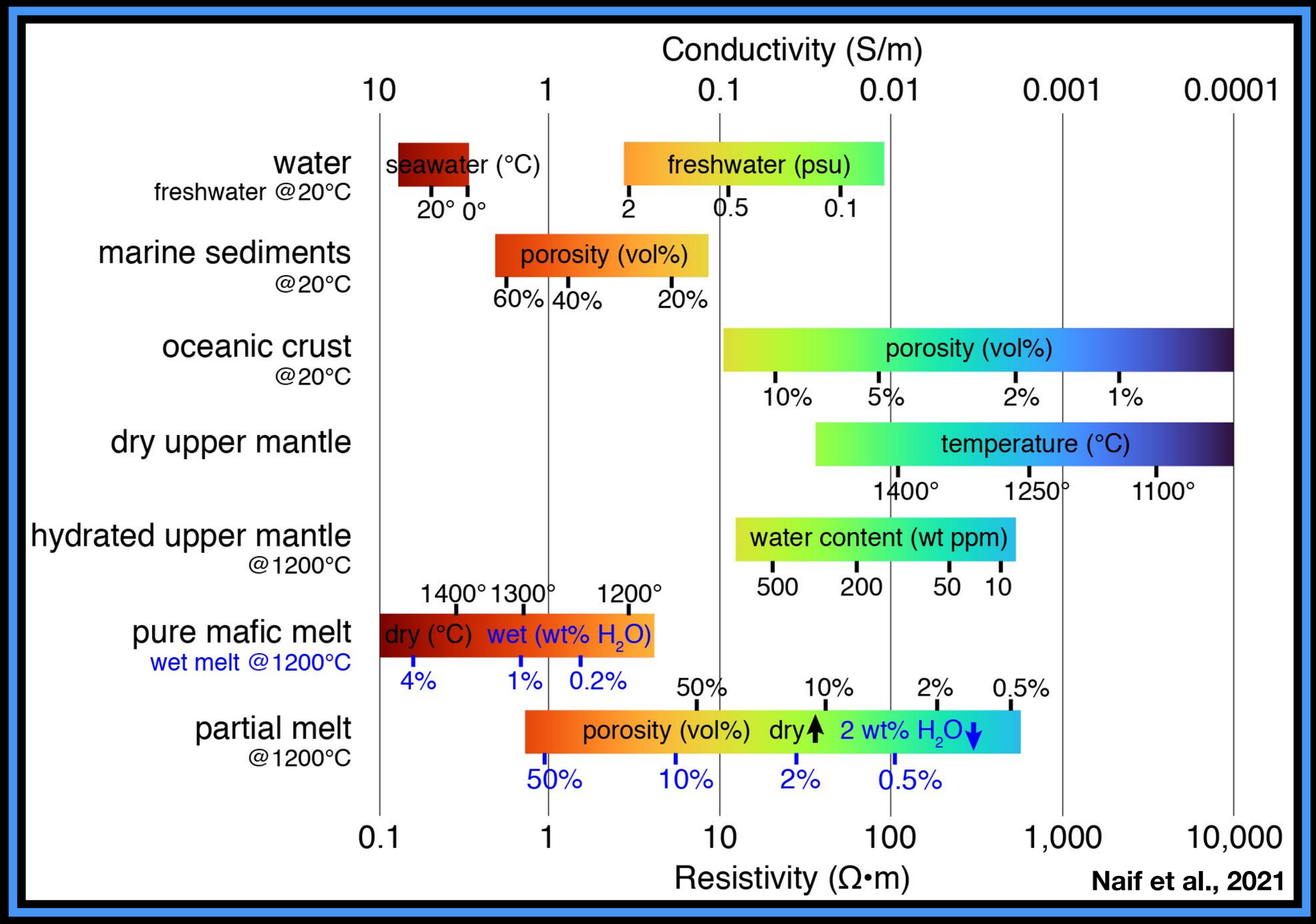
EM Geophysics as an Imaging Tool



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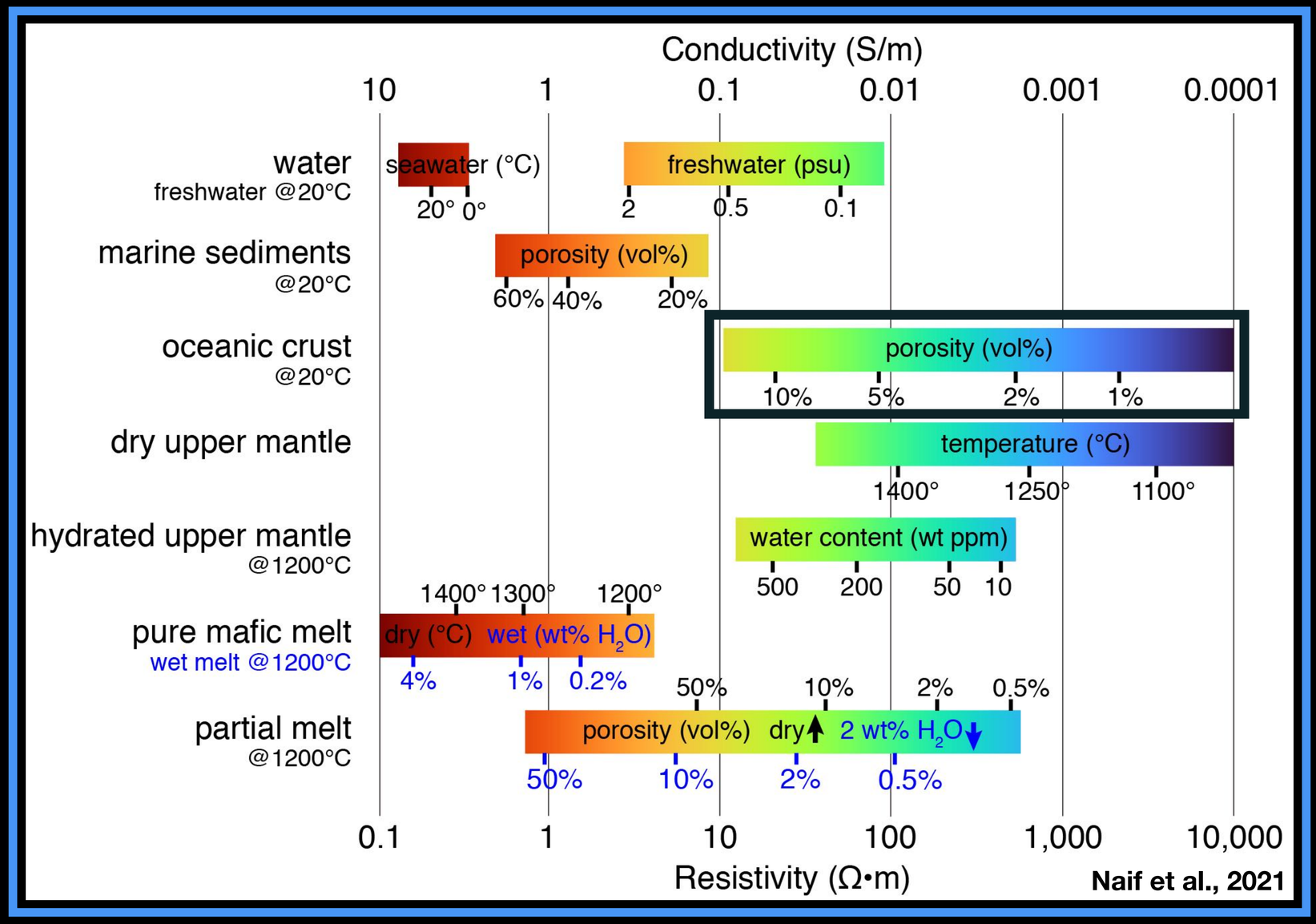

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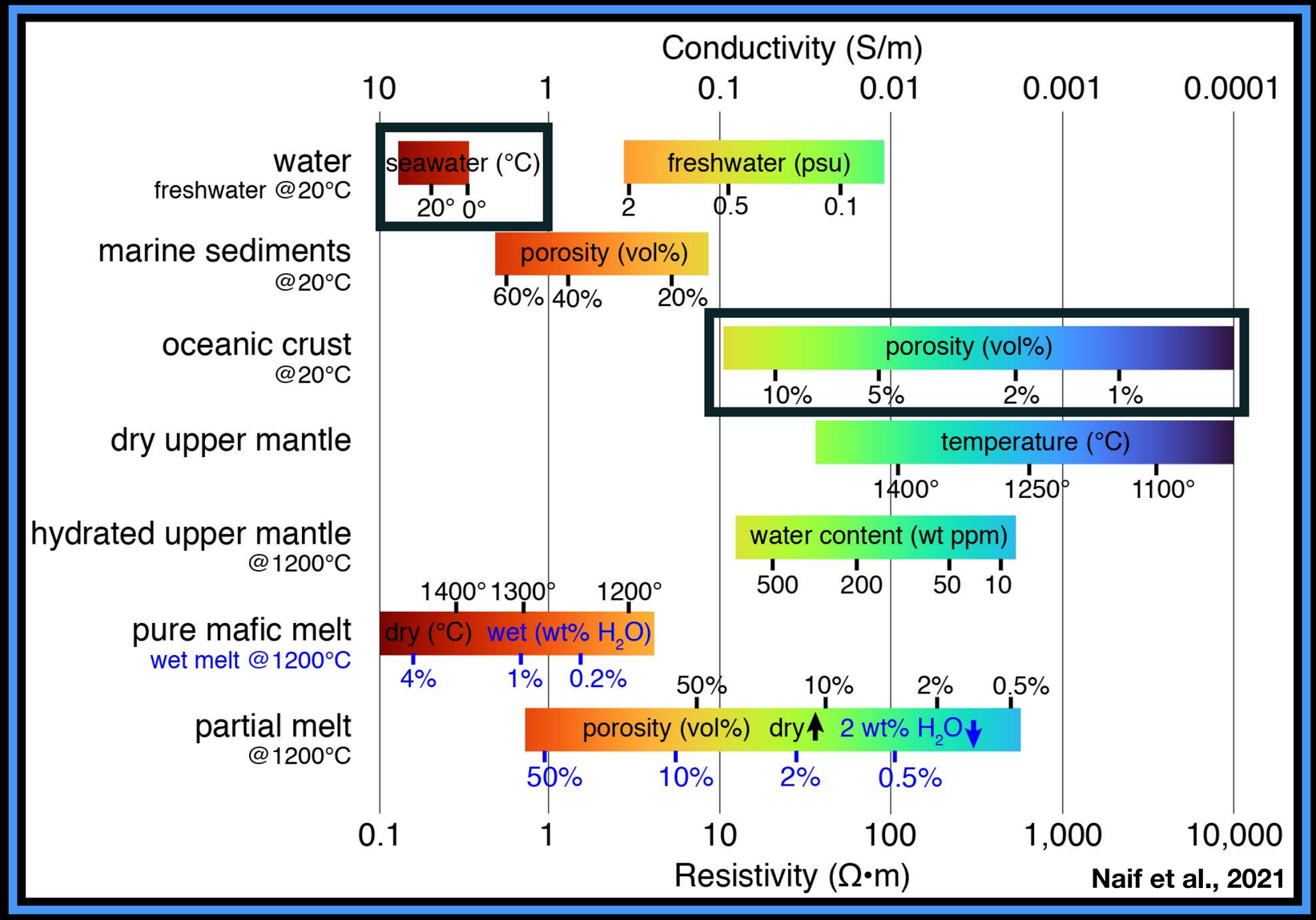

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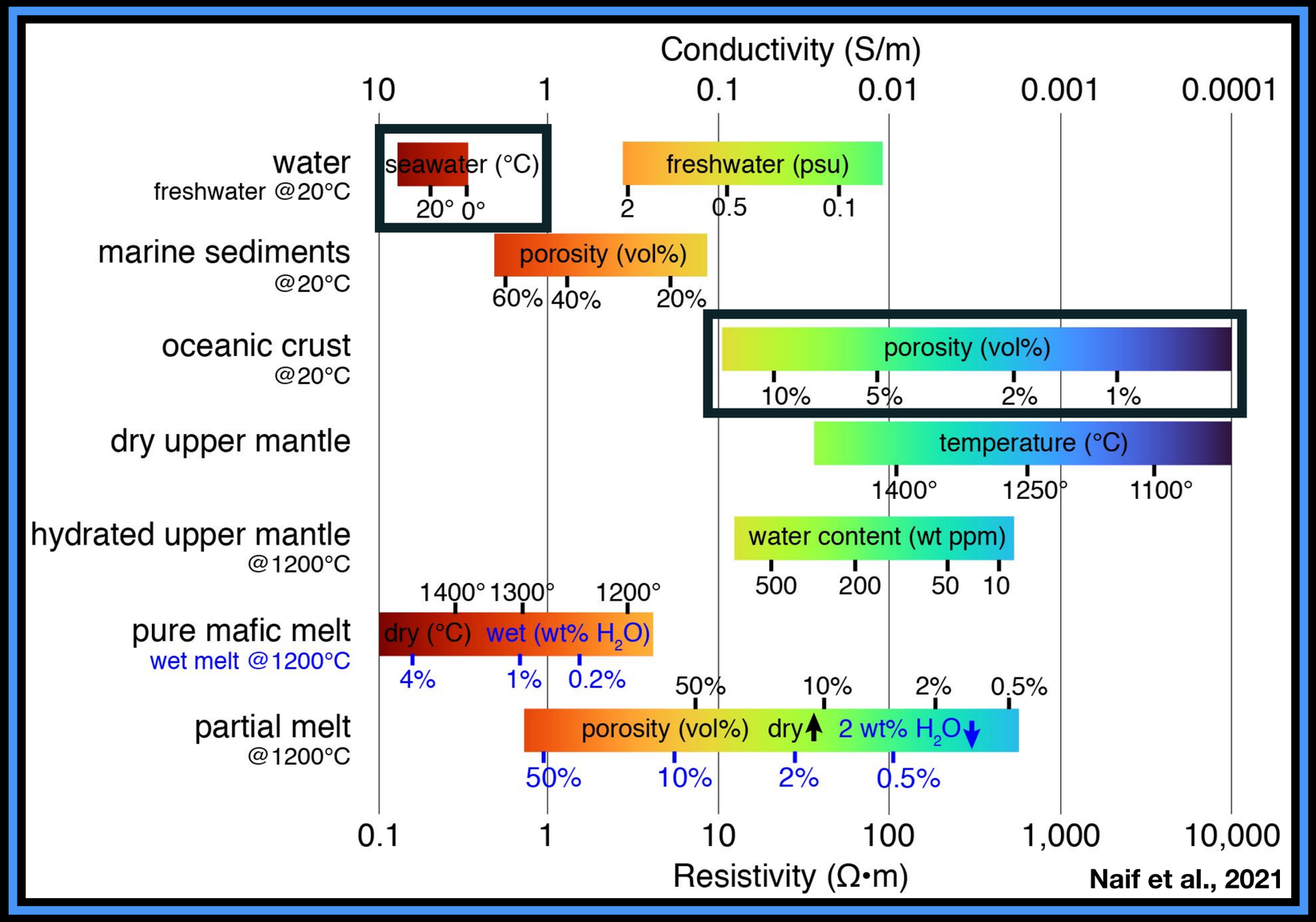

- Porosity is dominant control on resistivity of crust and sediments

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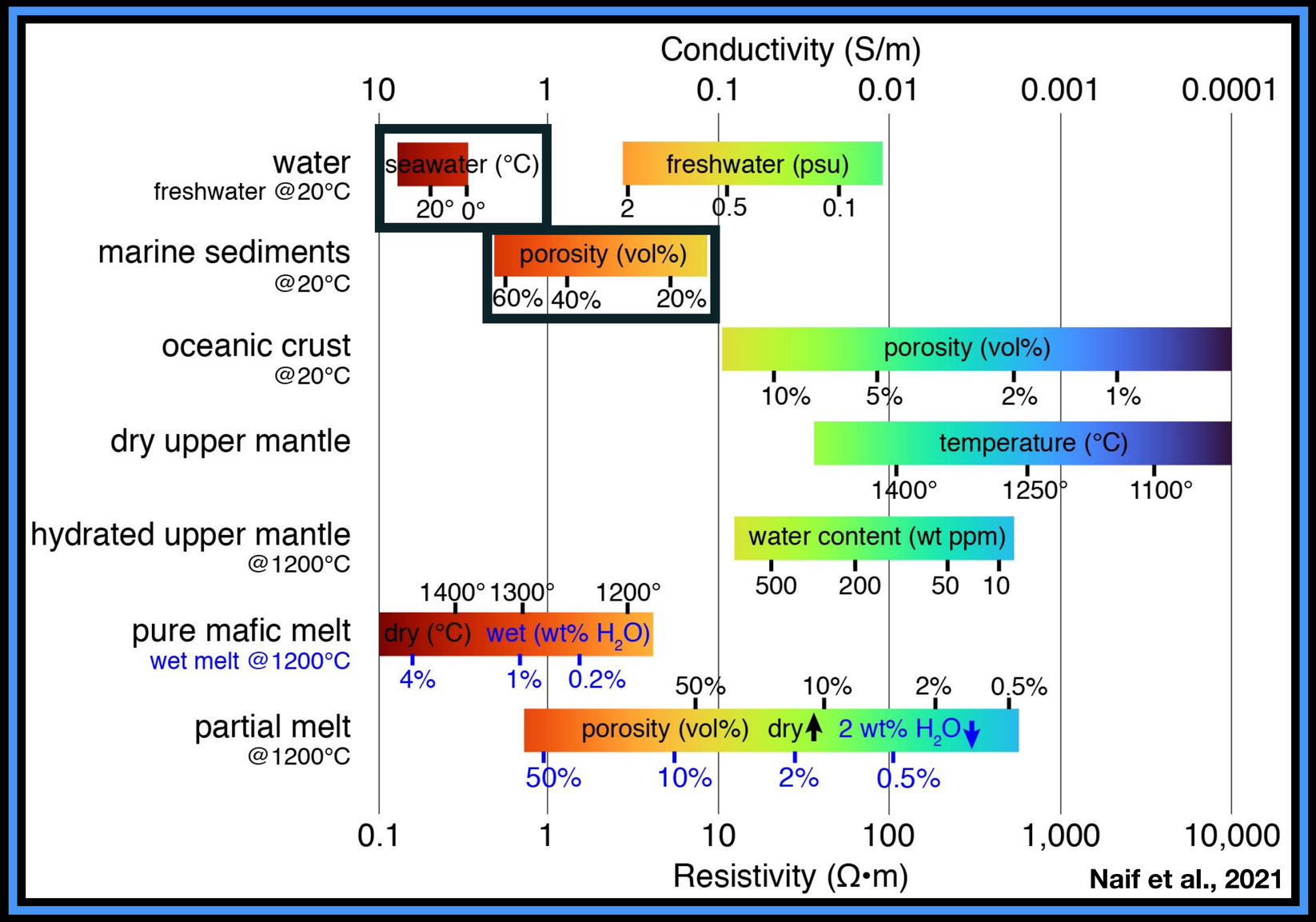

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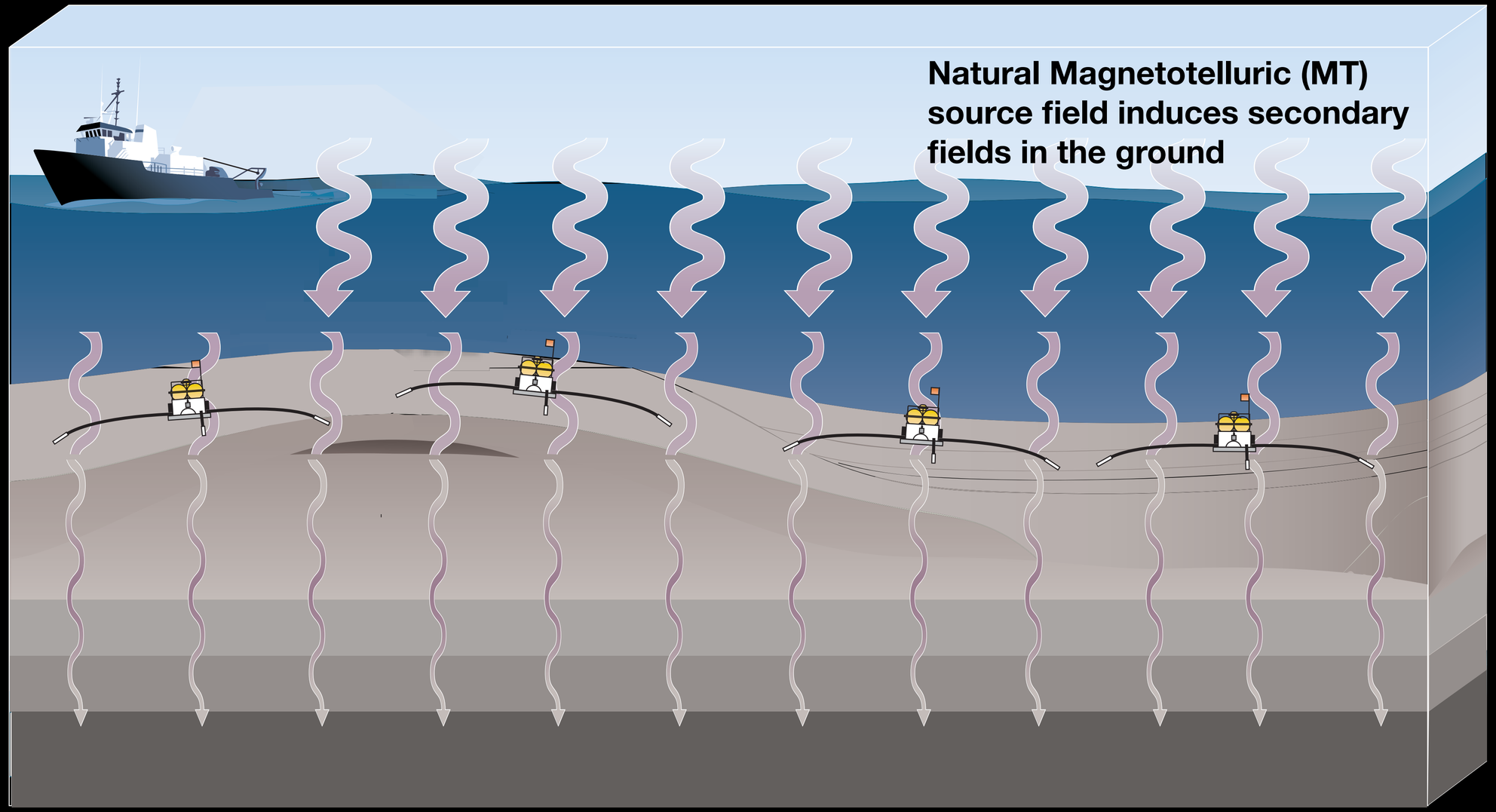
The Marine Electromagnetic Method



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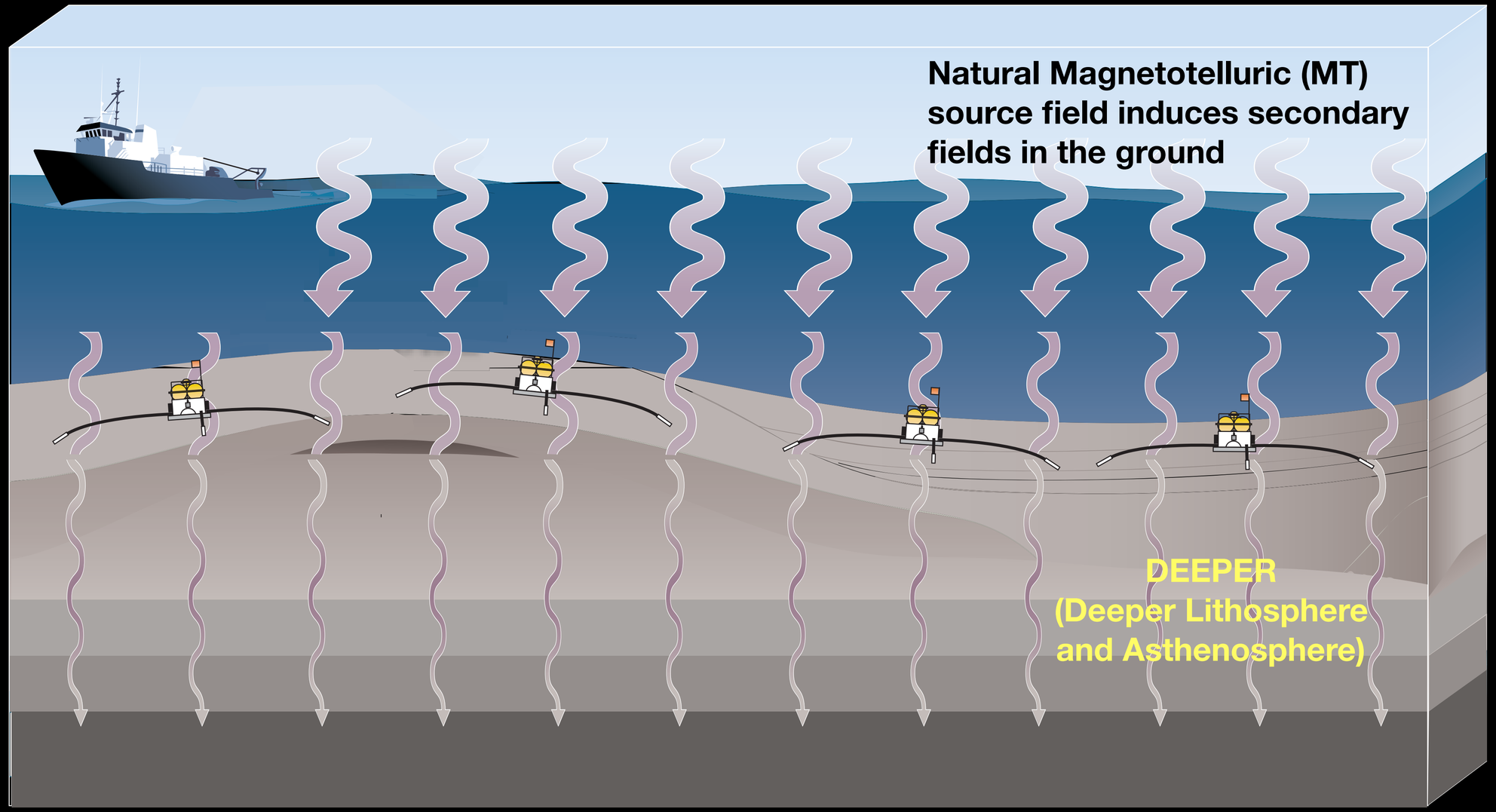

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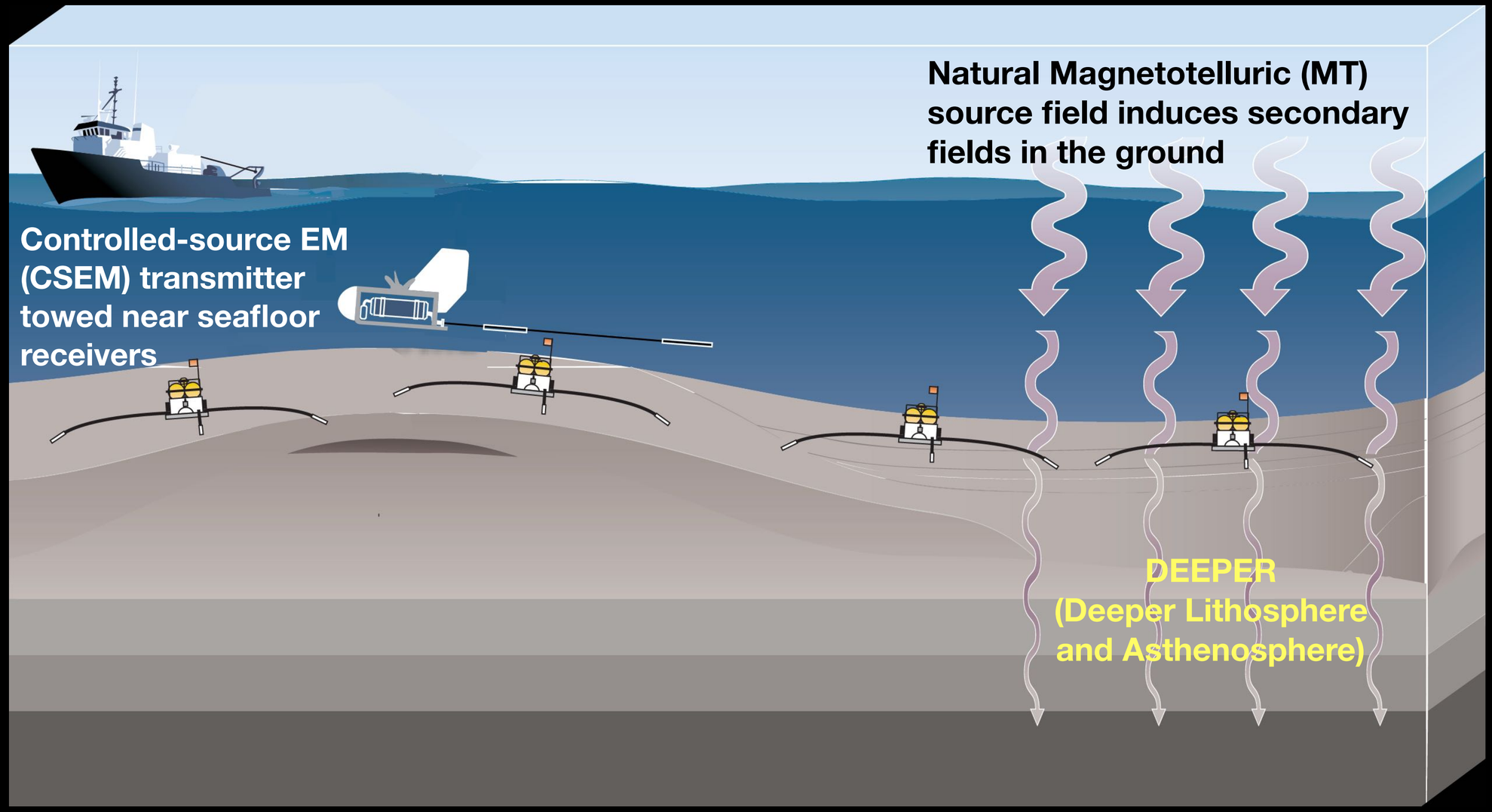

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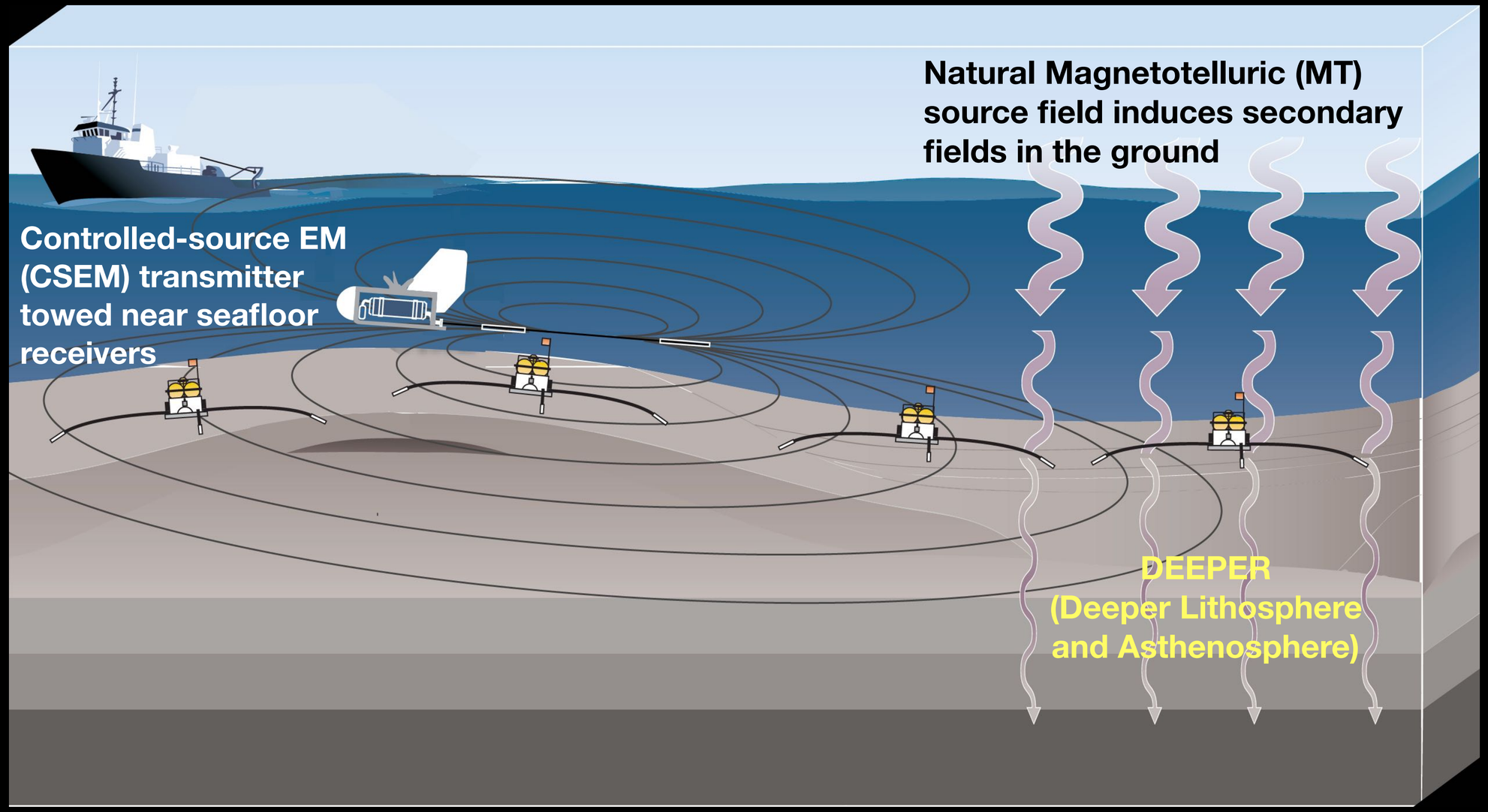

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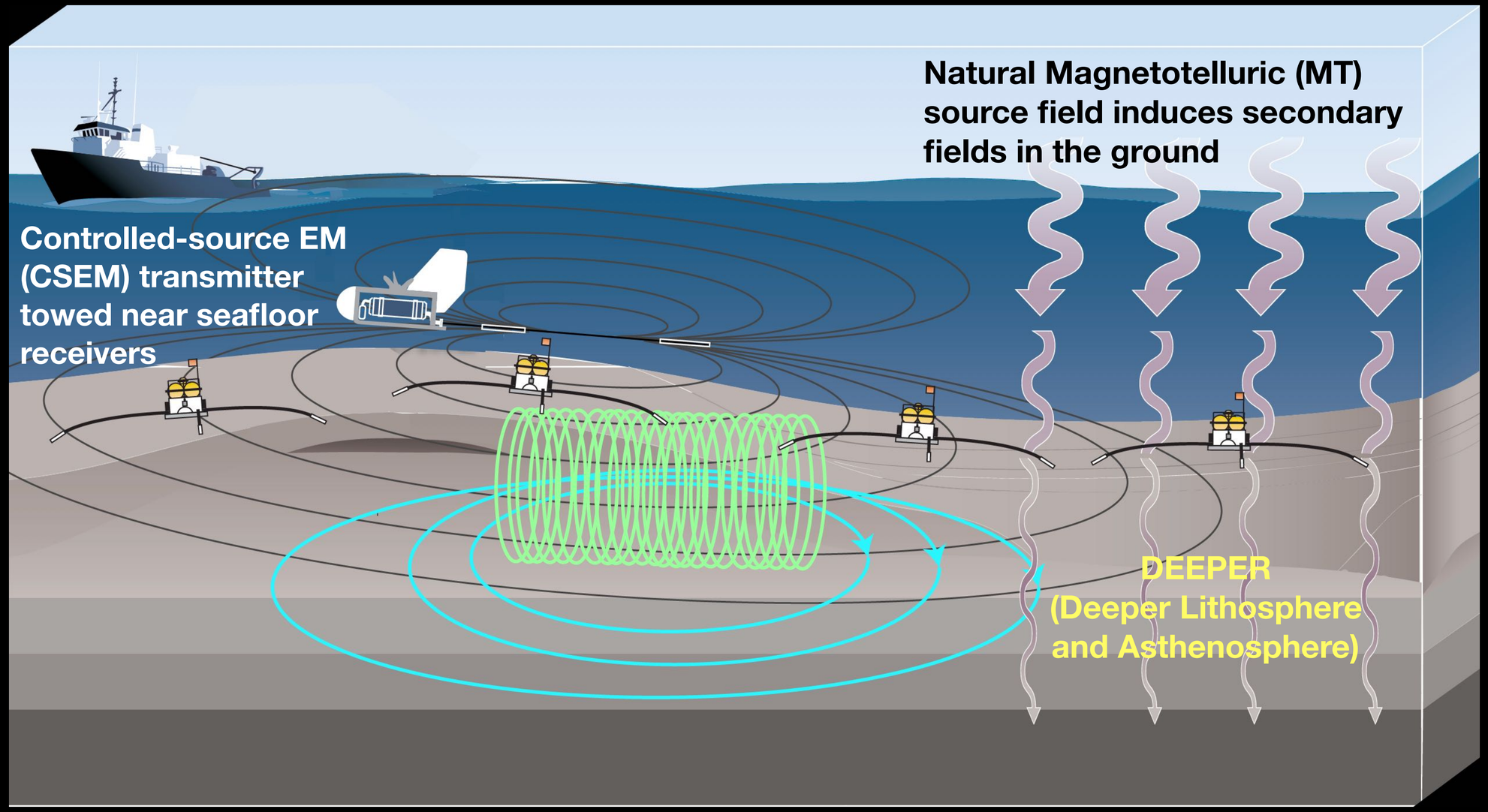

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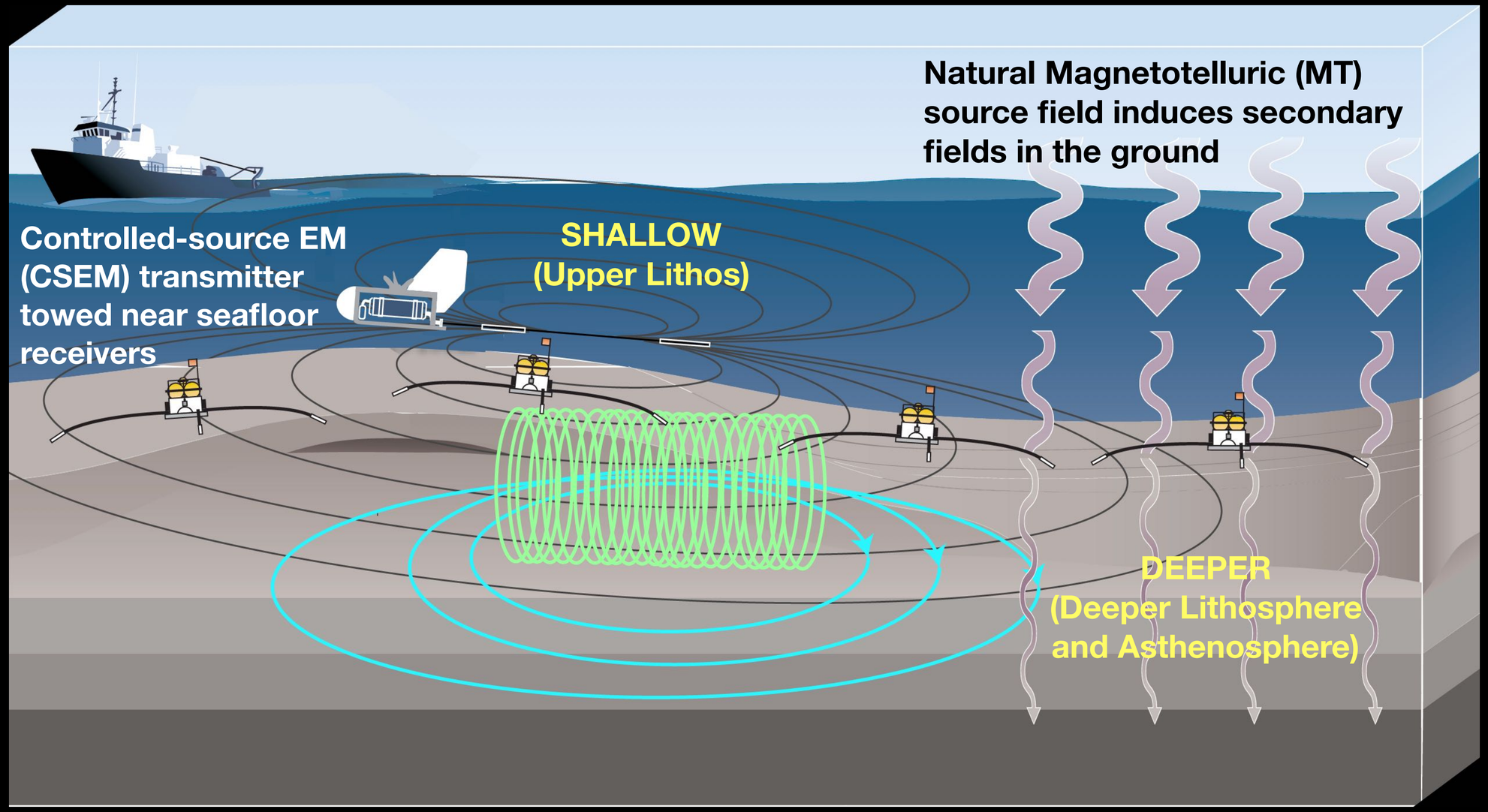
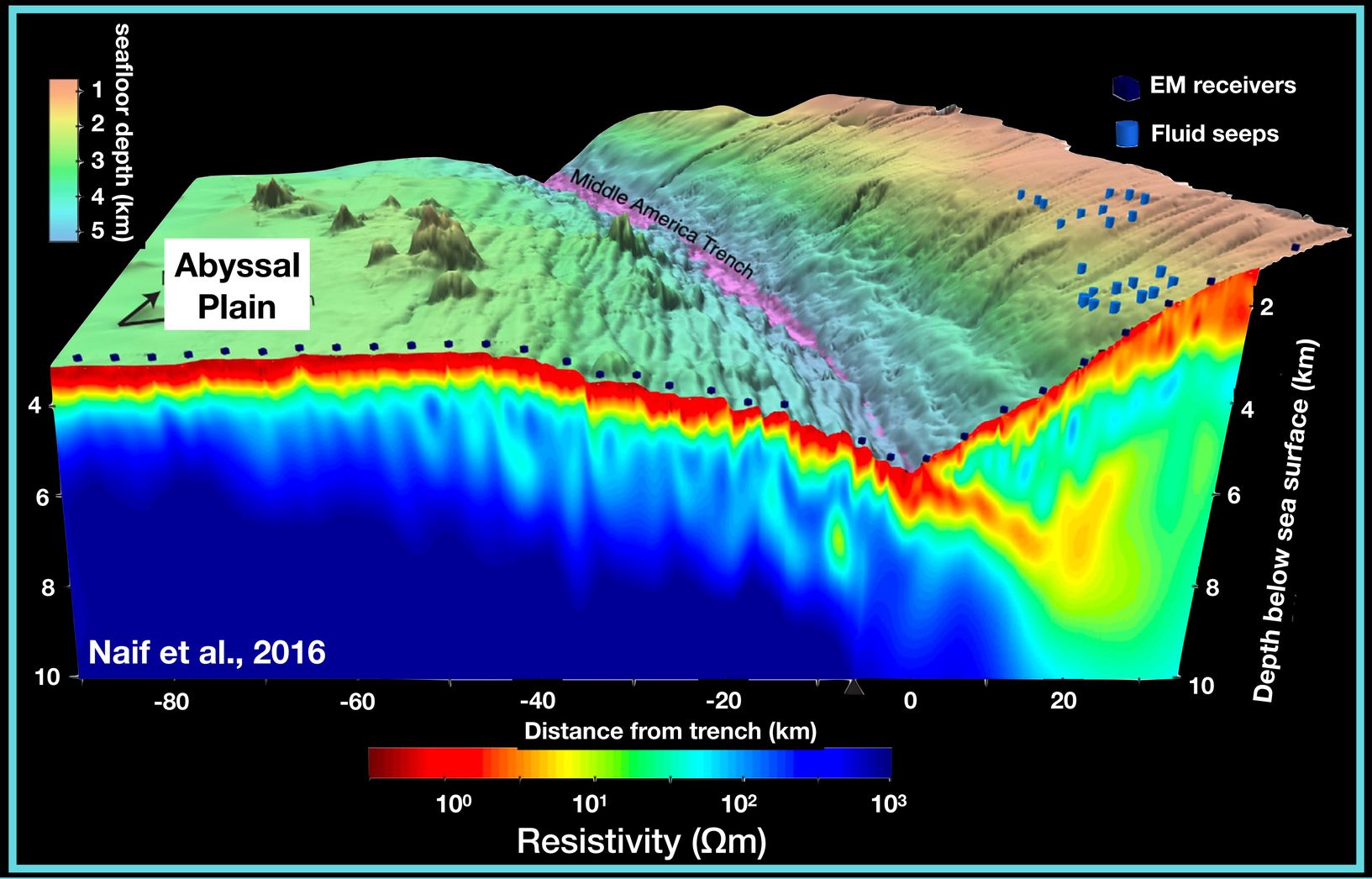


First CSEM survey across a subduction zone

Hydrated Outer-Rise Bending Faults at the Middle America Trench, Nicaragua



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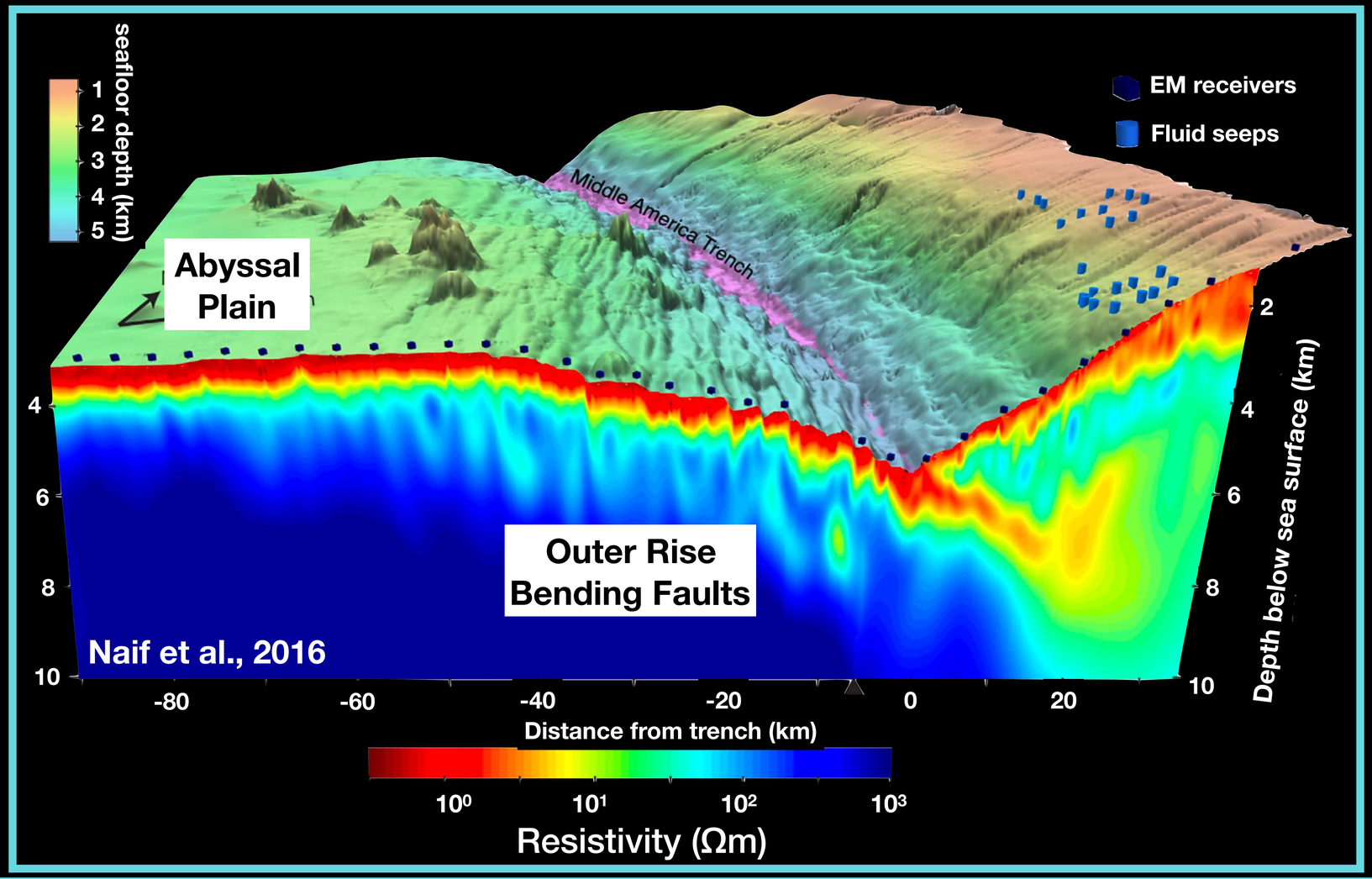

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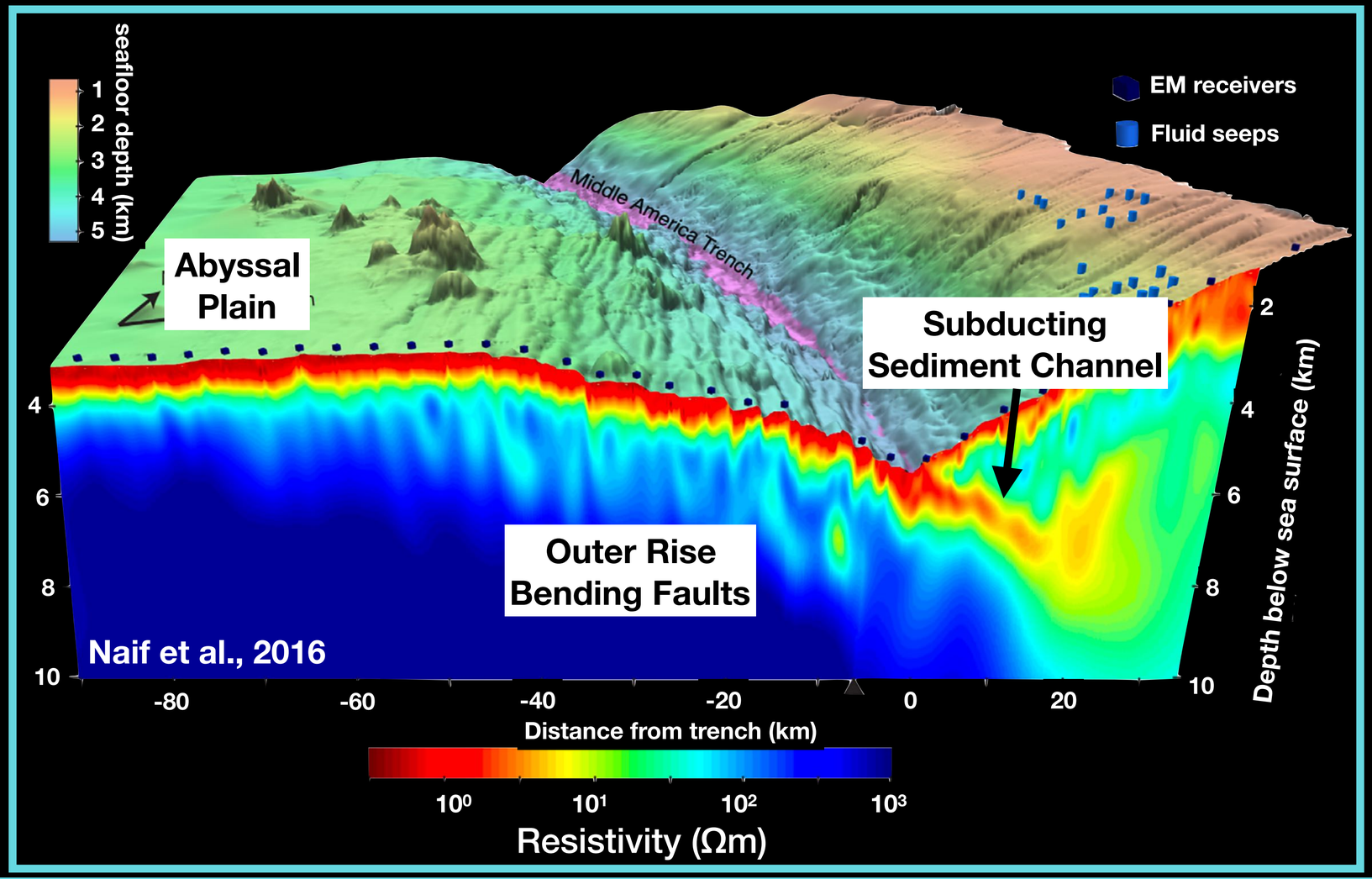
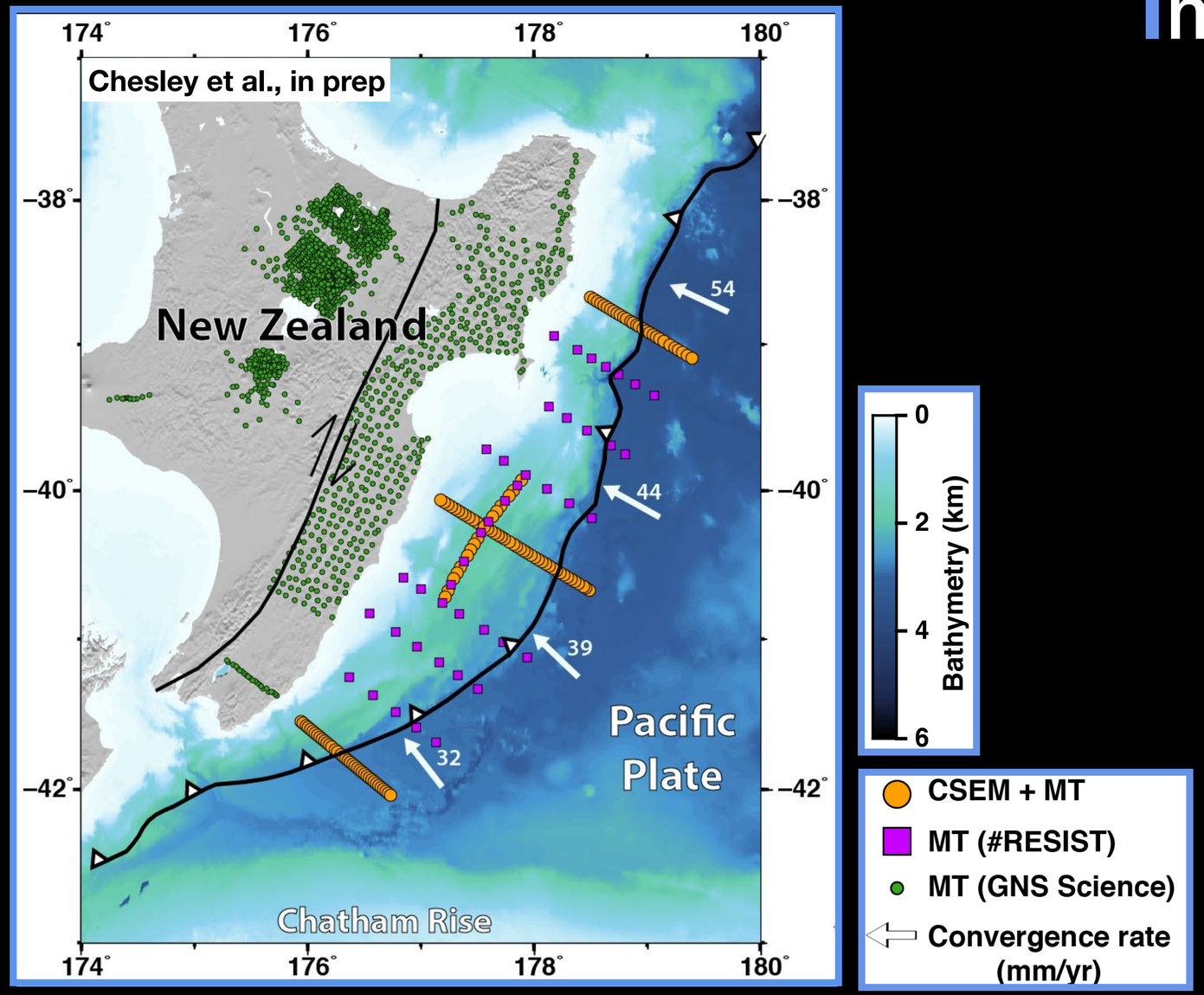


Hikurangi Trench Regional Electromagnetic Survey to Image the Subduction Thrust



- Dec 2018 - Feb 2019
- 132 OBEMs for CSEM + MT
- 42 OBEMs for 3D MT grid
- 100% instrument recovery

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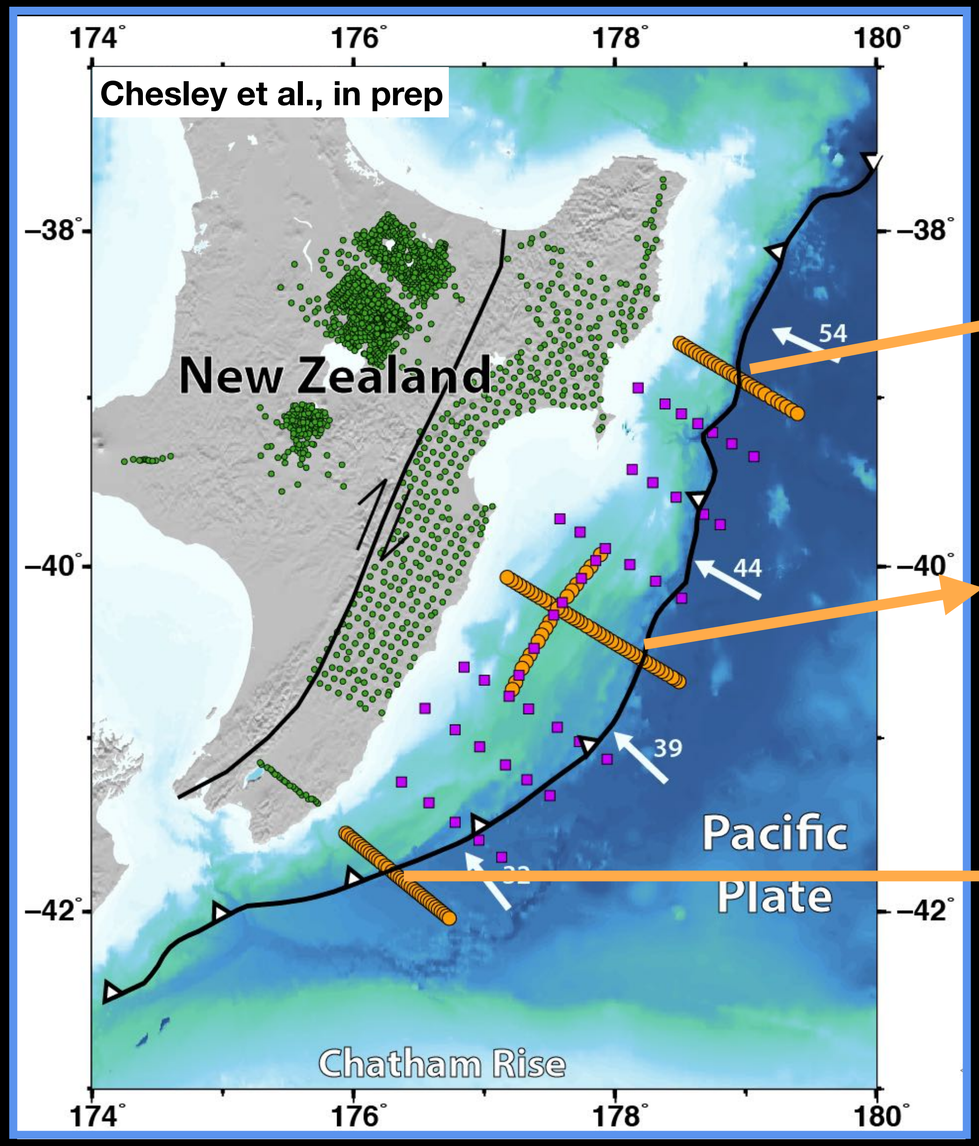

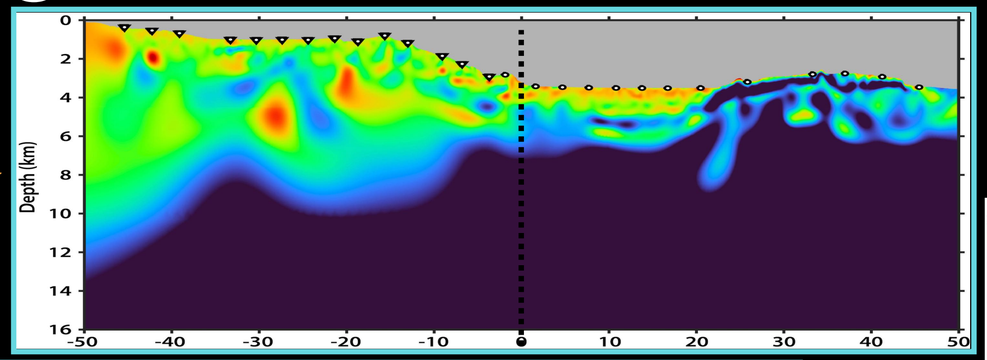

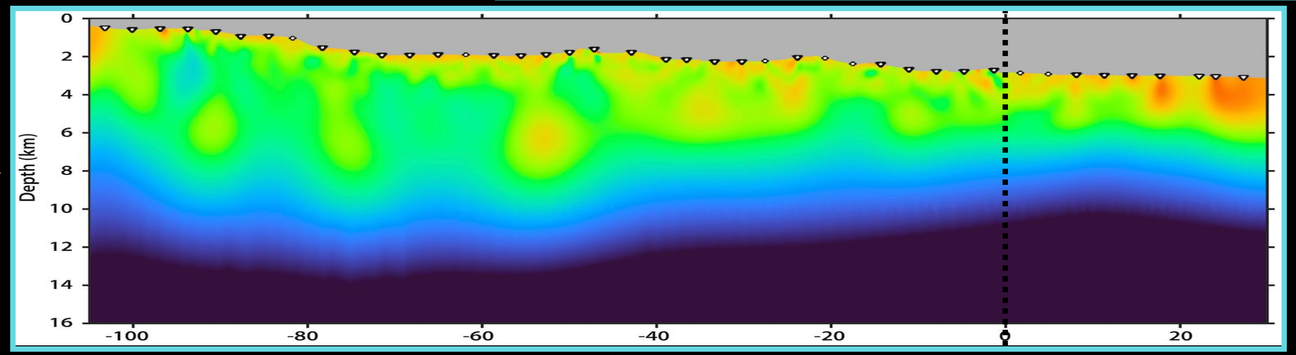

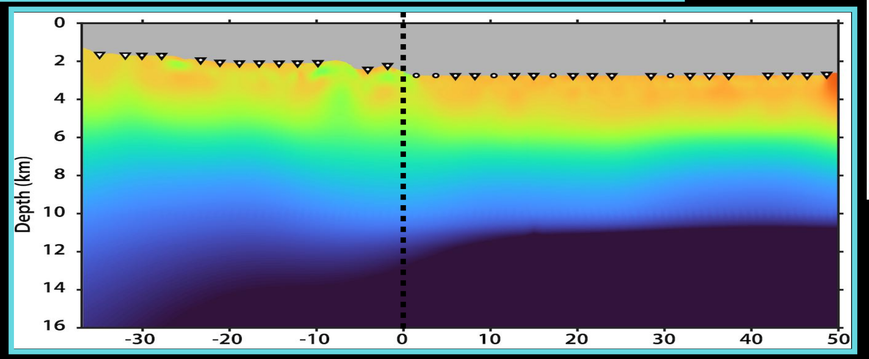

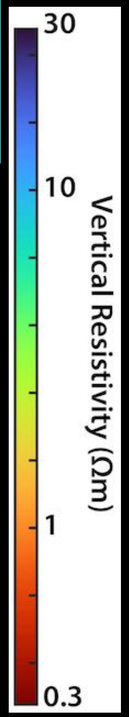

Distance from the trench (km)

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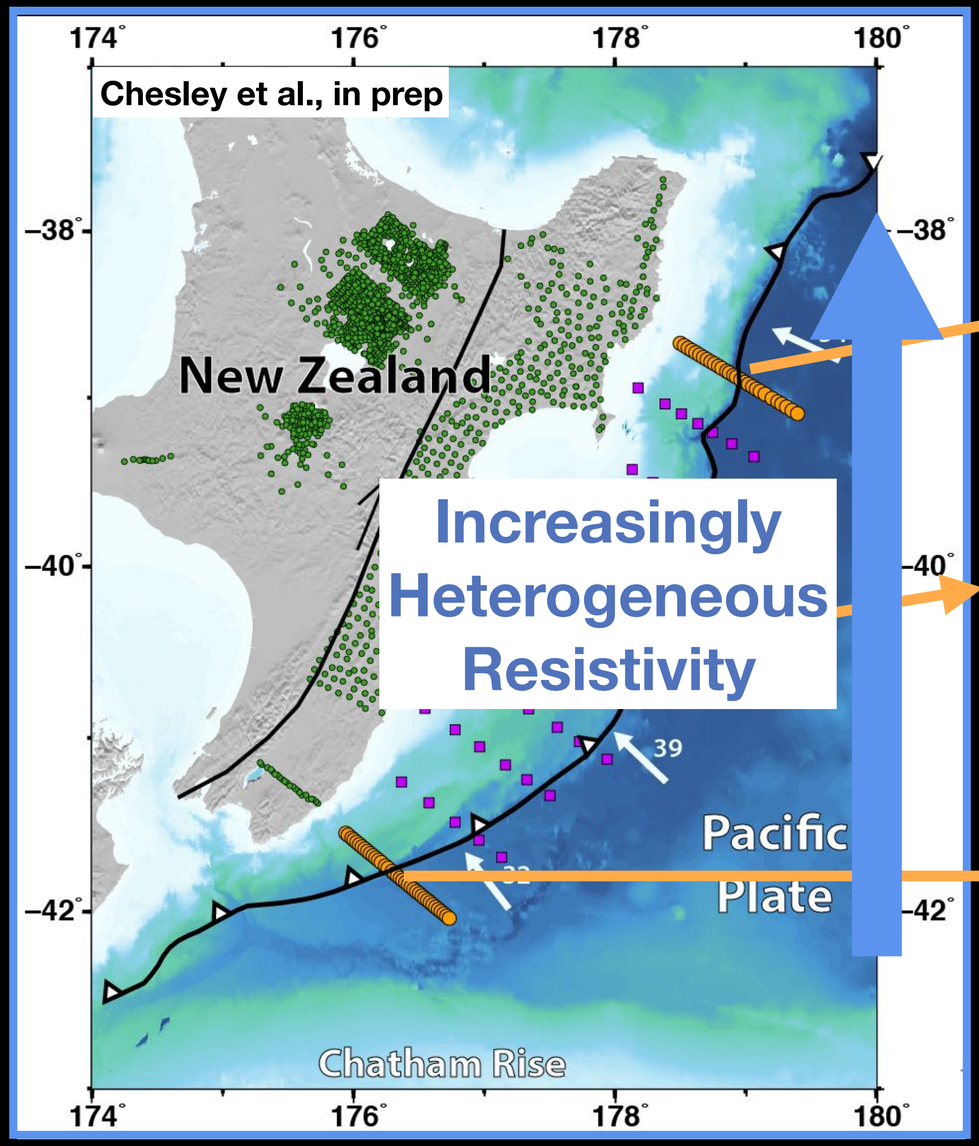

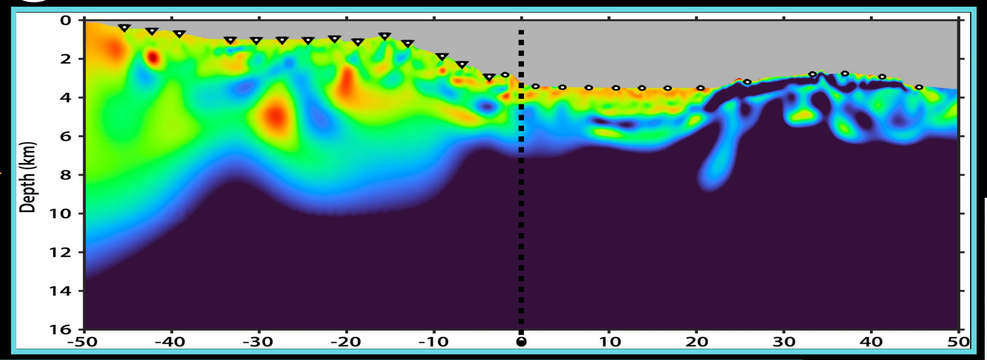

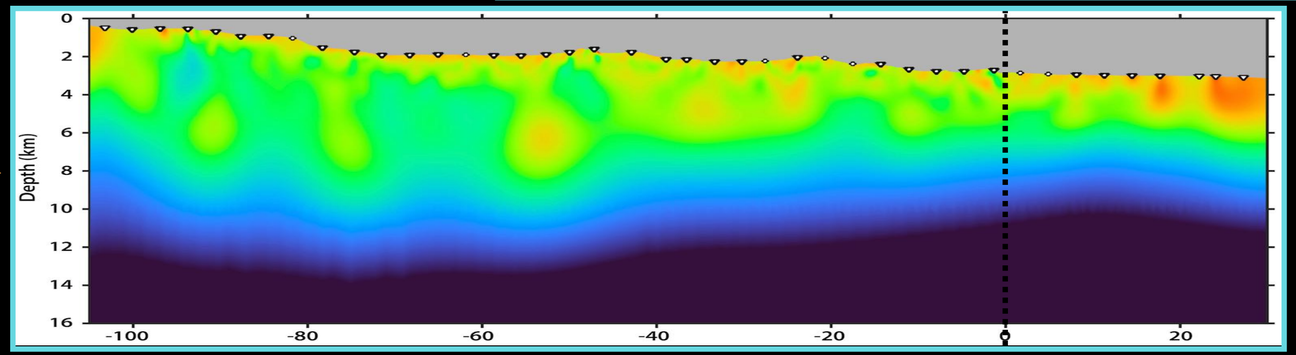

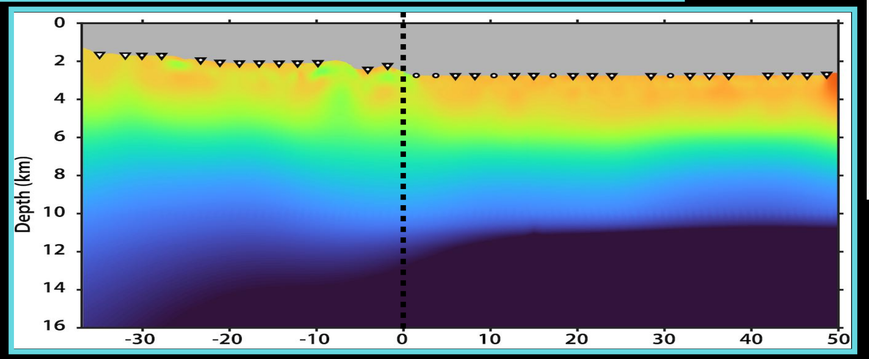

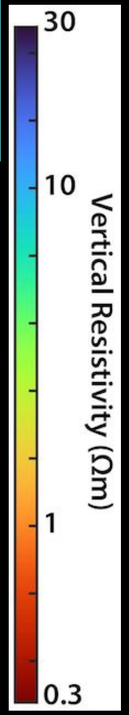

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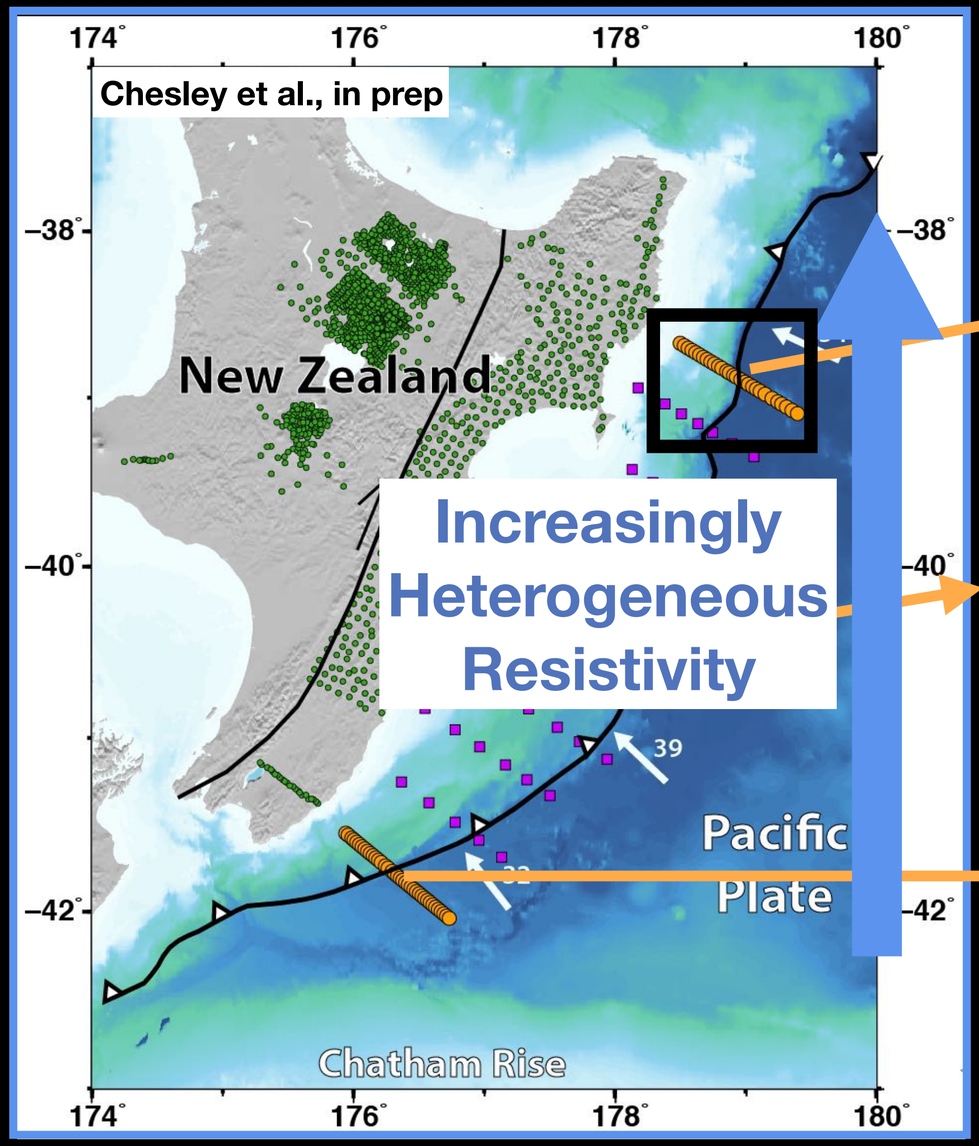
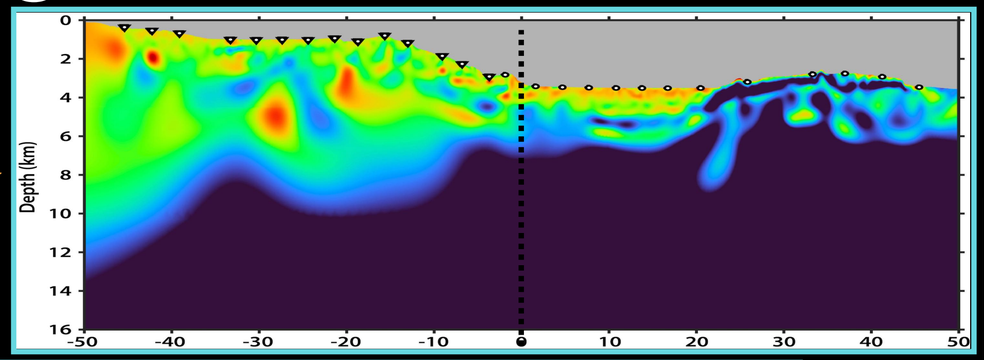
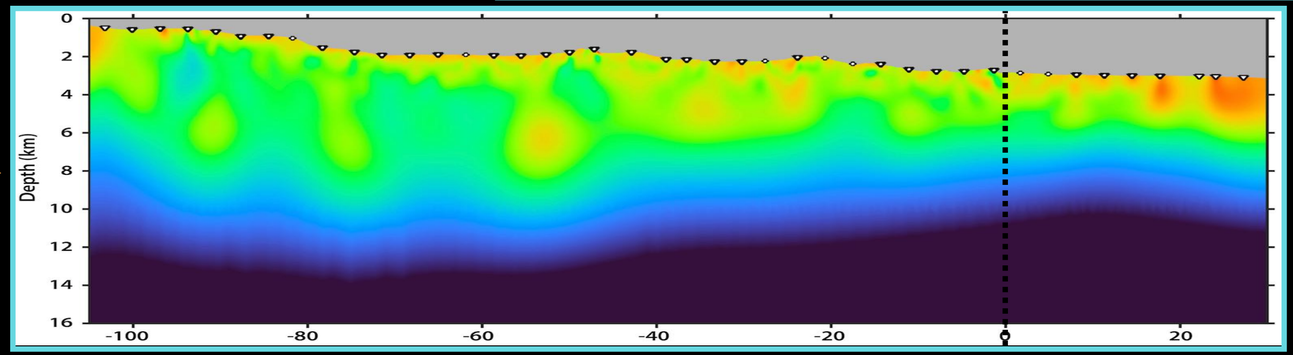
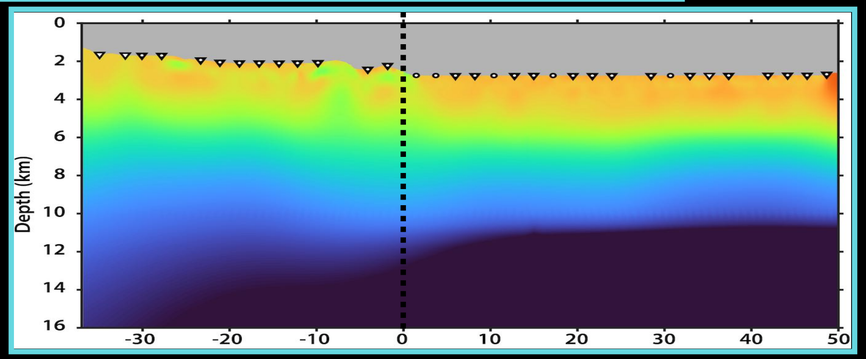
RESIST

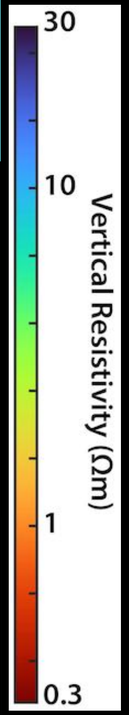
Hikurangi Trench Regional Electromagnetic Survey to Image the Subduction Thrust









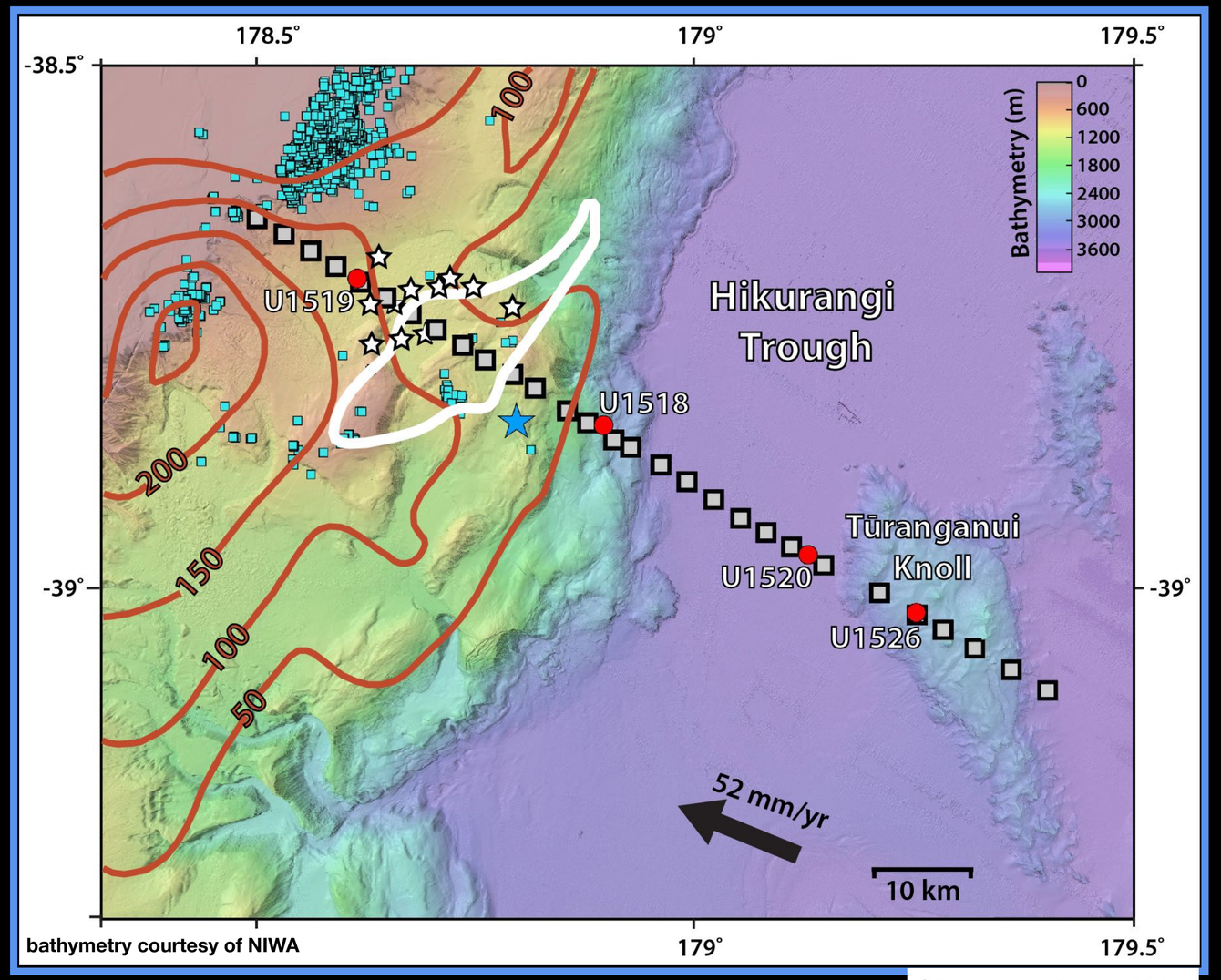


Distance from the trench (km)

RESIST

Observations in N. Hikurangi

- EM receivers
- IODP drill sites
- Slip from the Sept-Oct 2014 SSE **(Wallace et al., 2016)**
- subducting seamount from magnetic data **(Barker et al., 2018)**
- fluid seeps **(Watson et al., 2020)**
- repeating EQs associated with 2014 SSE **(Shaddox & Schwartz, 2019)**
- 1947 tsunami EQ **(Bell et al., 2014)**



Chesley et al., 2021

RESIST

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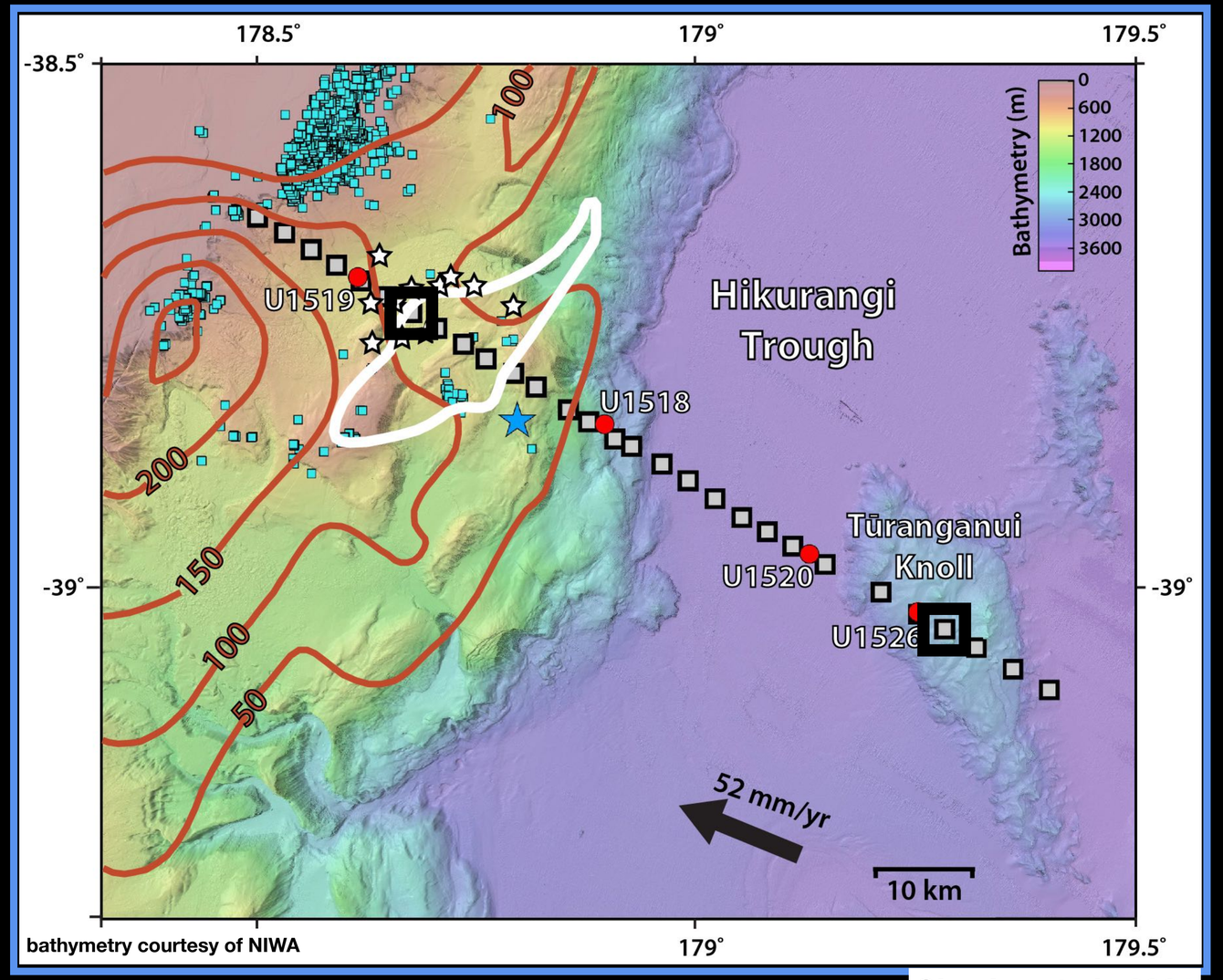
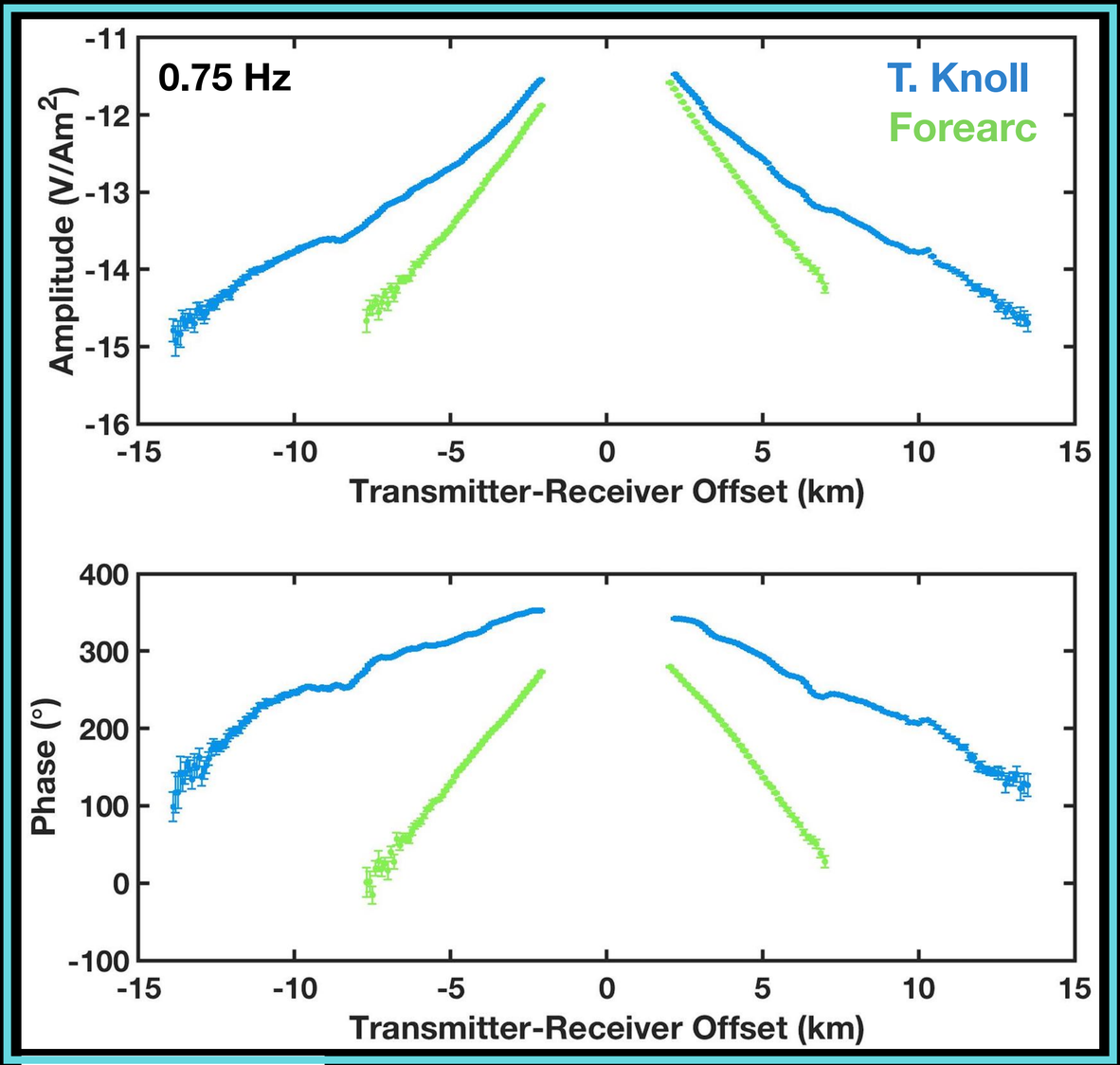


Chesley et al., 2021

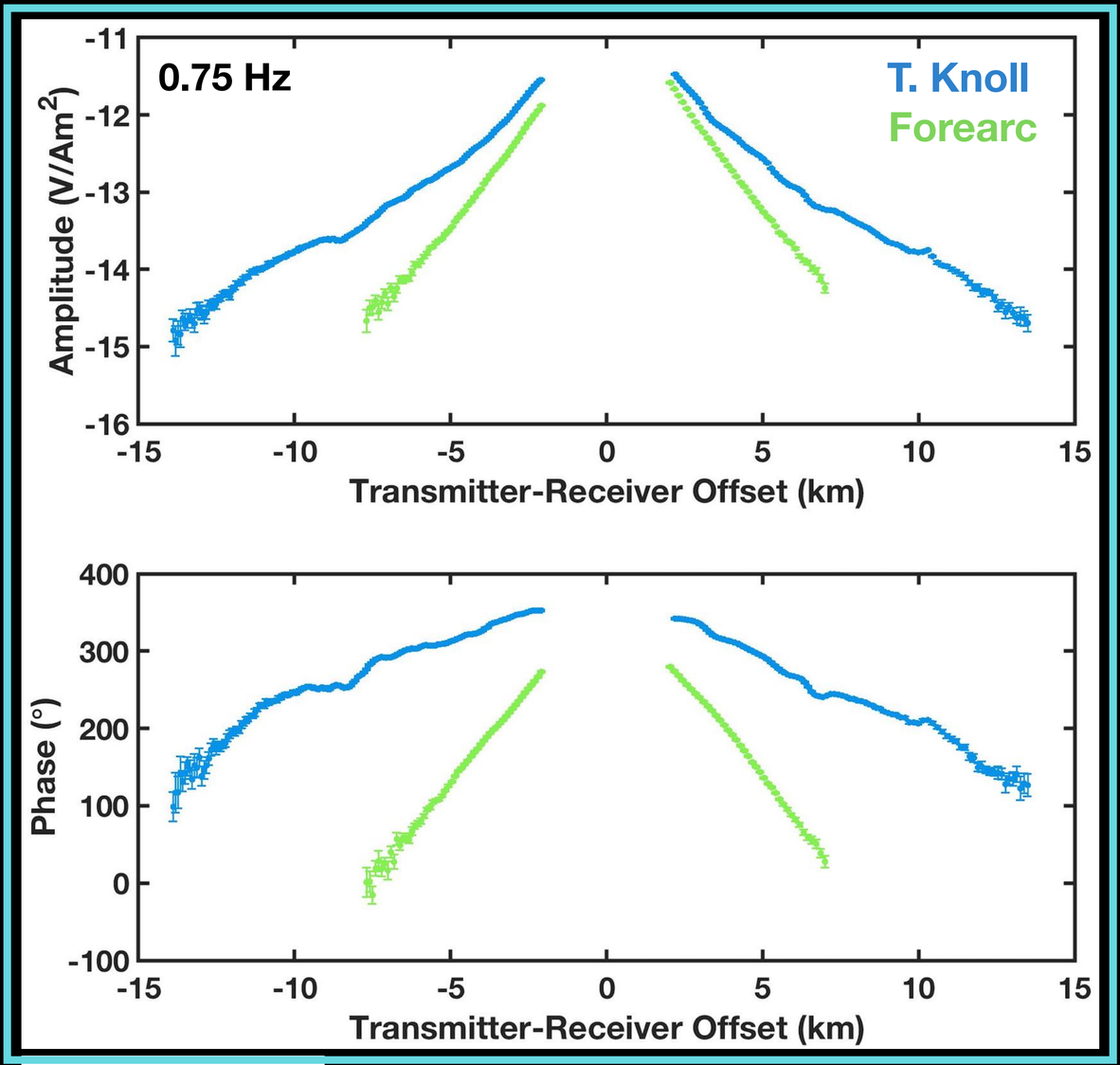
RESIST

CSEM Data Quality



Chesley et al., 2021

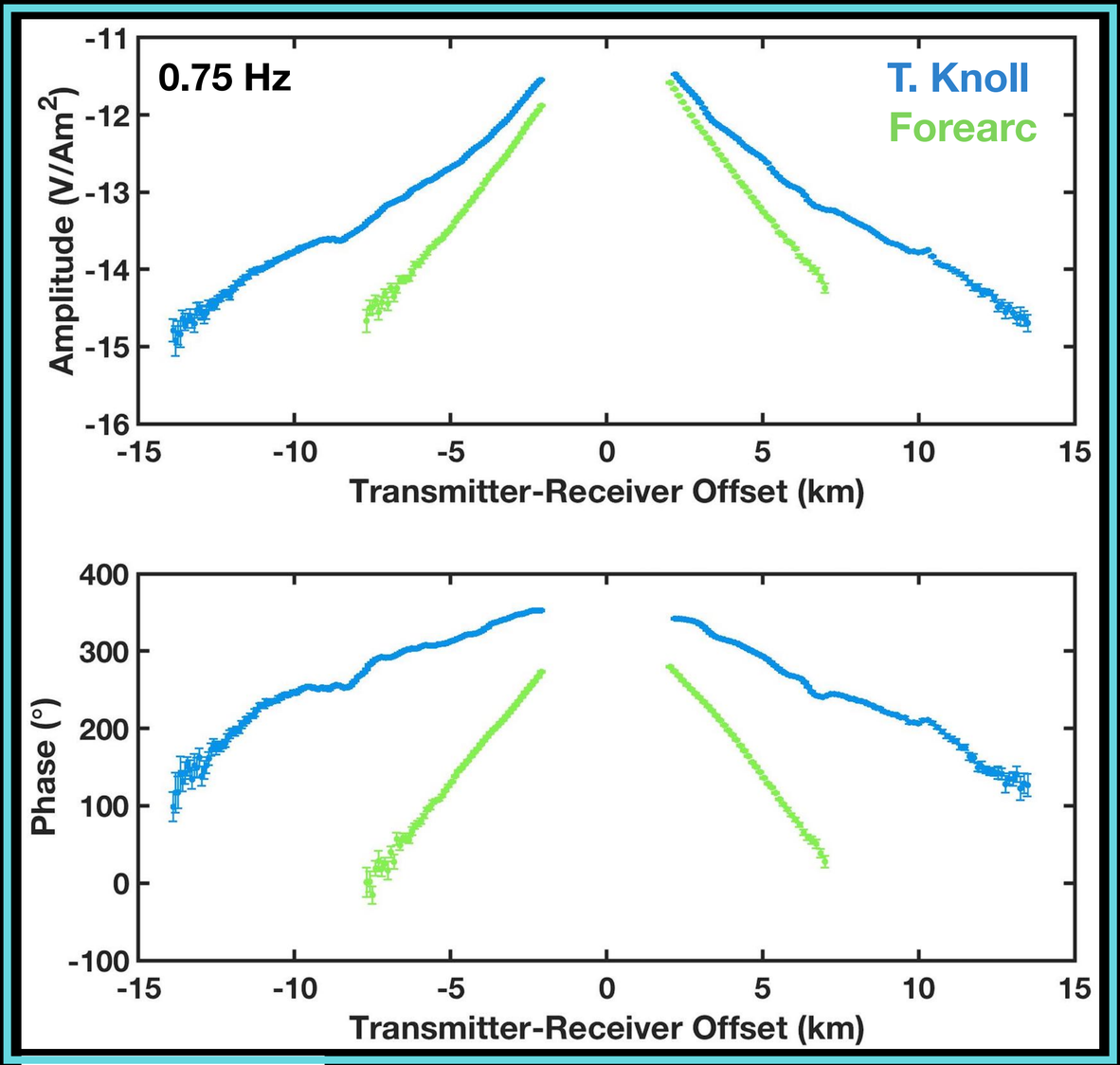
CSEM Data Quality



Chesley et al., 2021

- Clean, low-noise data

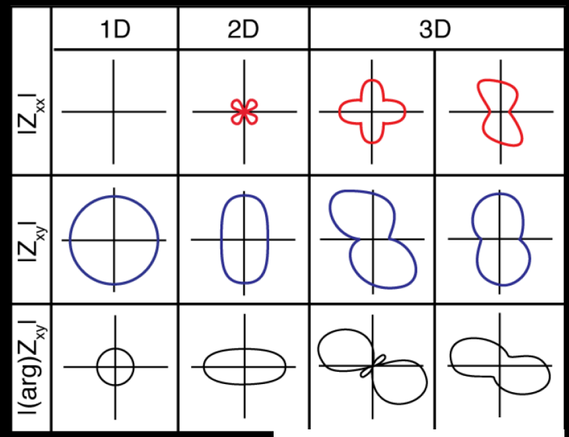
CSEM Data Quality



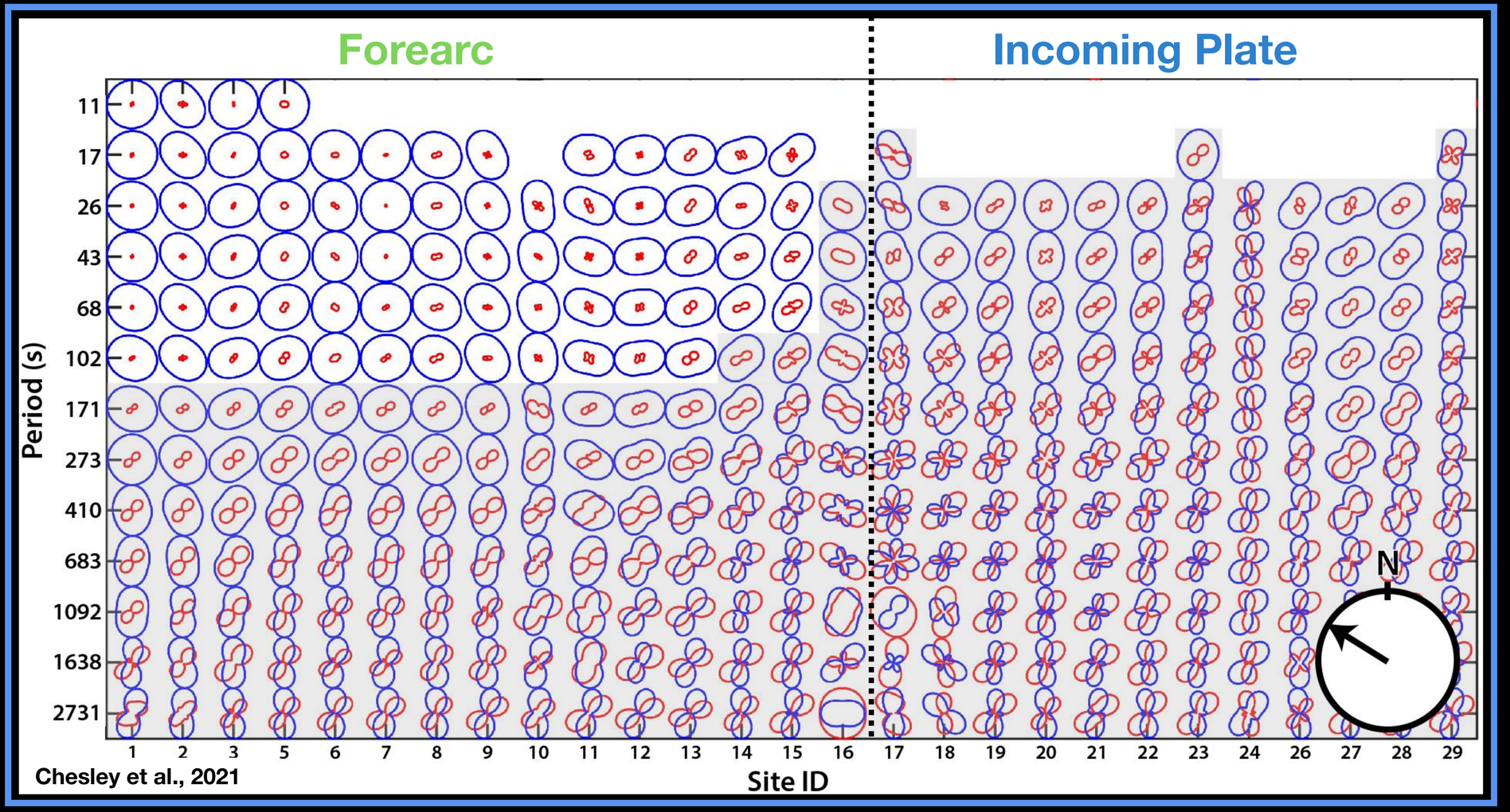
Chesley et al., 2021

- Clean, low-noise data
- Obvious structural differences

MT Data Dimensionality



S. Naif thesis, 2015



Chesley et al., 2021

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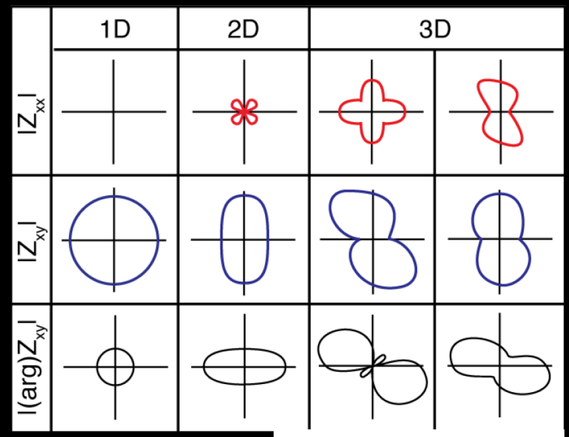

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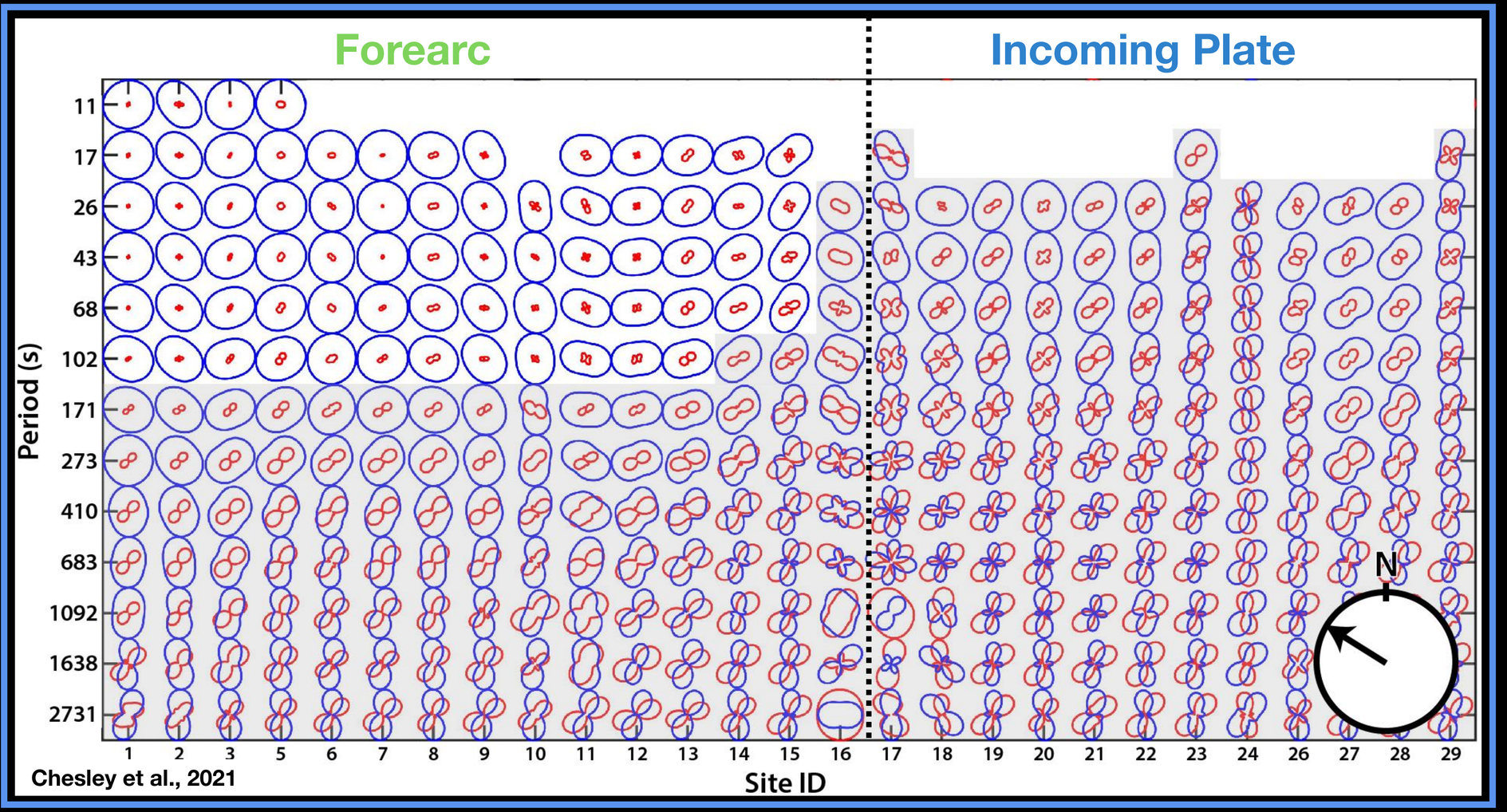
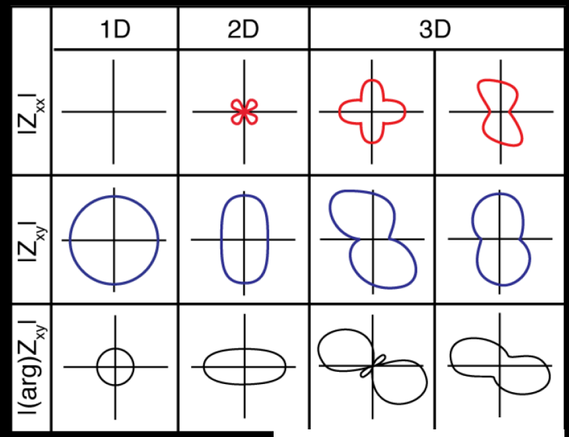


Chesley et al., 2021

- 3-D for periods > 171 s

MT Data Dimensionality



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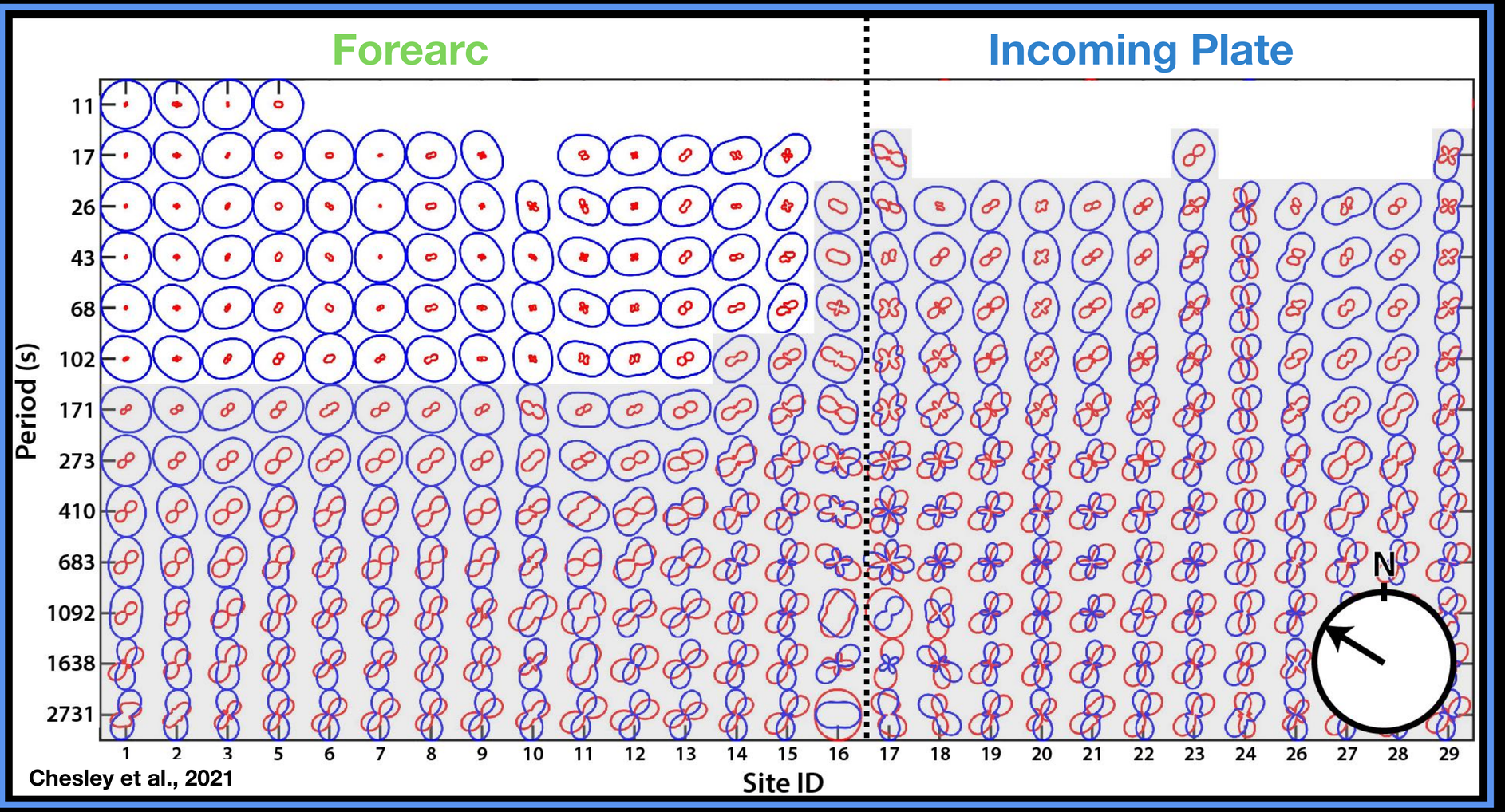
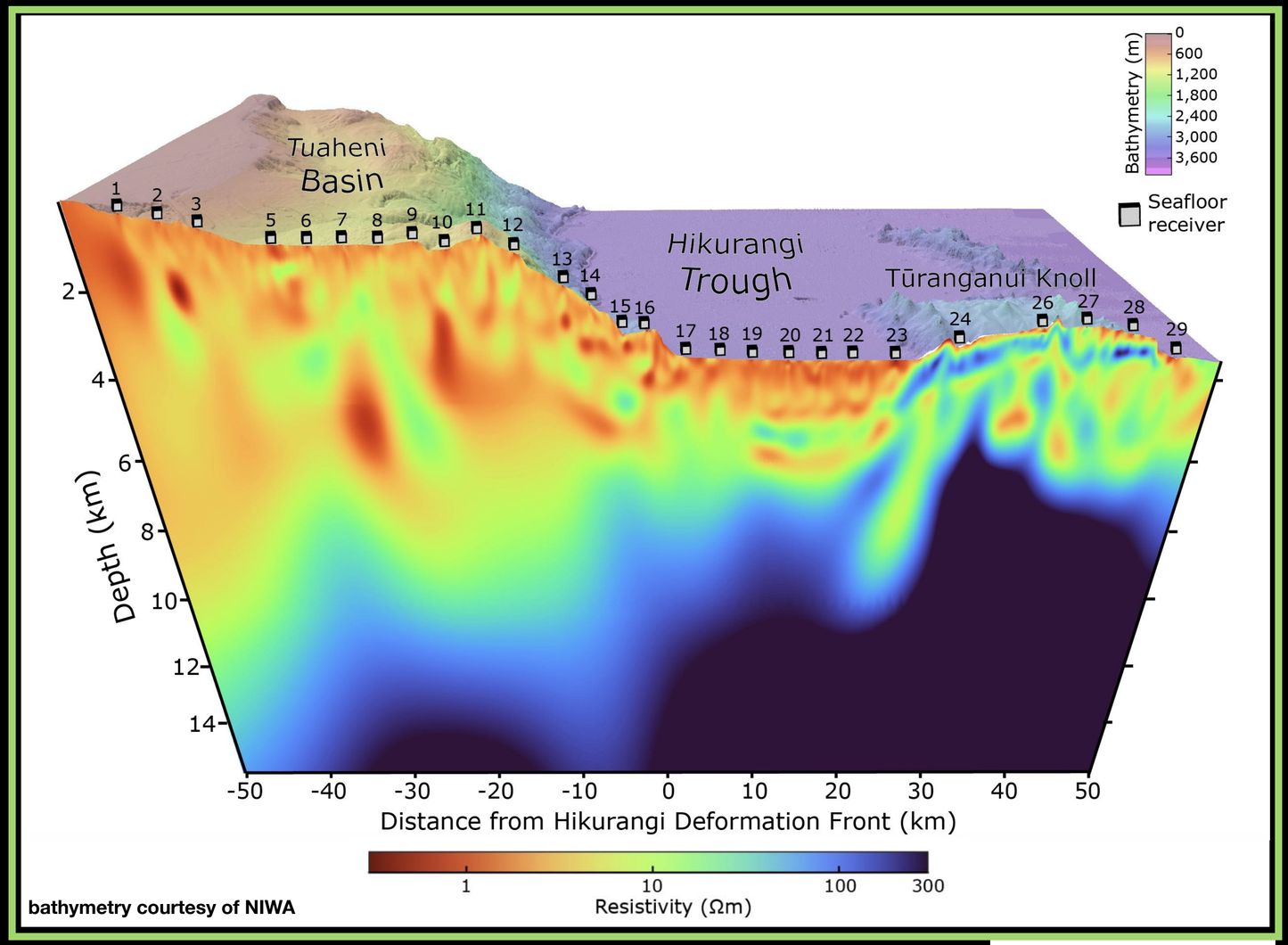


Chesley et al., 2021

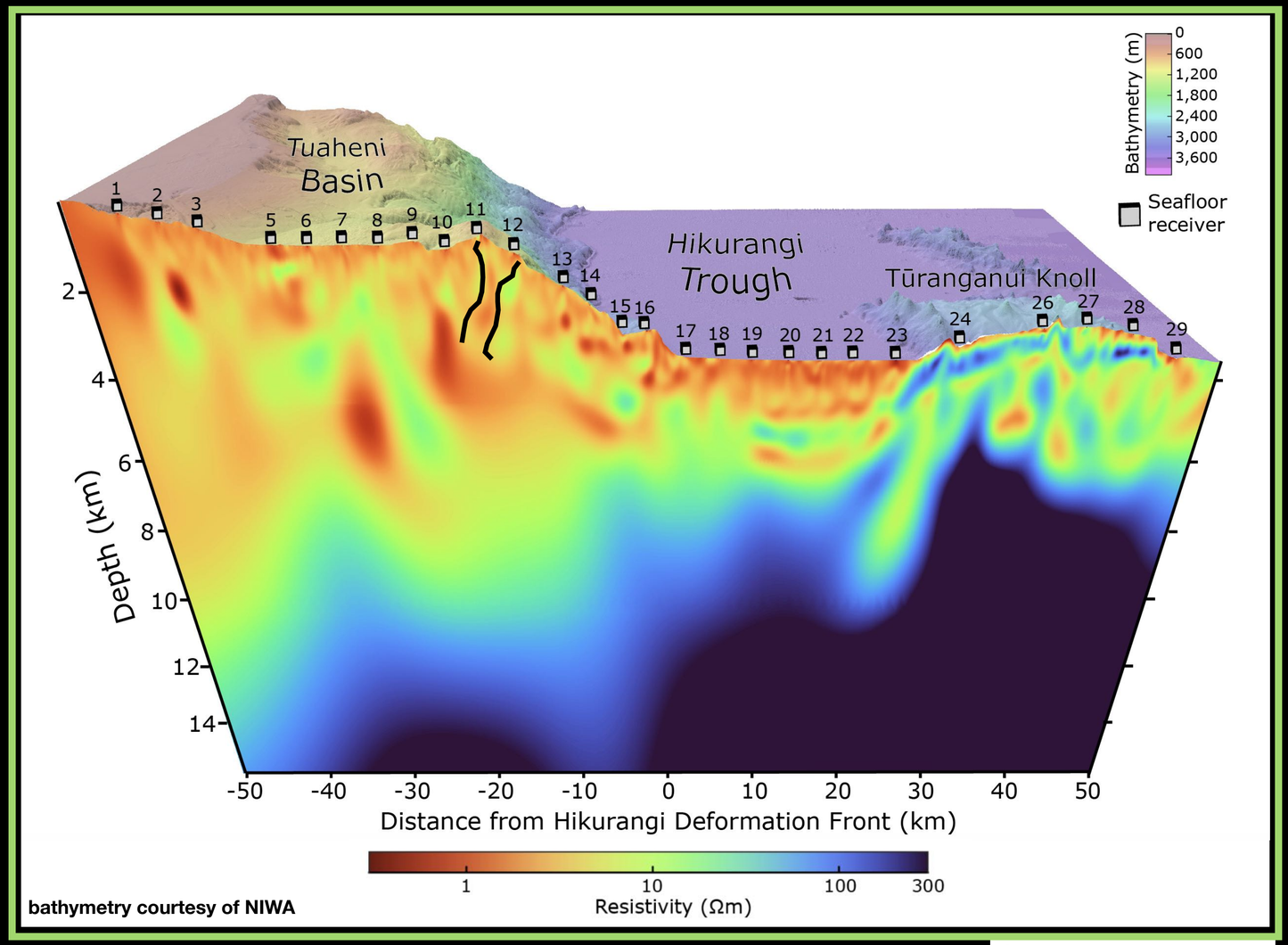
- 3-D for periods > 171 s
- Mostly 3-D on incoming plate

N. Hikurangi Resistivity



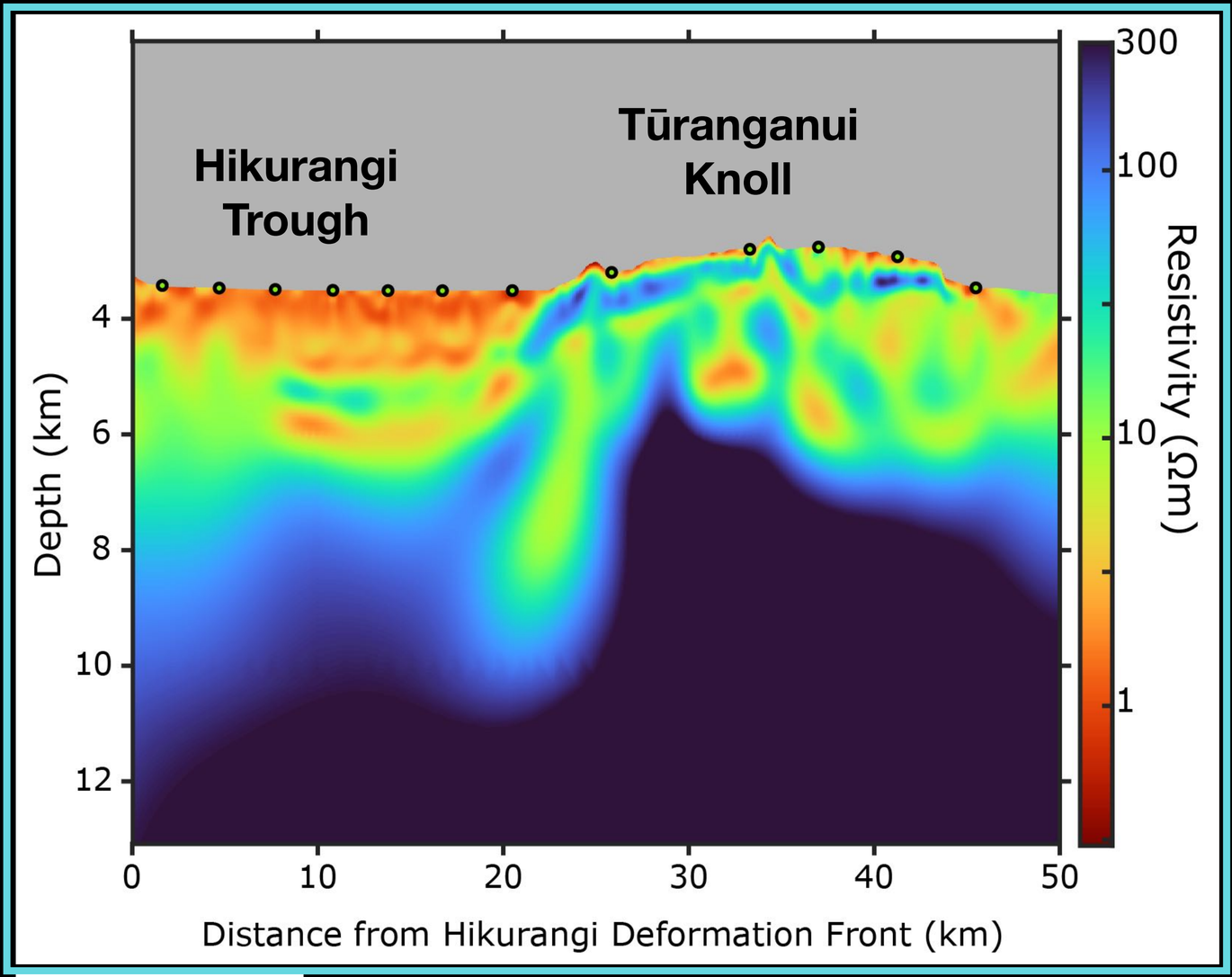
Chesley et al., 2021

N. Hikurangi Resistivity



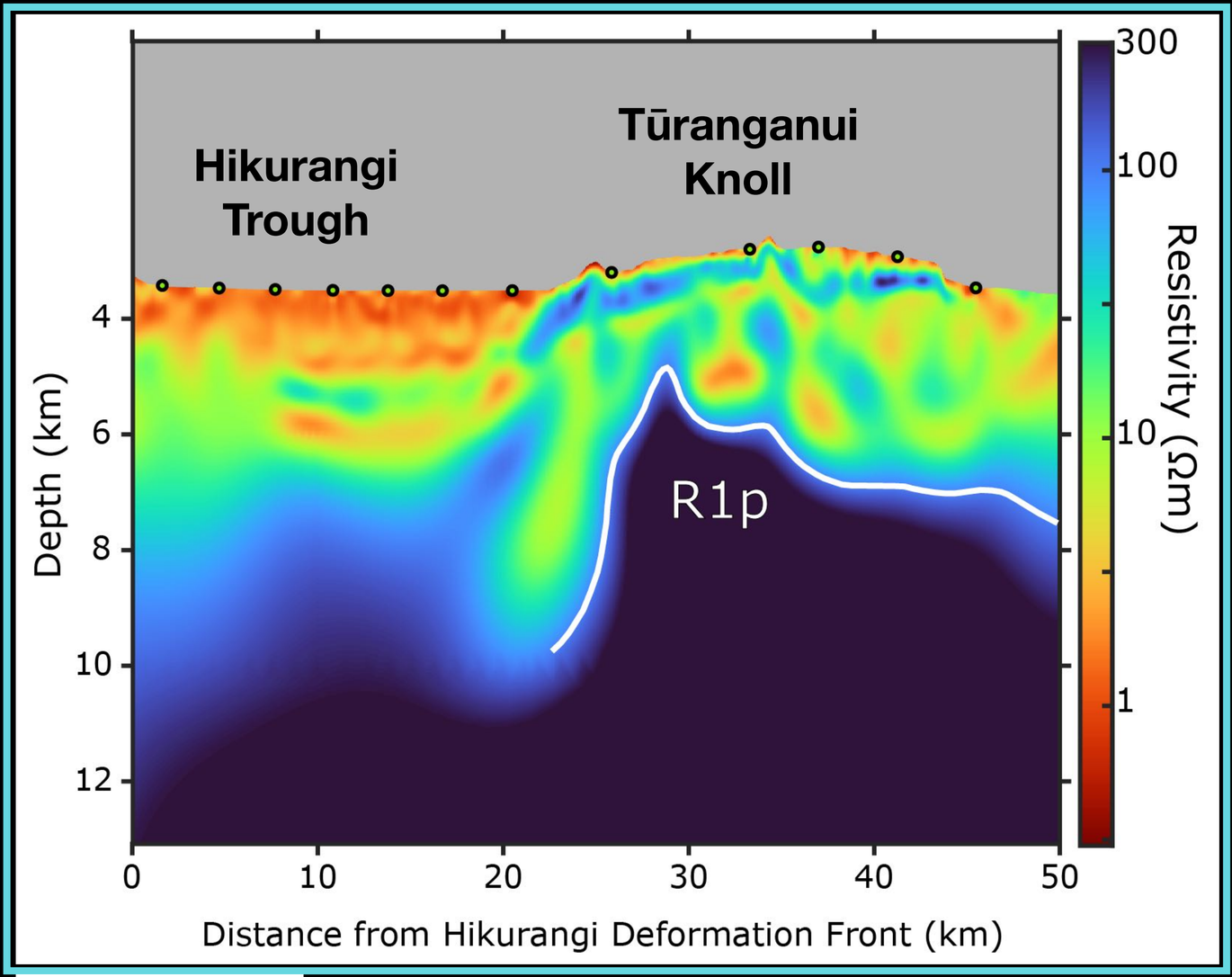
Chesley et al., 2021

Incoming Plate Resistivity



Chesley et al., 2021

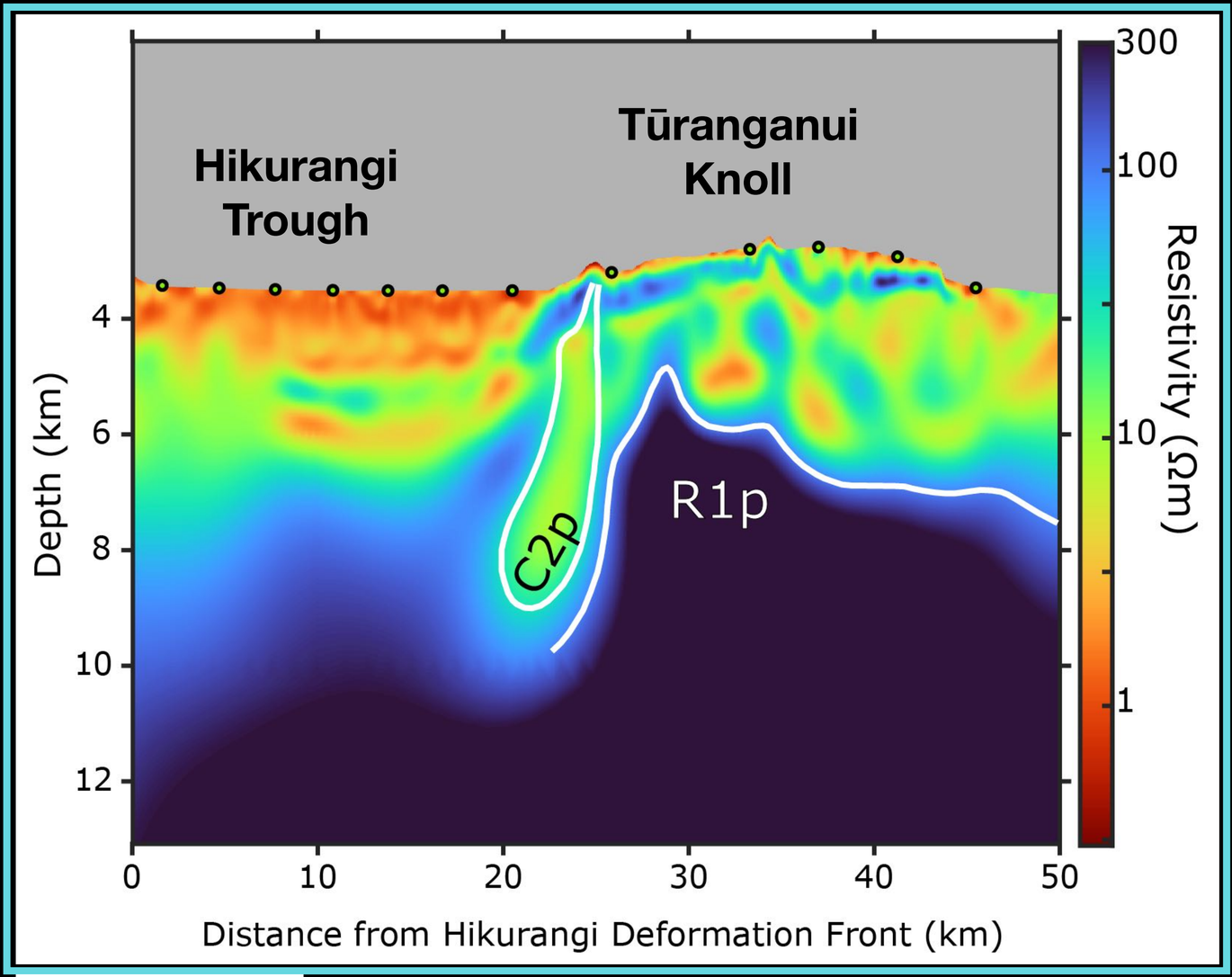
Electrical Characterization of a Seamount



Chesley et al., 2021

- R1p —> resistive core of seamount

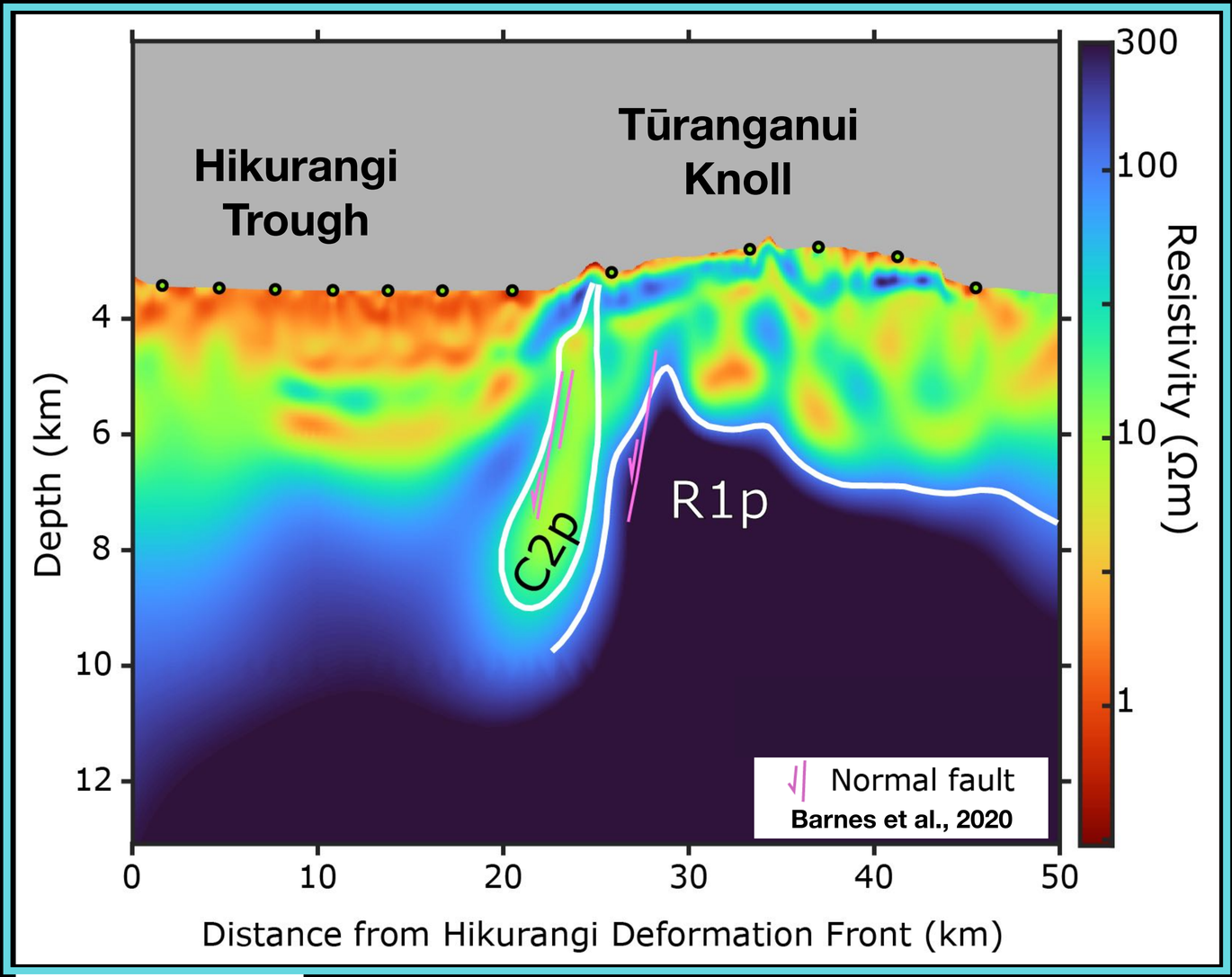
Electrical Characterization of a Seamount



Chesley et al., 2021

- C2p —> conductive normal fault
- R1p —> resistive core of seamount

Electrical Characterization of a Seamount



Chesley et al., 2021

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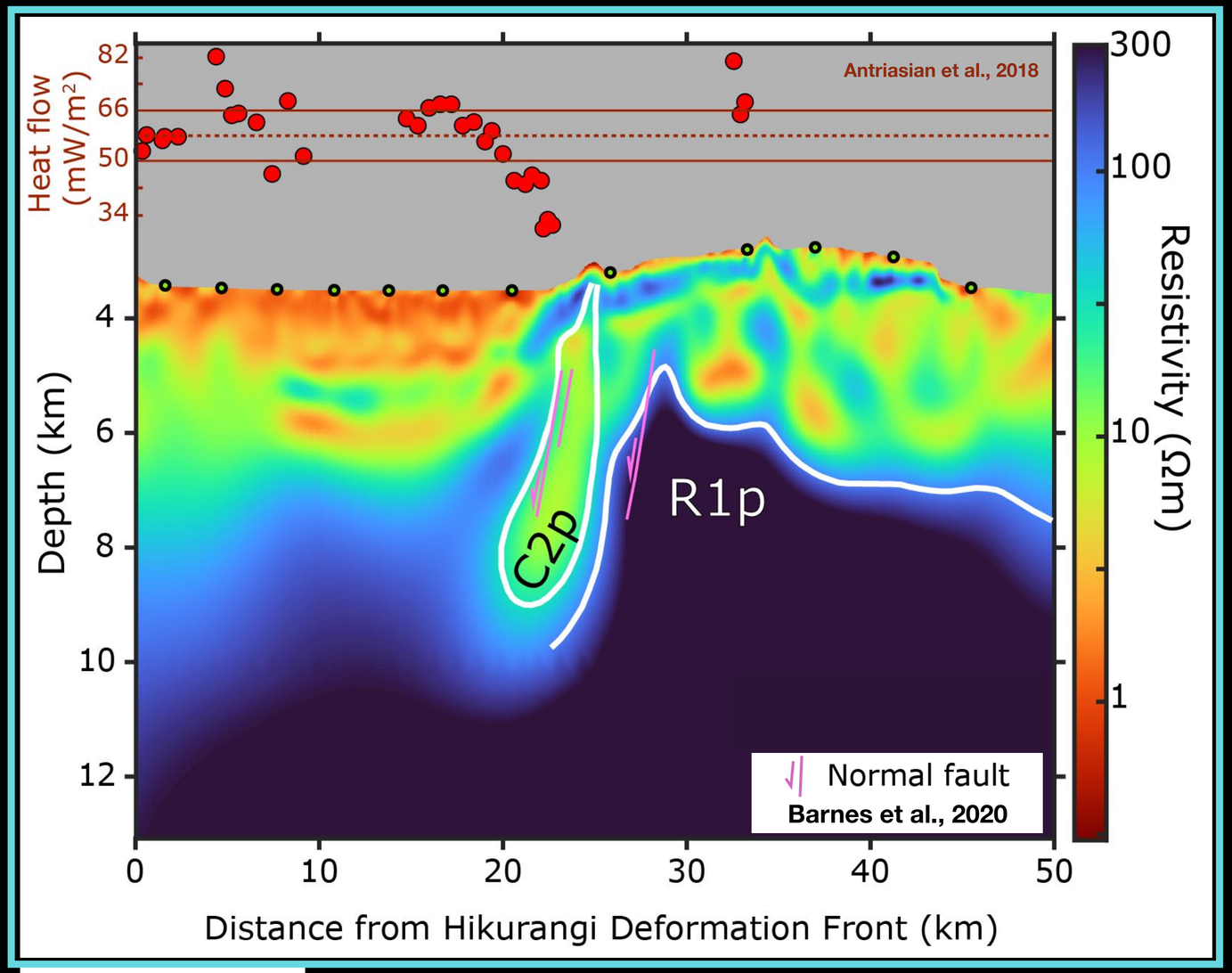

Chesley et al., 2021

- C2p —> conductive normal fault, hydrothermal pathway
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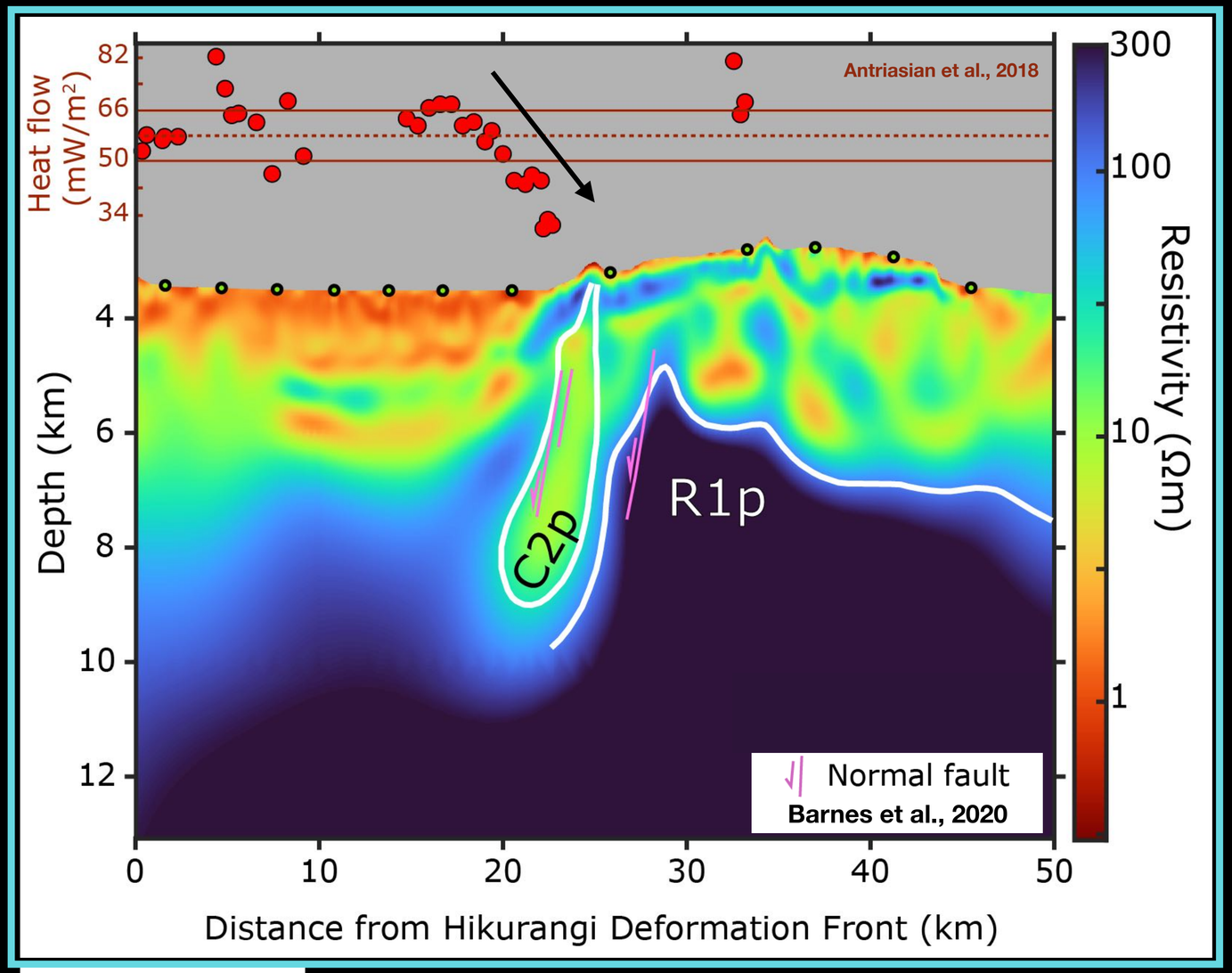
Electrical Characterization of a Seamount



Chesley et al., 2021

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RESIST

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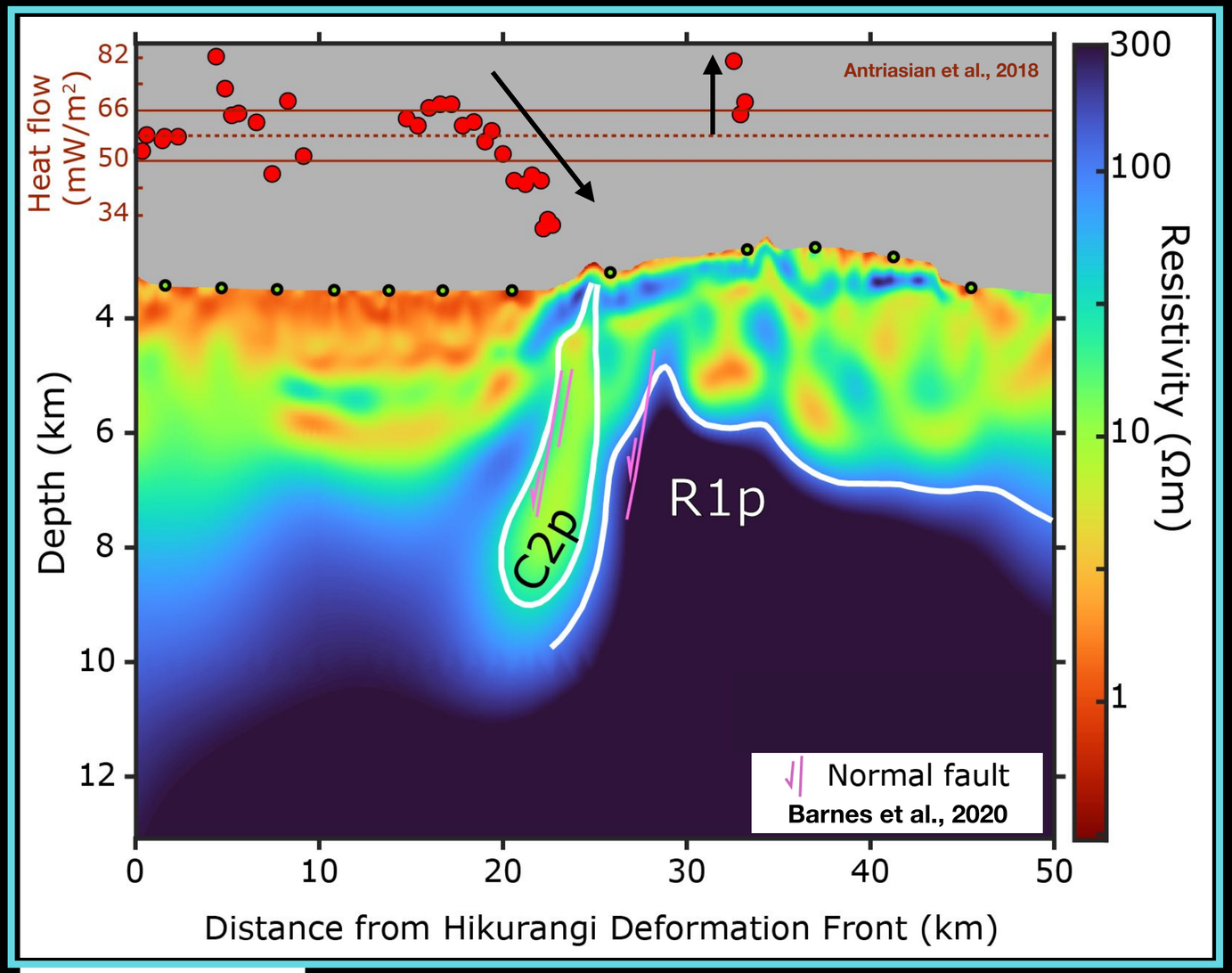

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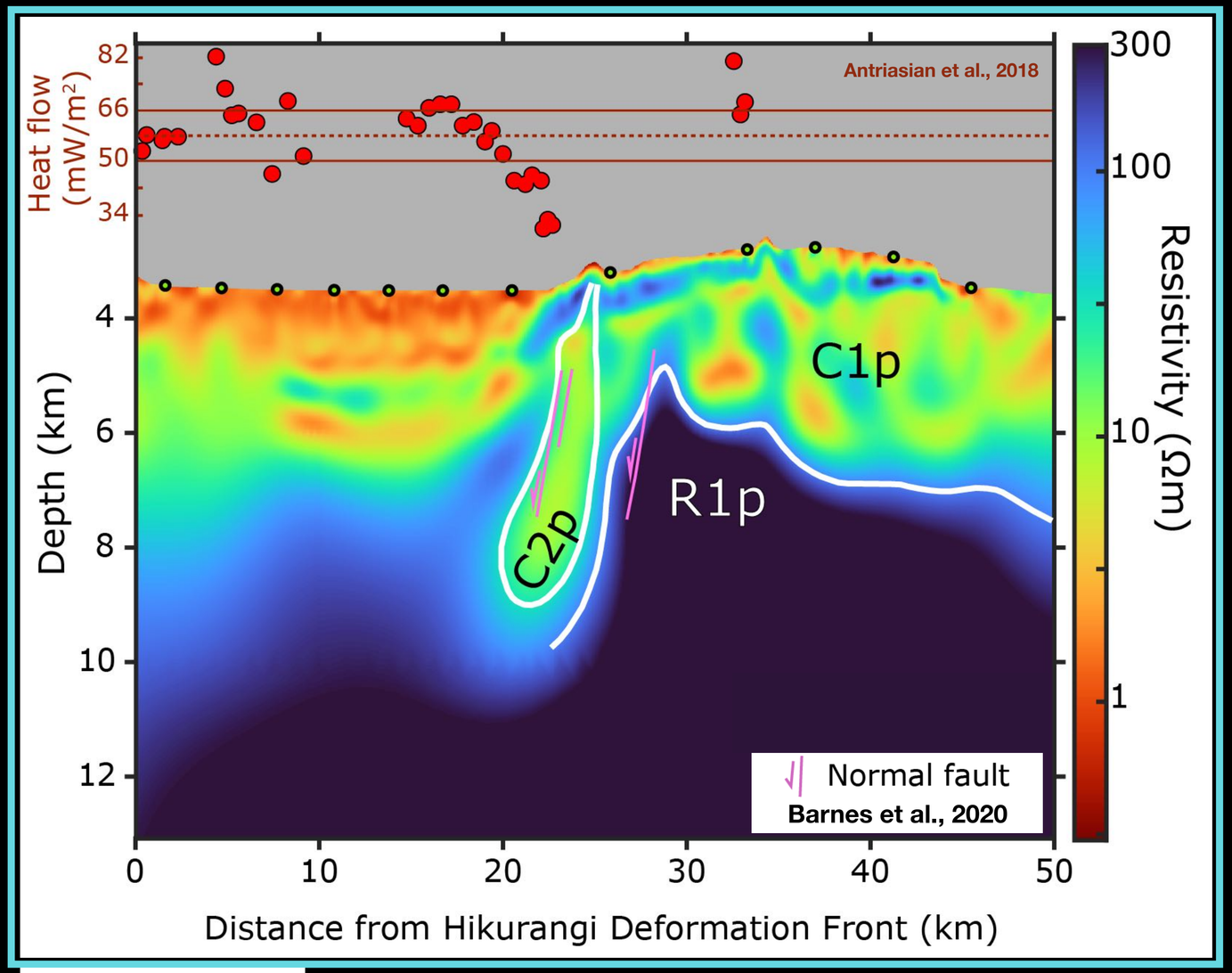

Chesley et al., 2021

- C1p —> volcaniclastics, extrusives, altered mins
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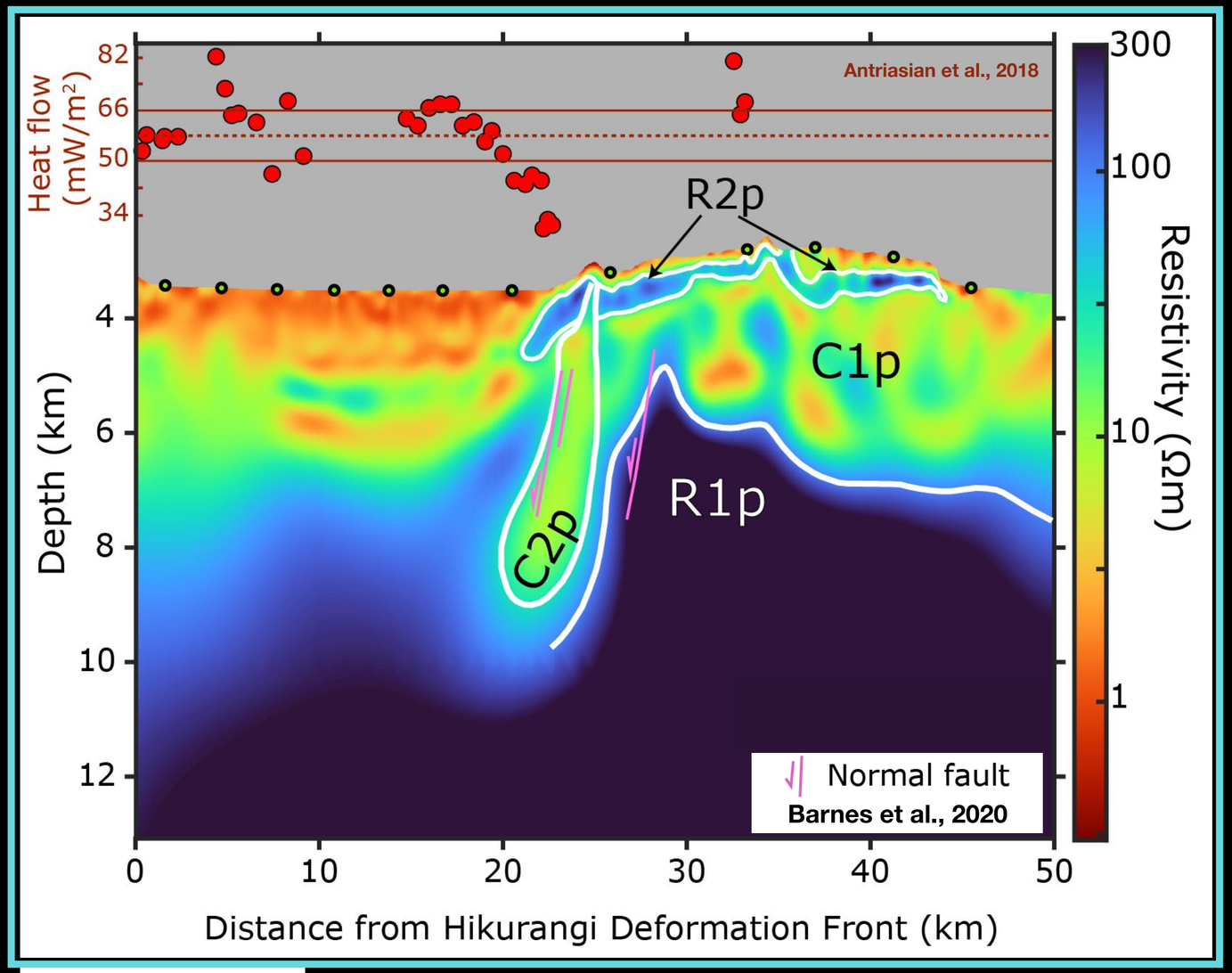
Electrical Characterization of a Seamount



Chesley et al., 2021

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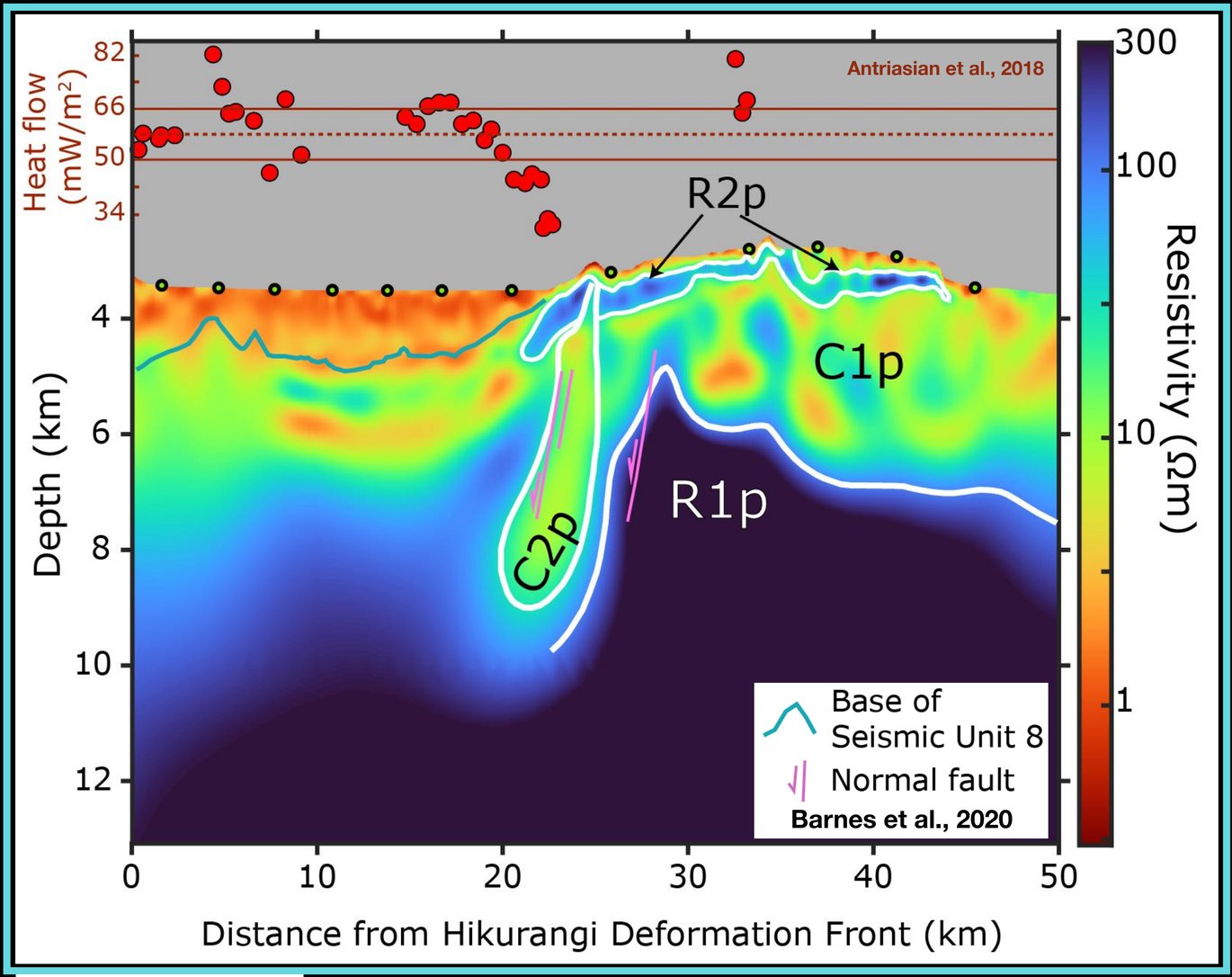
- R2p —> basaltic cap from submarine-subaerial transition

Hikurangi Trough Resistivity



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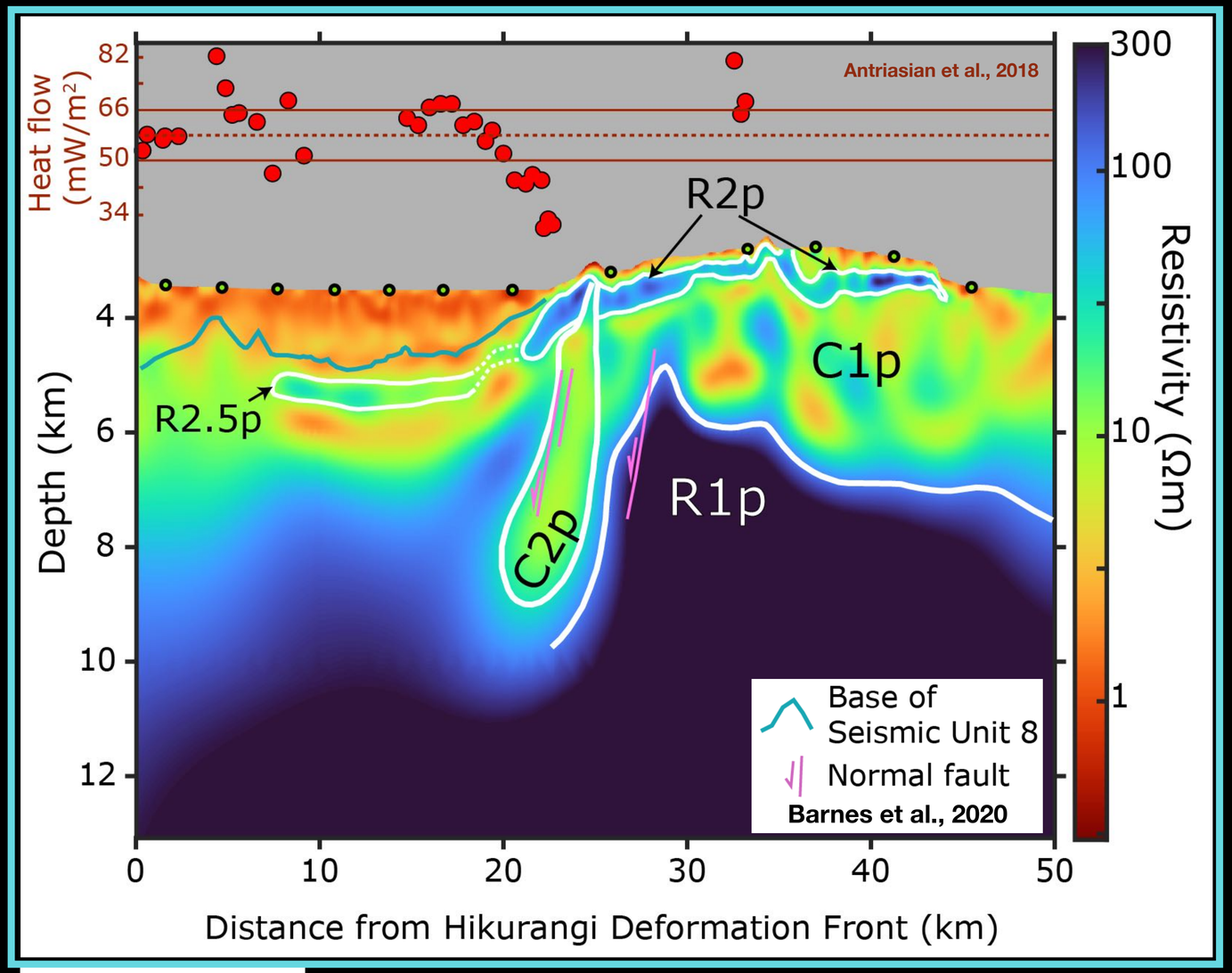

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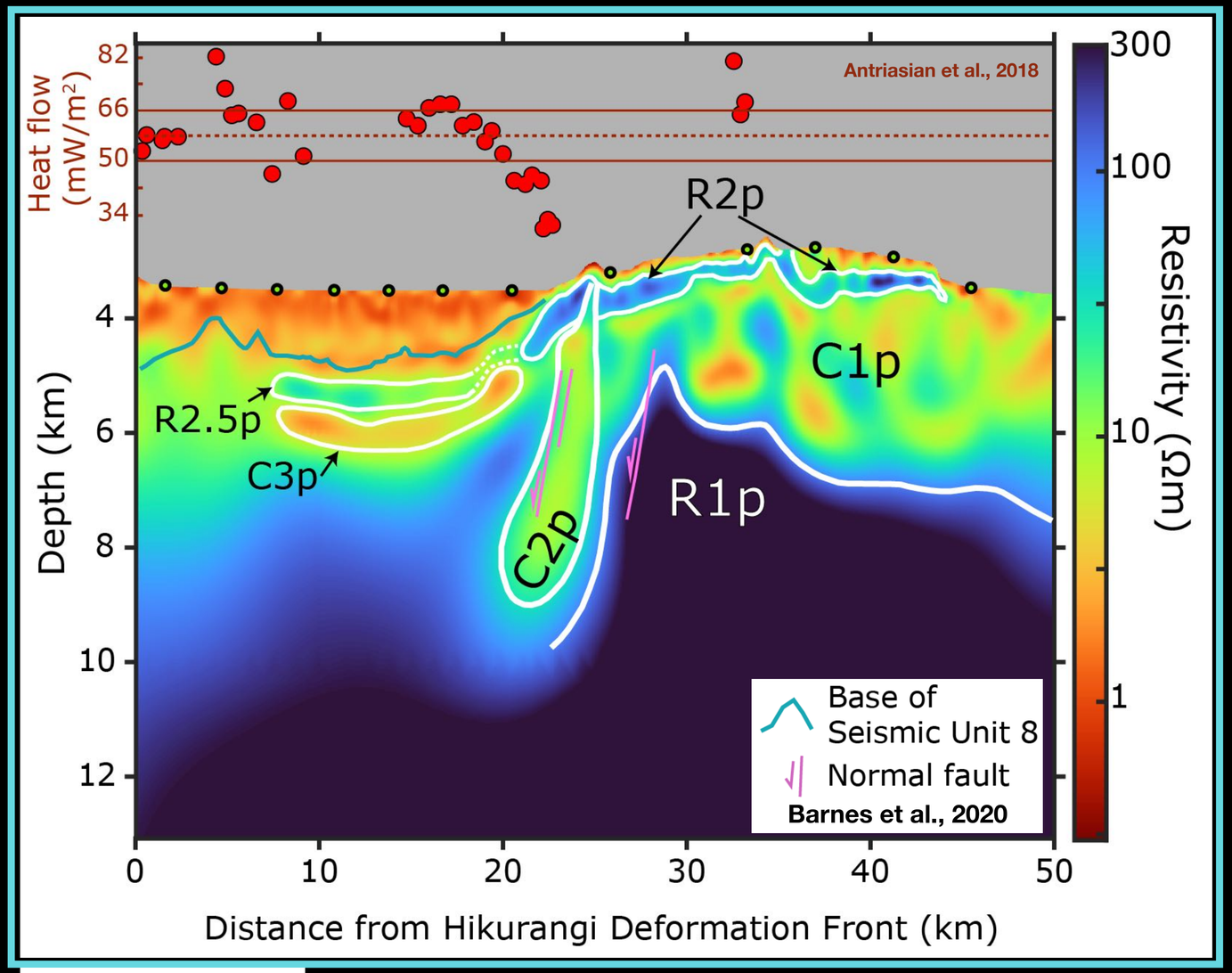
- R2.5p —> basalt flow, continuation of R2p?

Hikurangi Trough Resistivity



Chesley et al., 2021

- C1p —> volcaniclastics, extrusives, altered mins
- C2p —> conductive normal fault, hydrothermal pathway
- C3p —> buried sediments
- R1p —> resistive core of seamount
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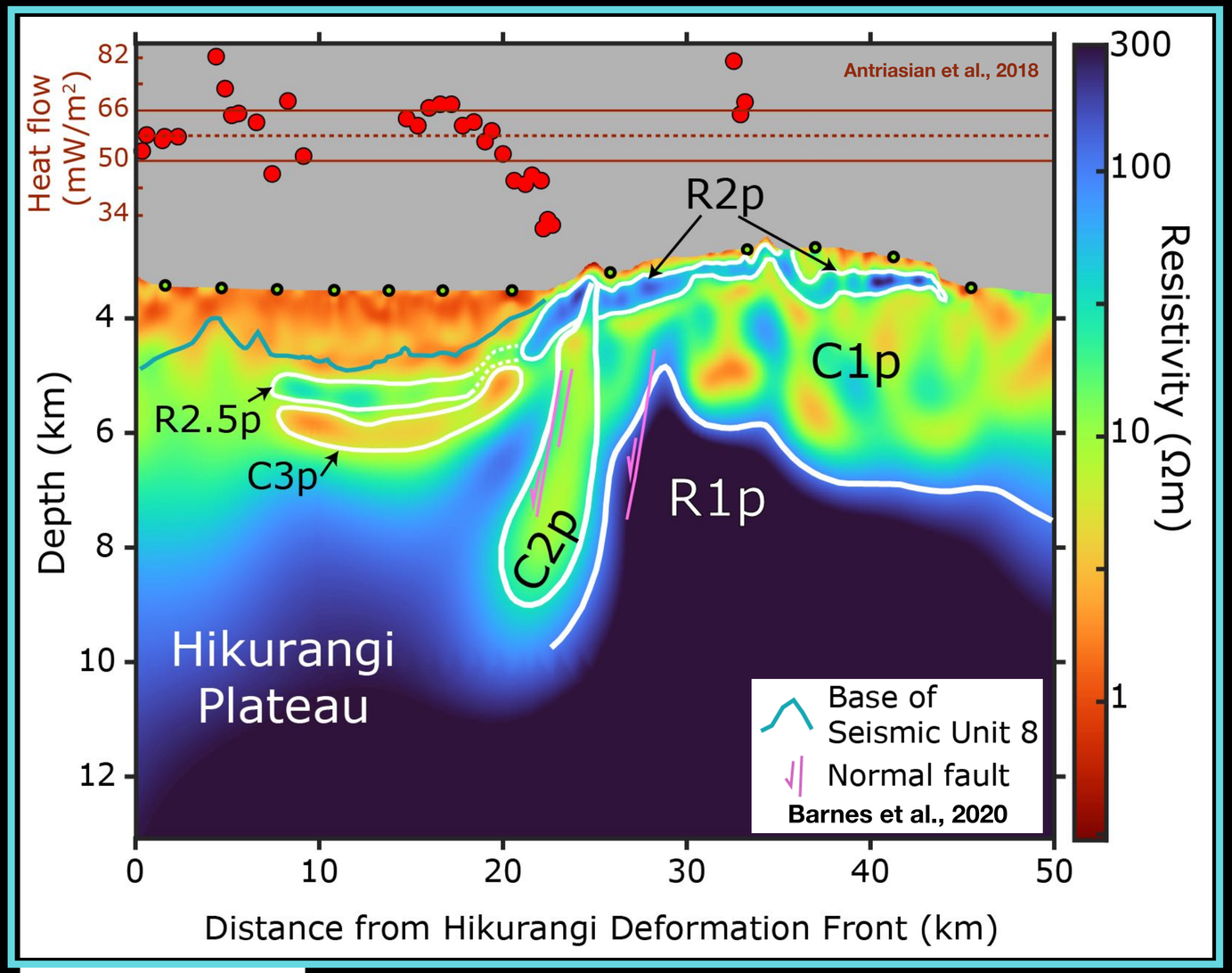
- R2.5p —> basalt flow, continuation of R2p?

Hikurangi Trough Resistivity



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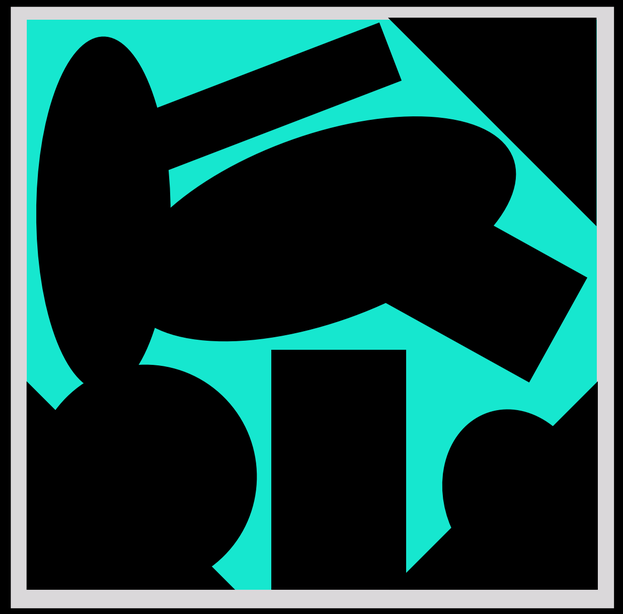
Archie's Law

$$\phi = \left(\frac{\rho_w}{\rho}\right)^{1/m}$$



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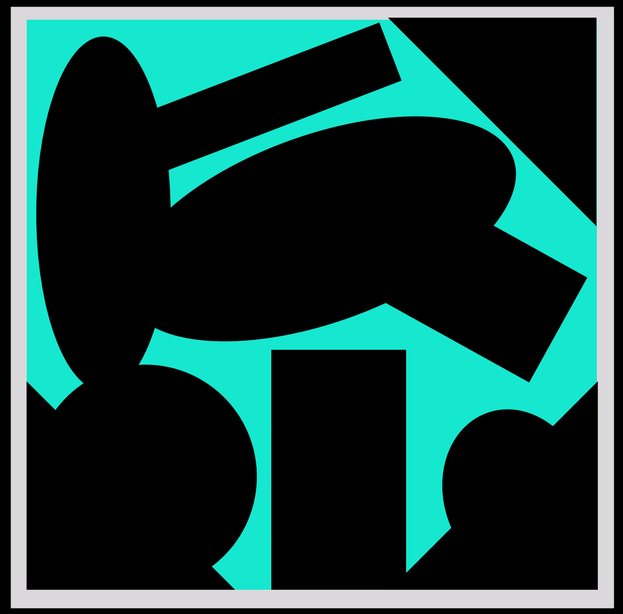


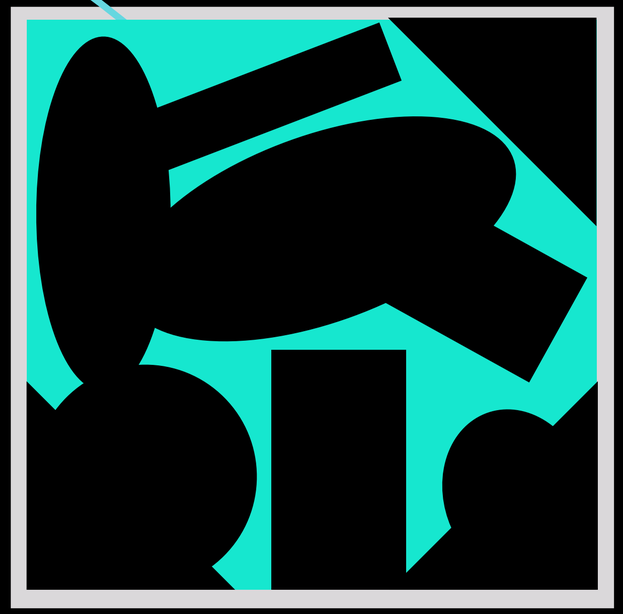
Bulk resistivity (ρ)
- constrained by EM data

Archie's Law

$$\phi = \left(\frac{\rho_w}{\rho}\right)^{1/m}$$

fluid resistivity (ρ_w)

- ρ_w = f(T*, P, salinity*)
- depth variation due to thermal gradient (Constable et al., 2009)
- geotherm from IODP U1518 and U1520



Bulk resistivity (ρ)

- constrained by EM data

Archie's Law

$$\phi = \left(\frac{\rho_w}{\rho}\right)^{1/m}$$

pore interconnectivity
m = 2.4
(Schwalenberg et al., 2017)

fluid resistivity (ρ_w)
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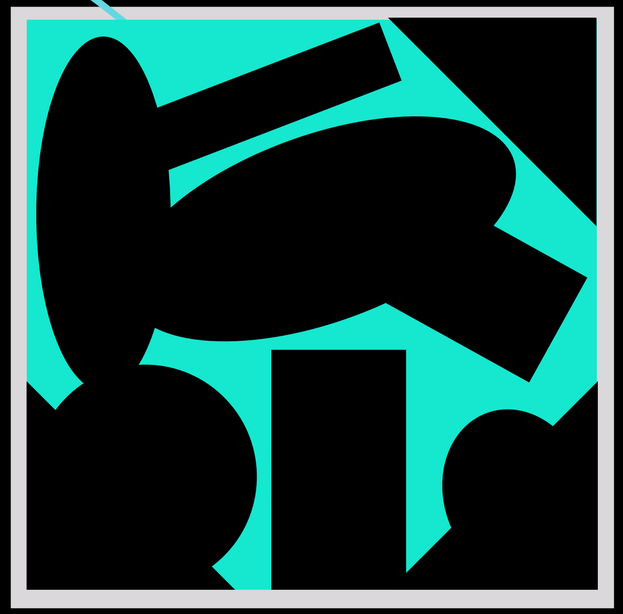

Bulk resistivity (ρ)
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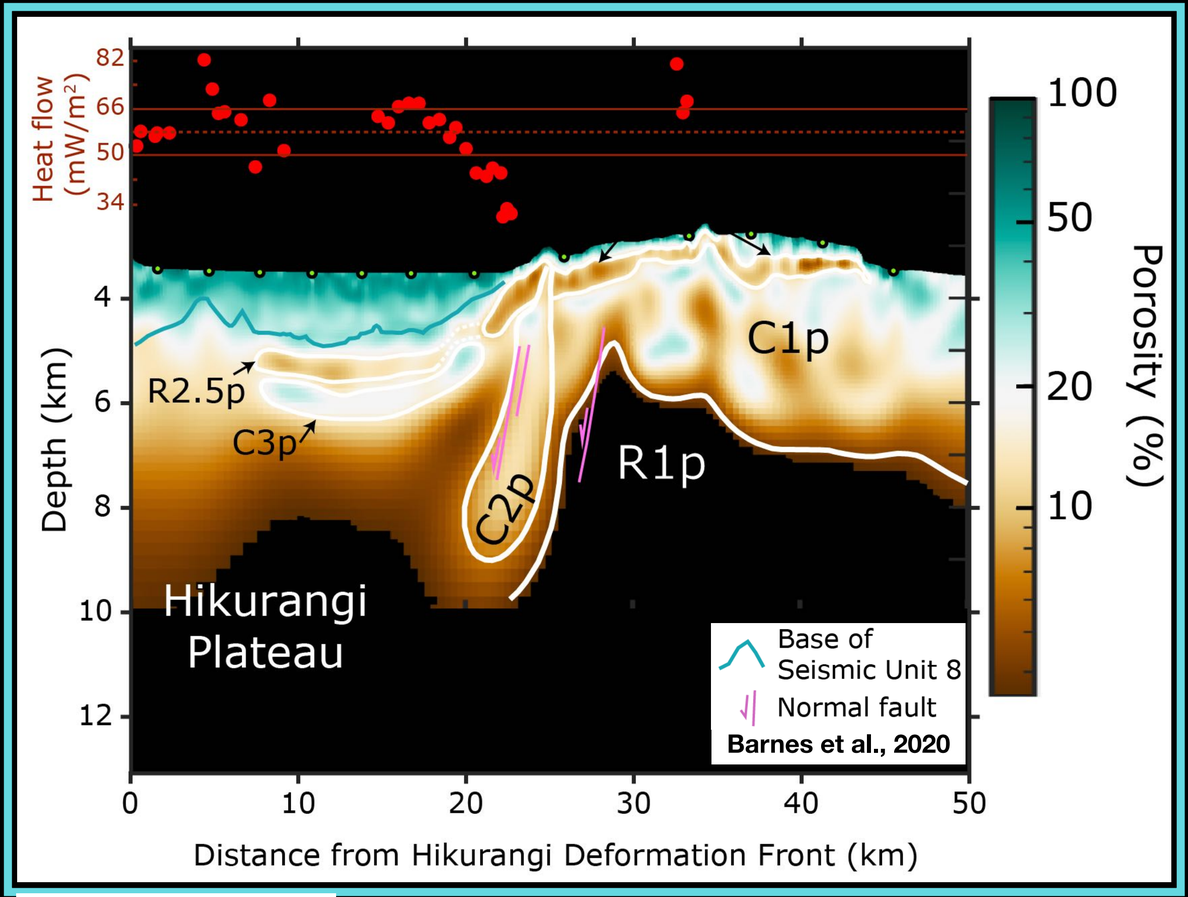
Seamounts = Water Vessels



Chesley et al., 2021

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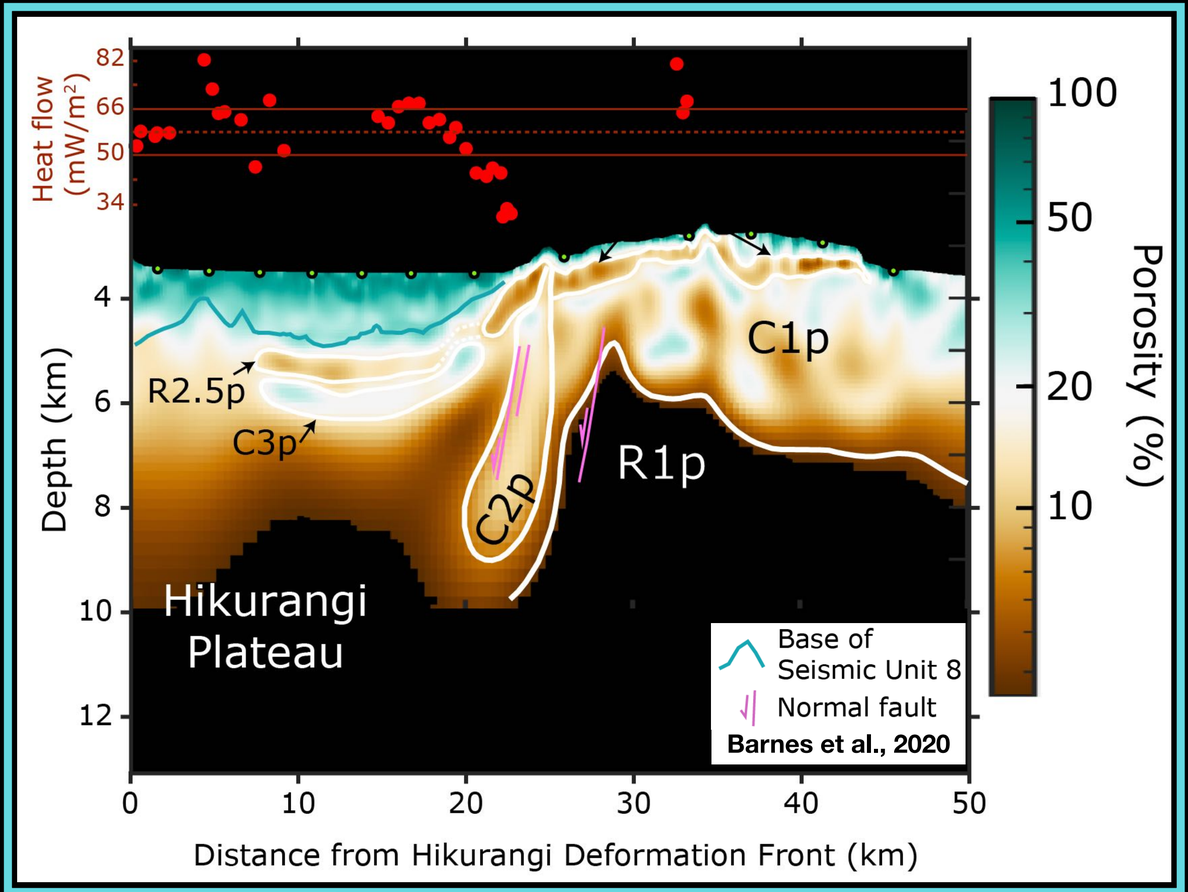
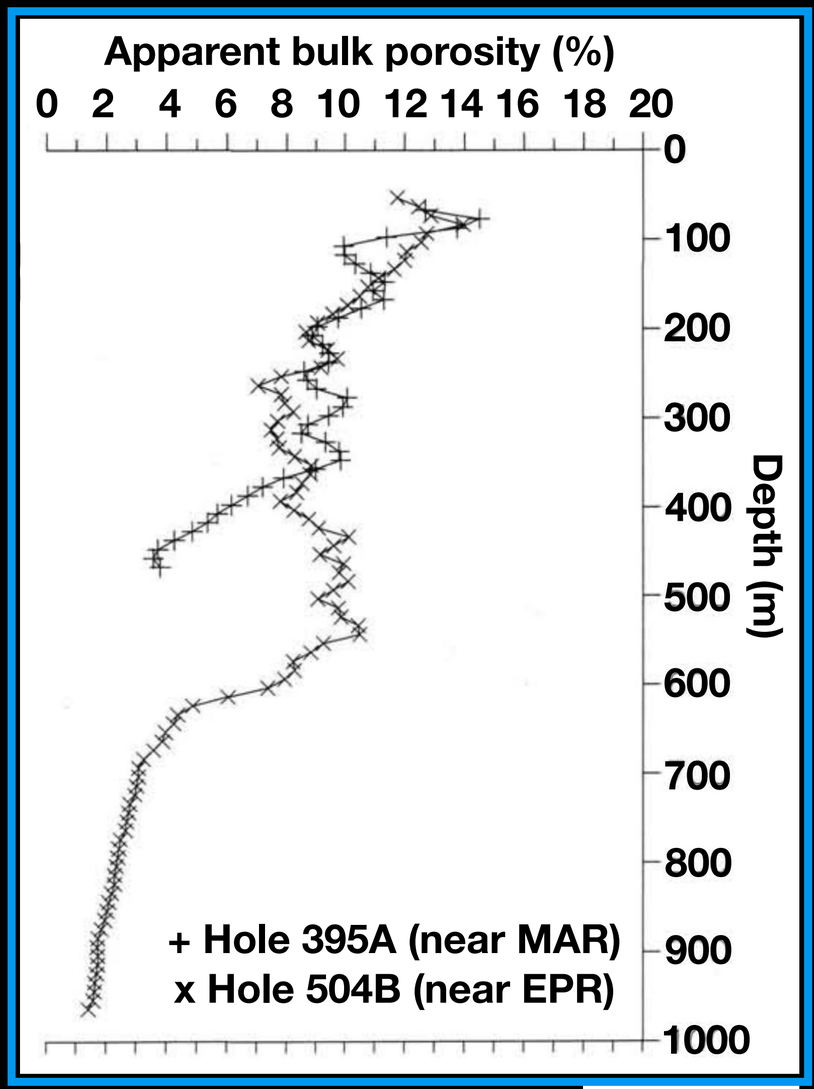


Chesley et al., 2021



Becker, 1990

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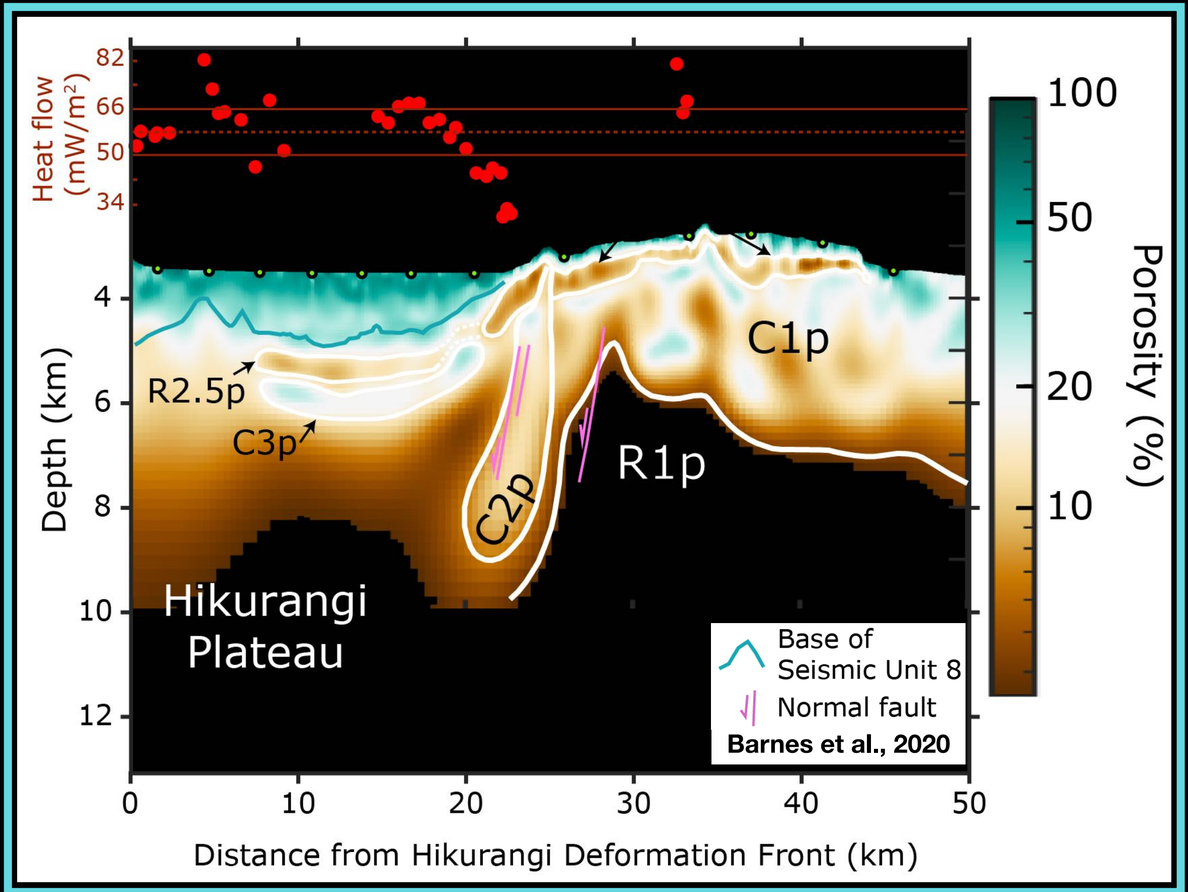
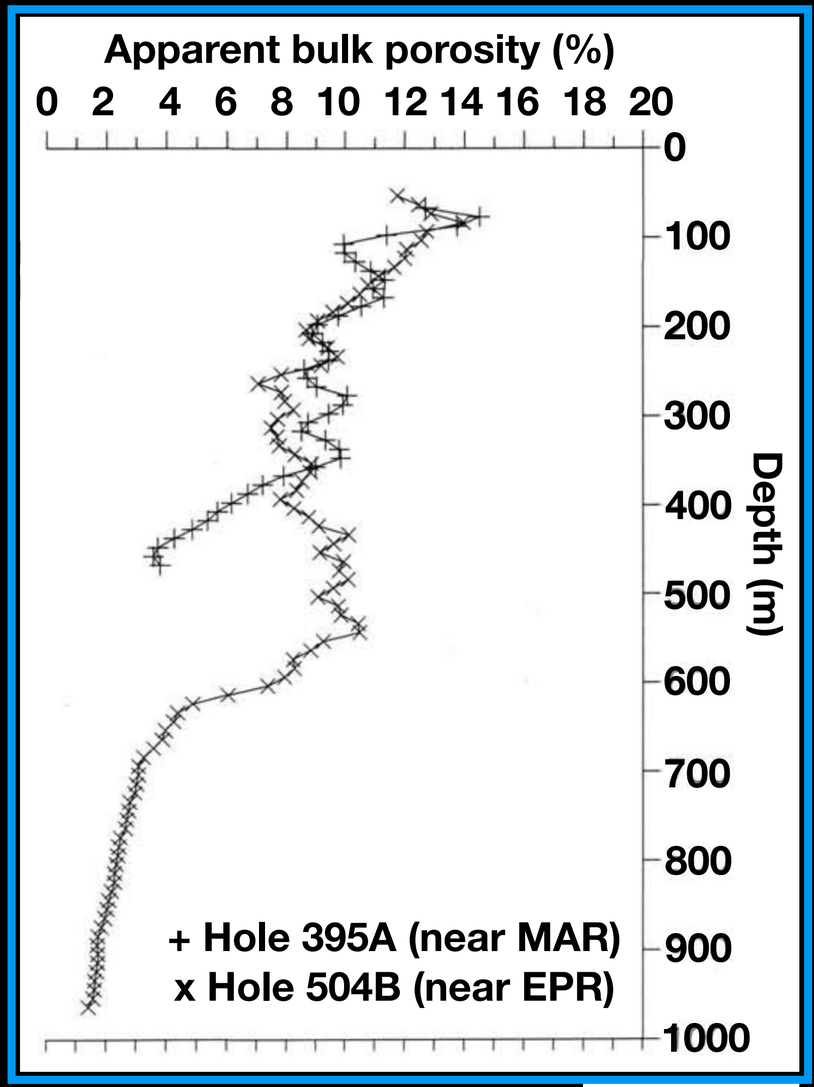


Chesley et al., 2021

Tūranganui Knoll is more porous than average oceanic crust



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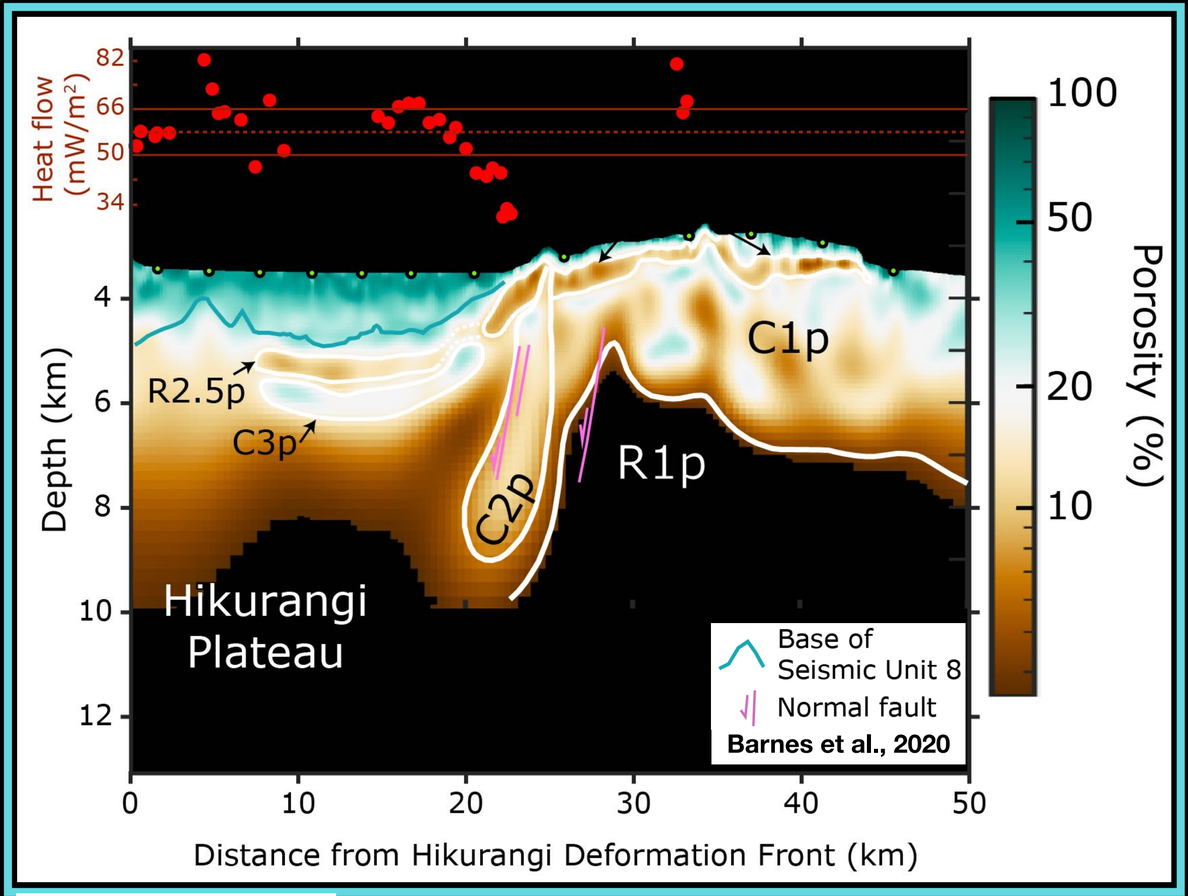

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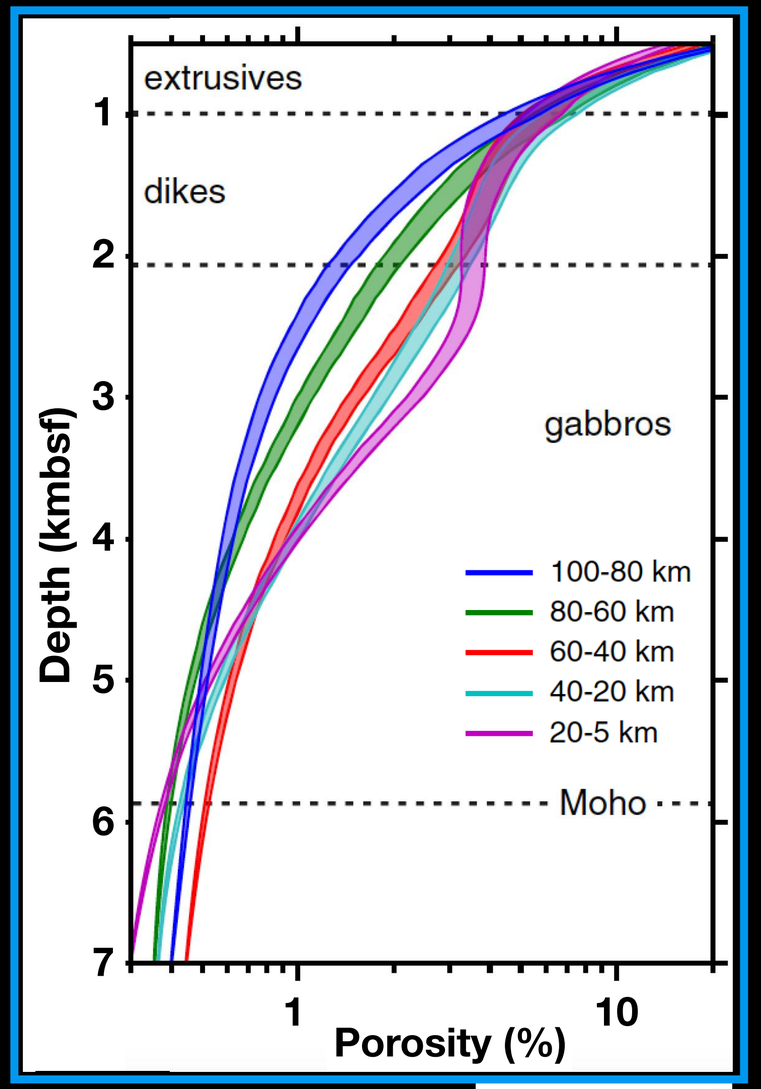

Naif et al., 2015

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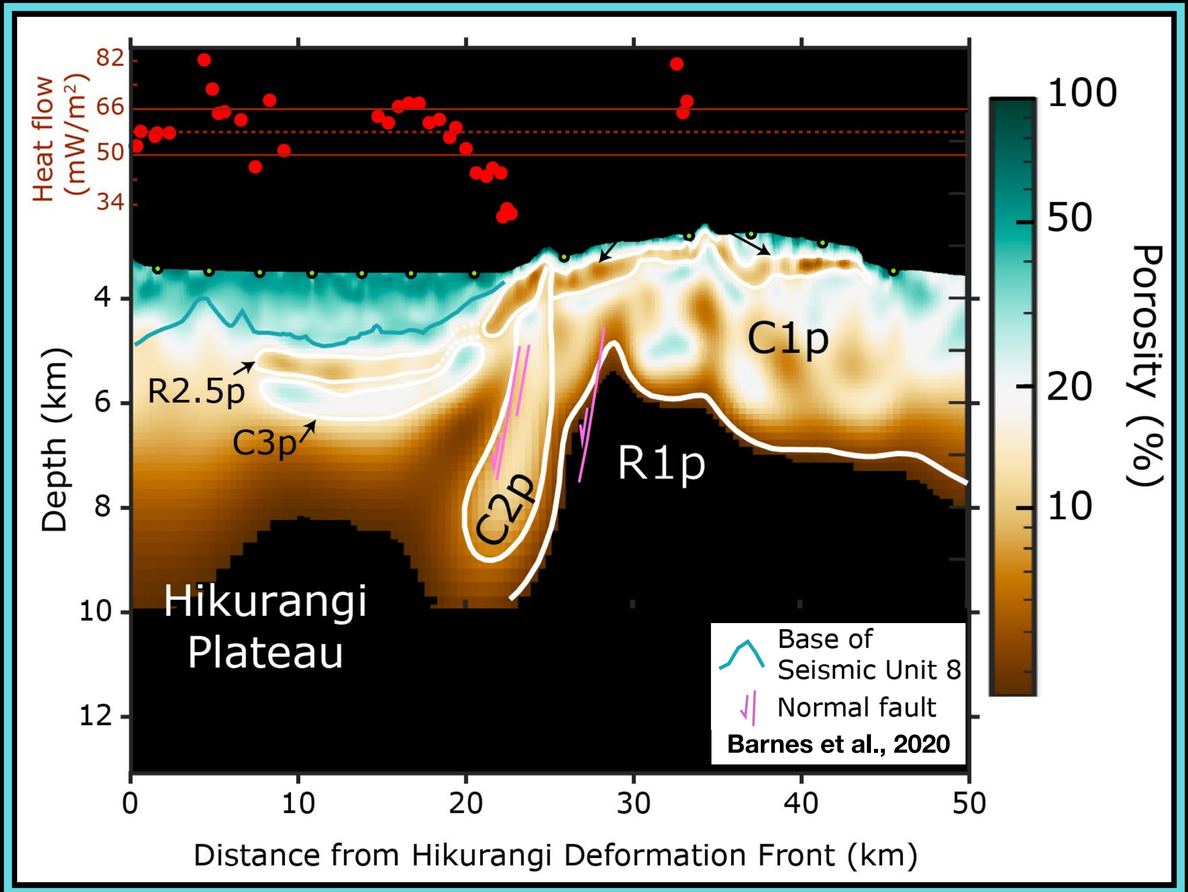
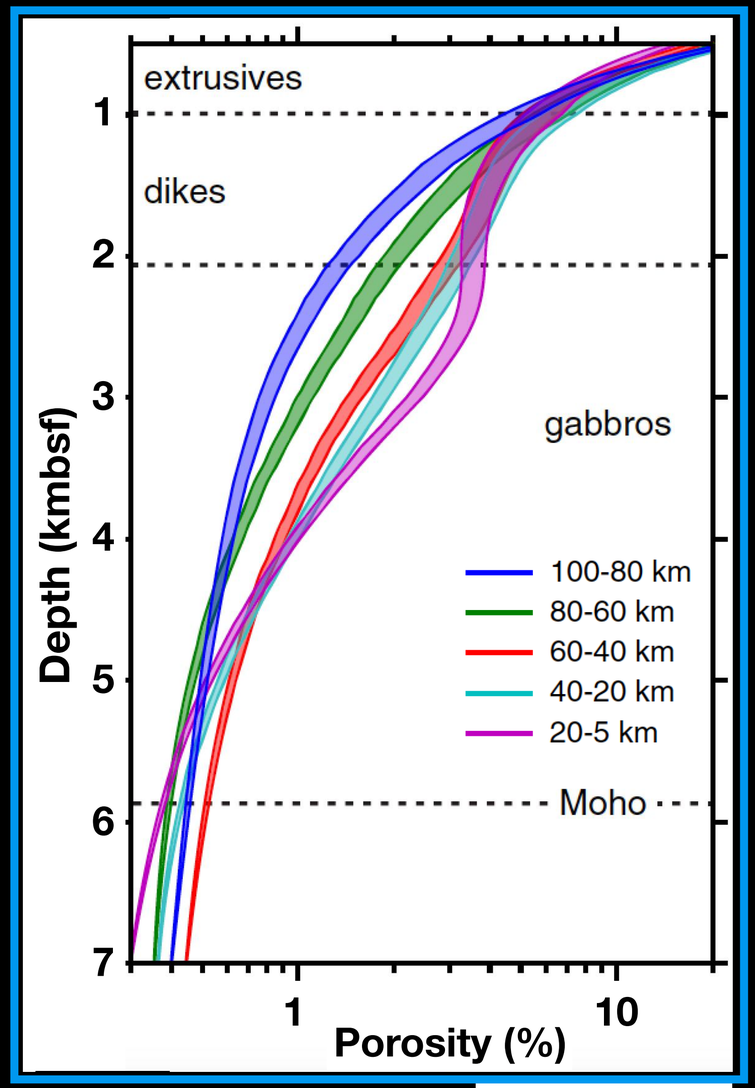


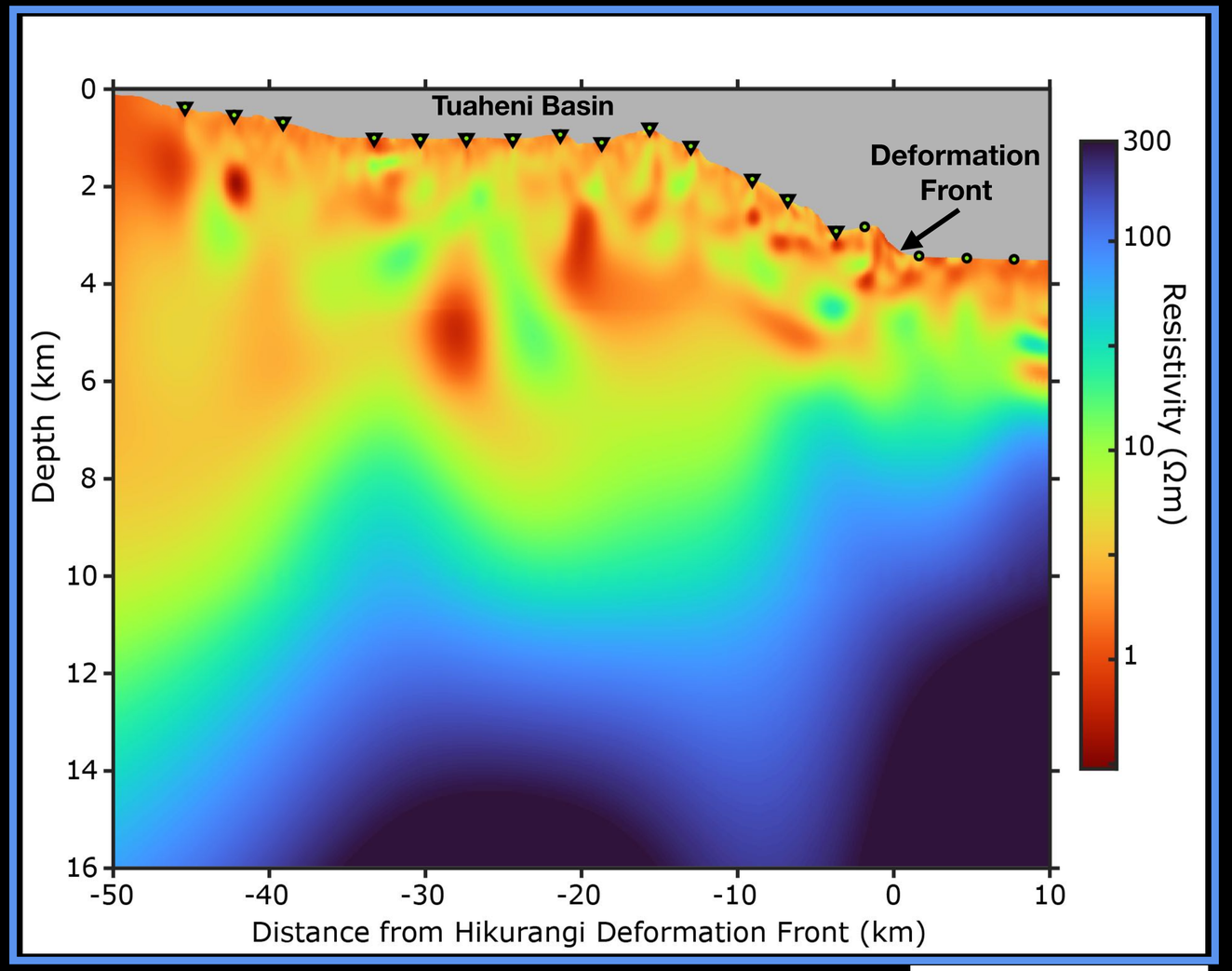
Chesley et al., 2021

Tūranganui Knoll will subduct ~3.2—4.7x more water than normal, unfaulted crust



Naif et al., 2015

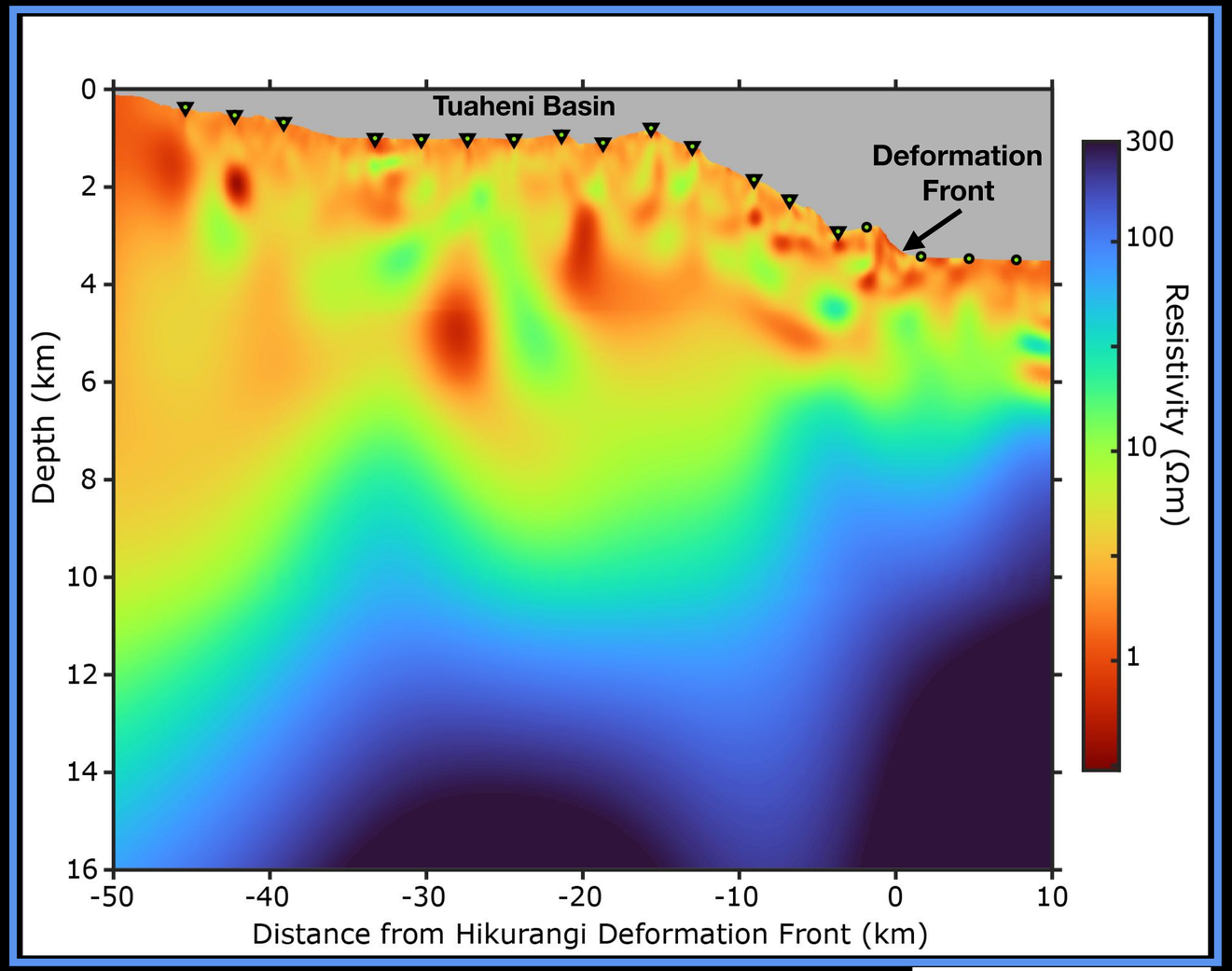
Forearc Resistivity



Chesley et al., 2021

Forearc Resistivity

- Heterogeneous forearc resistivity



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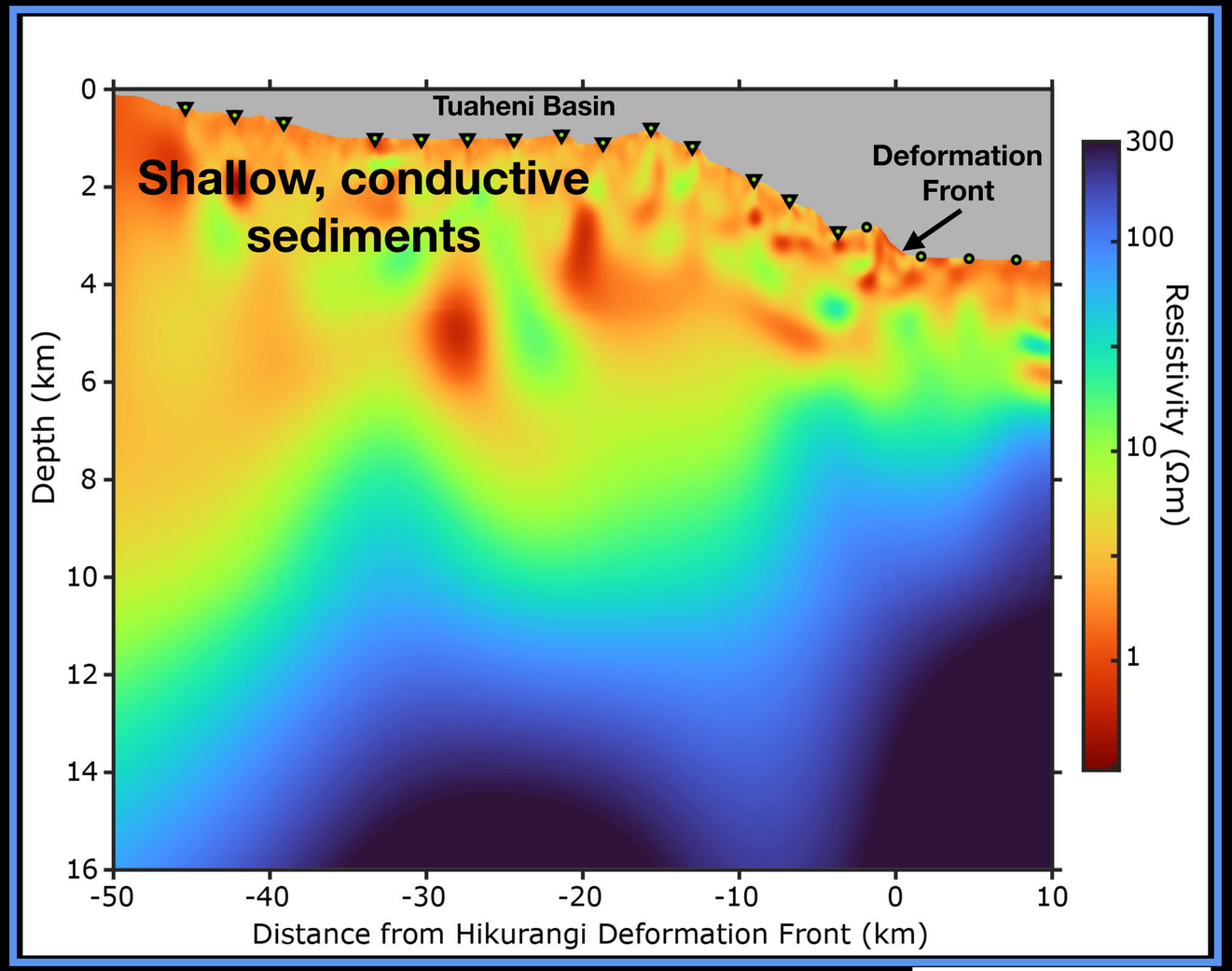

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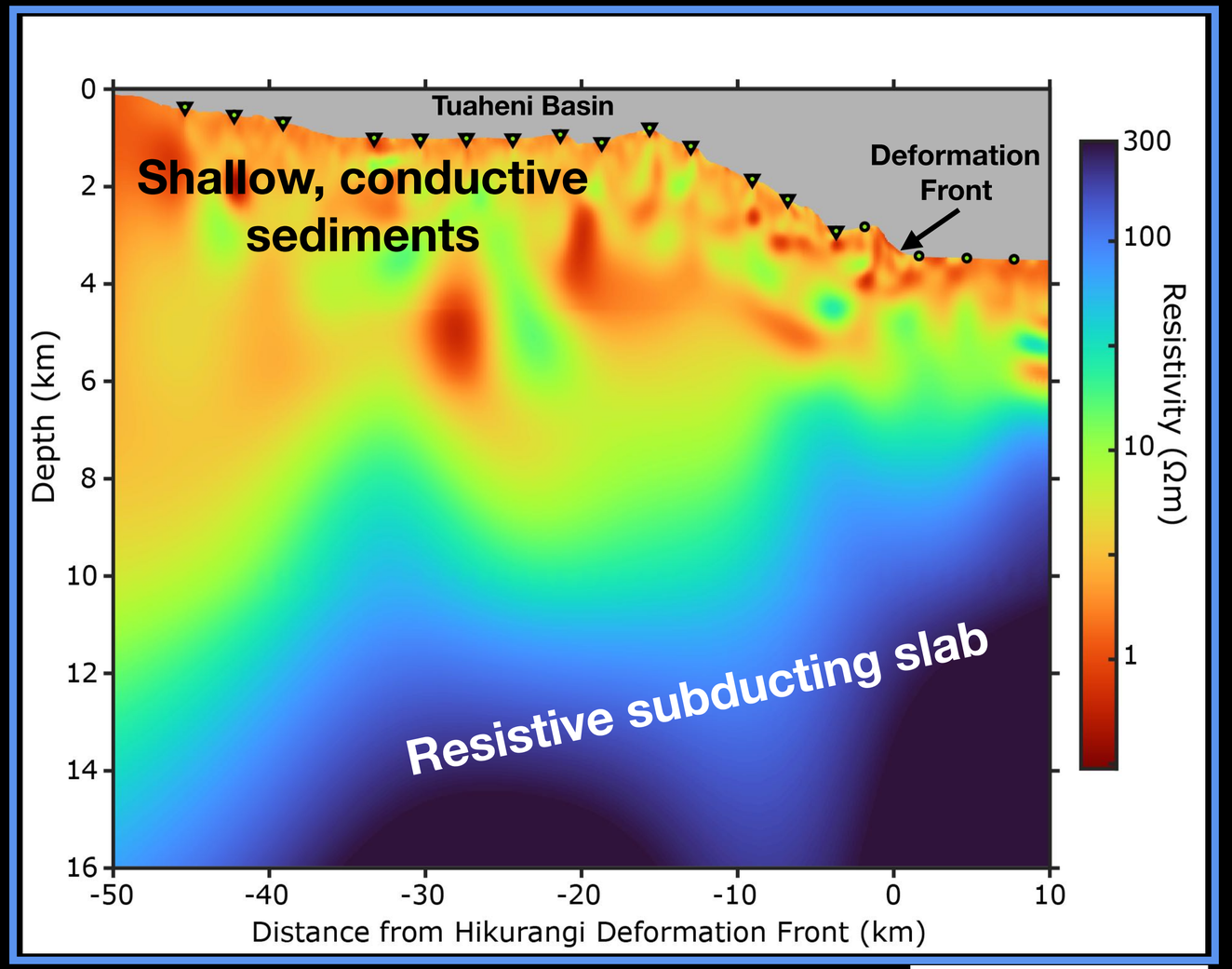
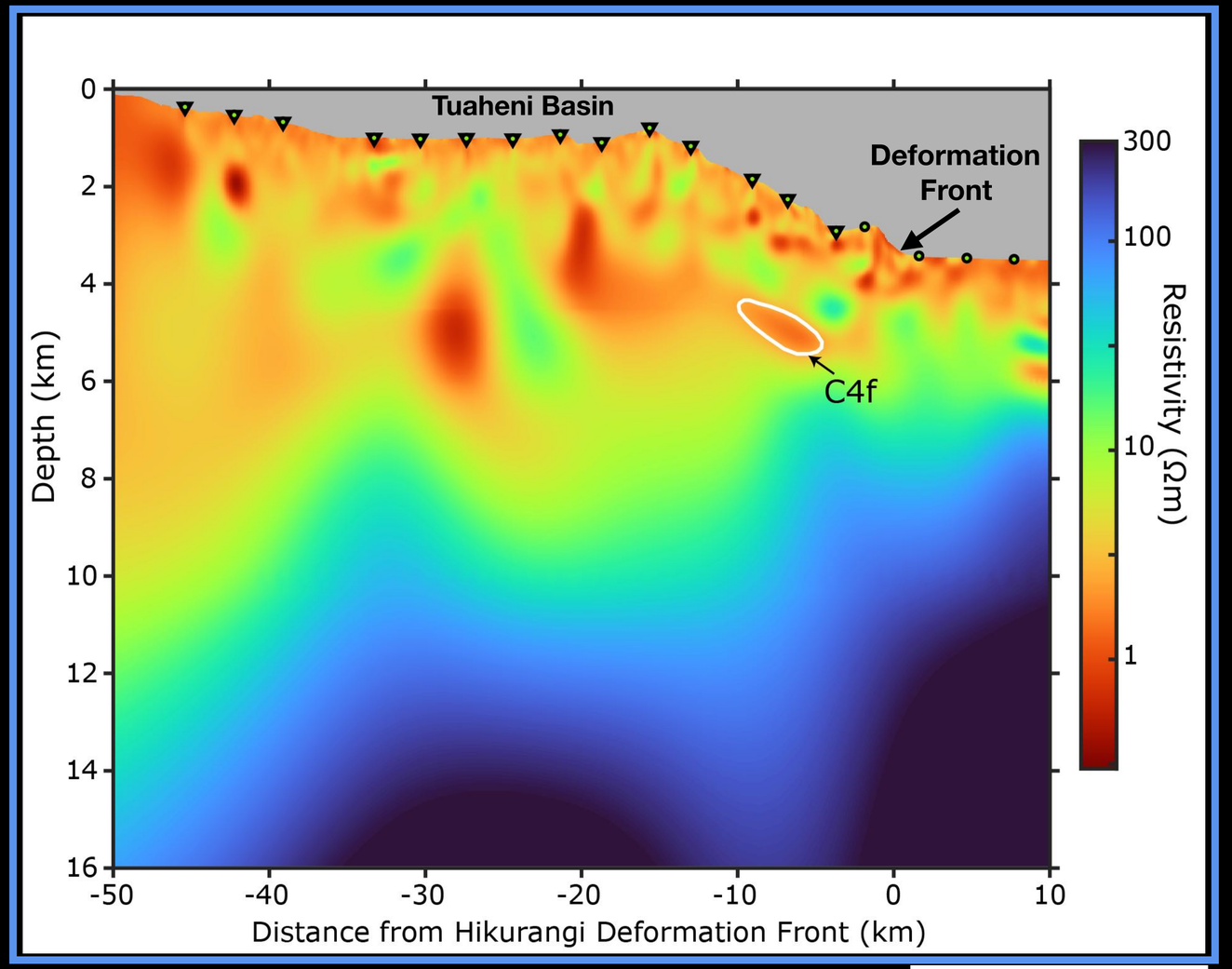


Chesley et al., 2021

Forearc Resistivity

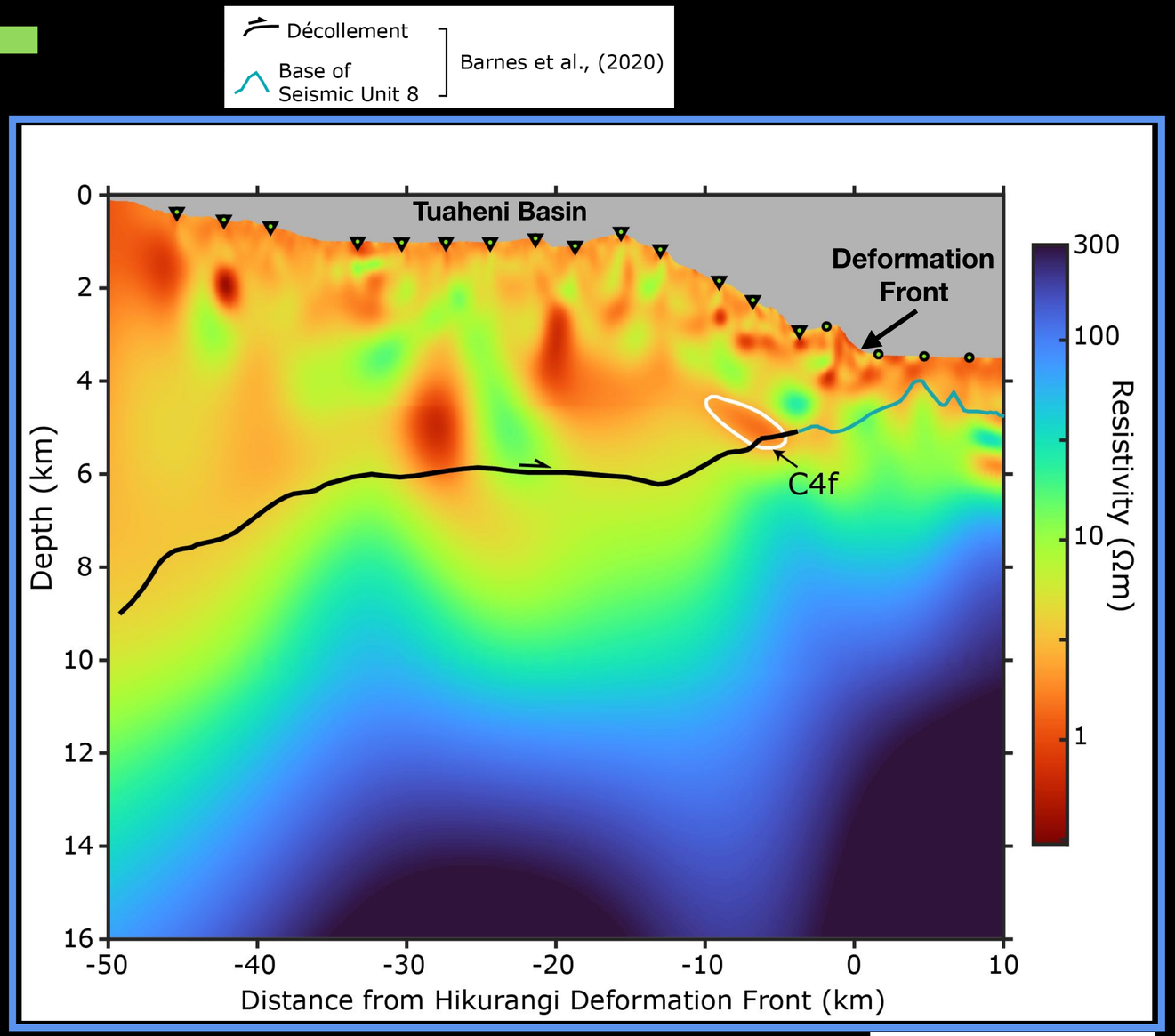
- C4f



Chesley et al., 2021

Forearc Resistivity

- C4f —> Subducting sediment

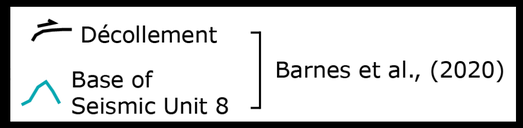


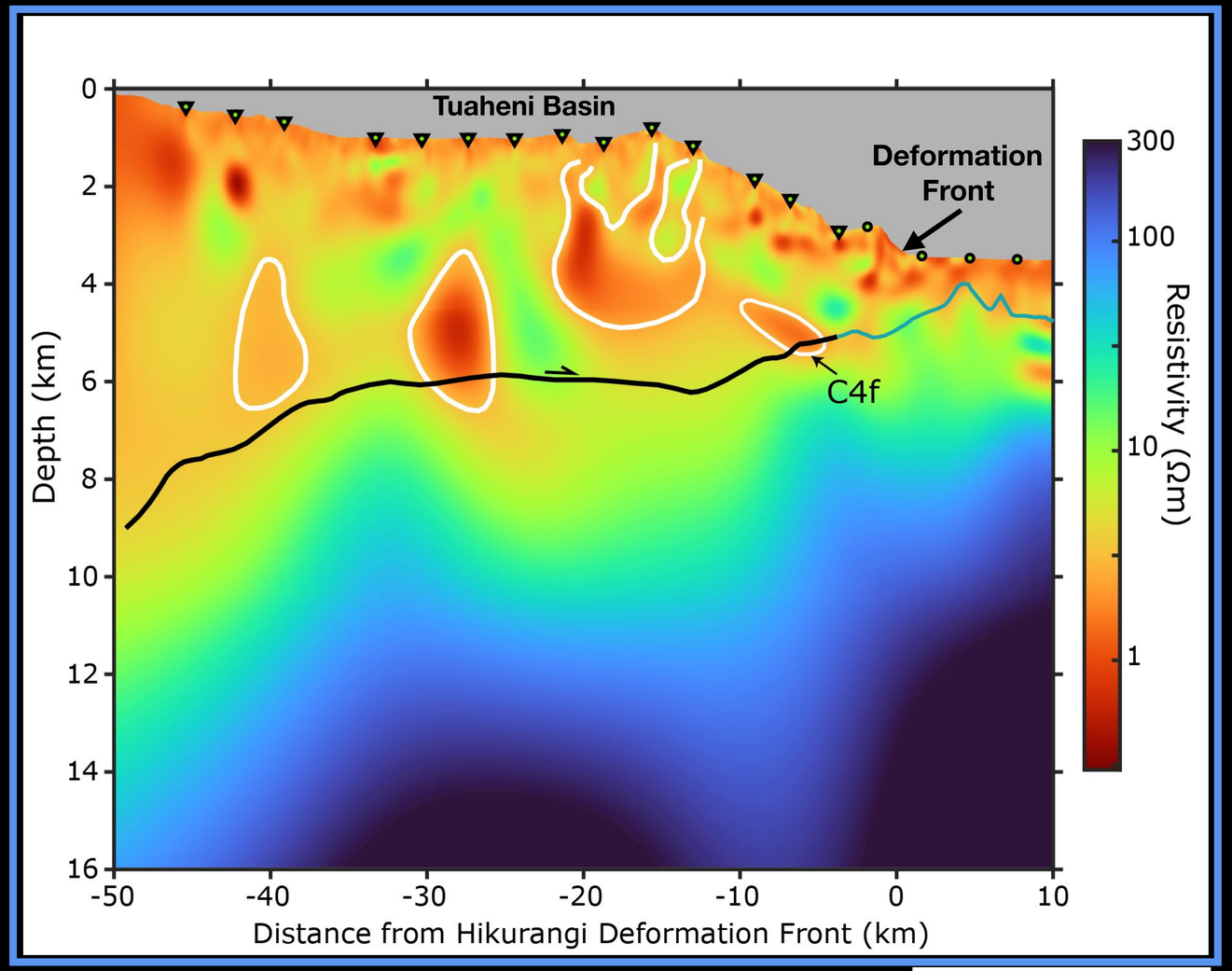
Chesley et al., 2021

Forearc Resistivity

Conductors embedded in resistive background

- C4f —> Subducting sediment



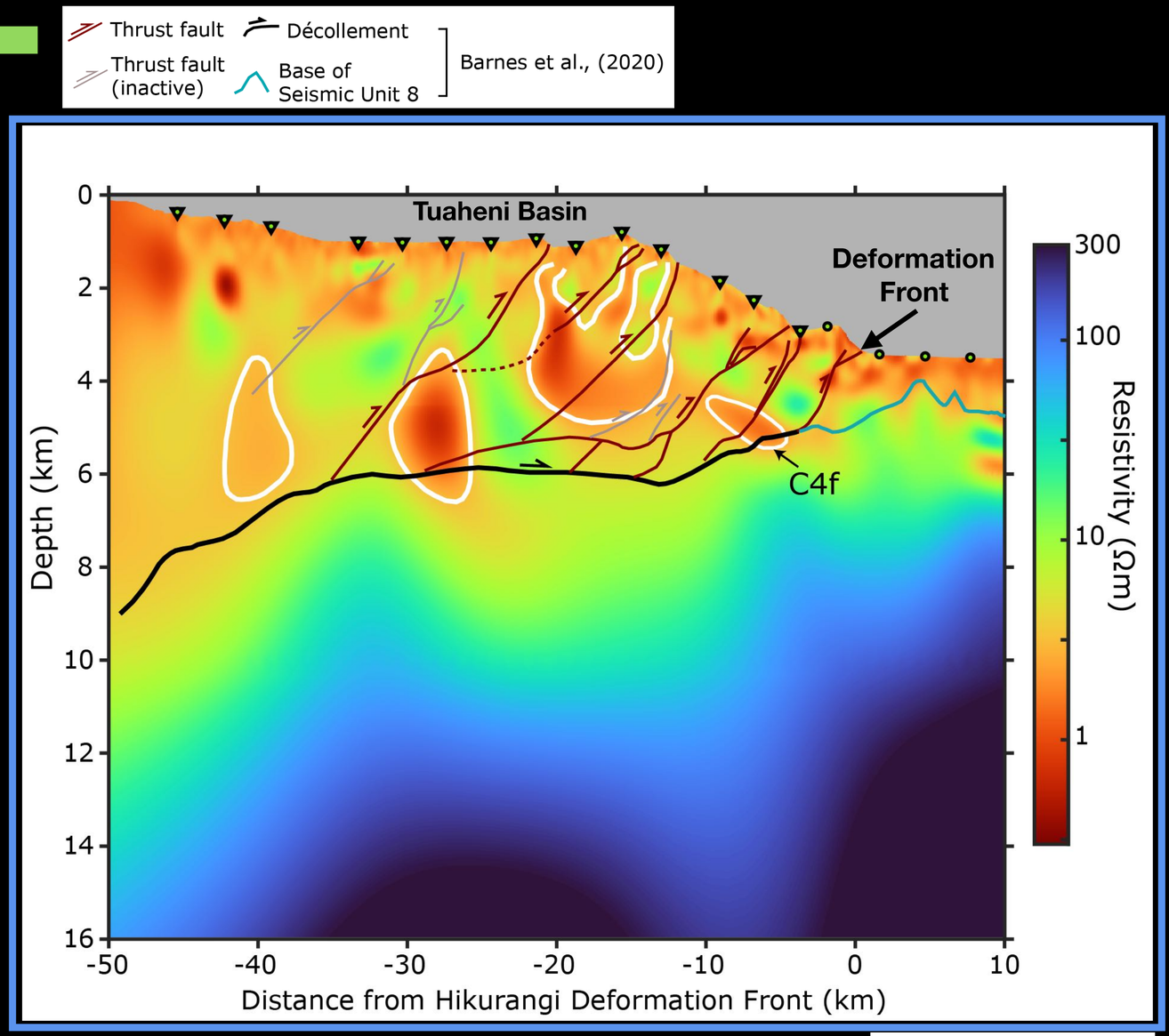


Chesley et al., 2021

Forearc Resistivity

Some conductors bounded by active thrust faults

- C4f —> Subducting sediment

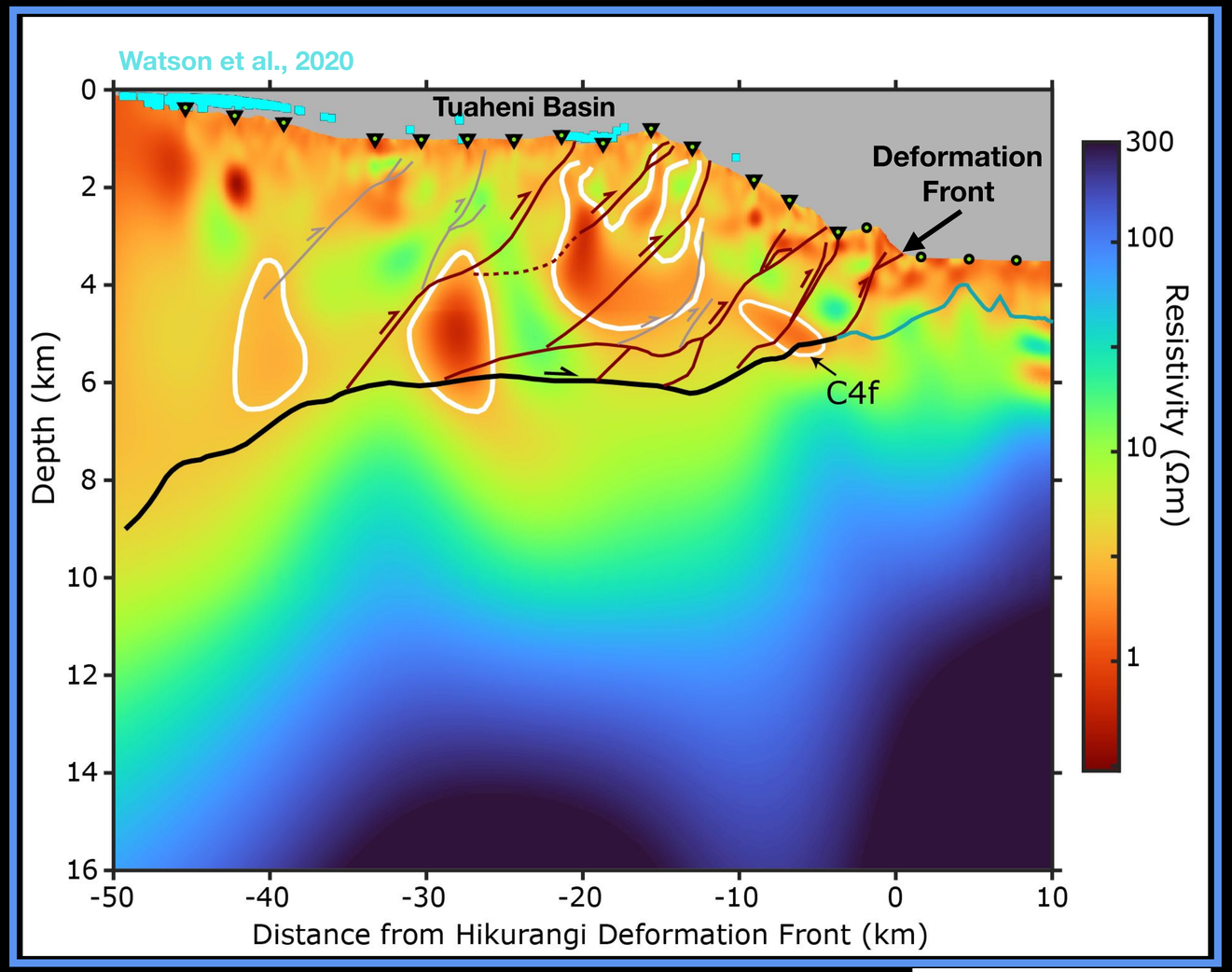


Chesley et al., 2021

Forearc Resistivity

Some conductors bounded by active thrust faults
—> Fluid paths for seeps?

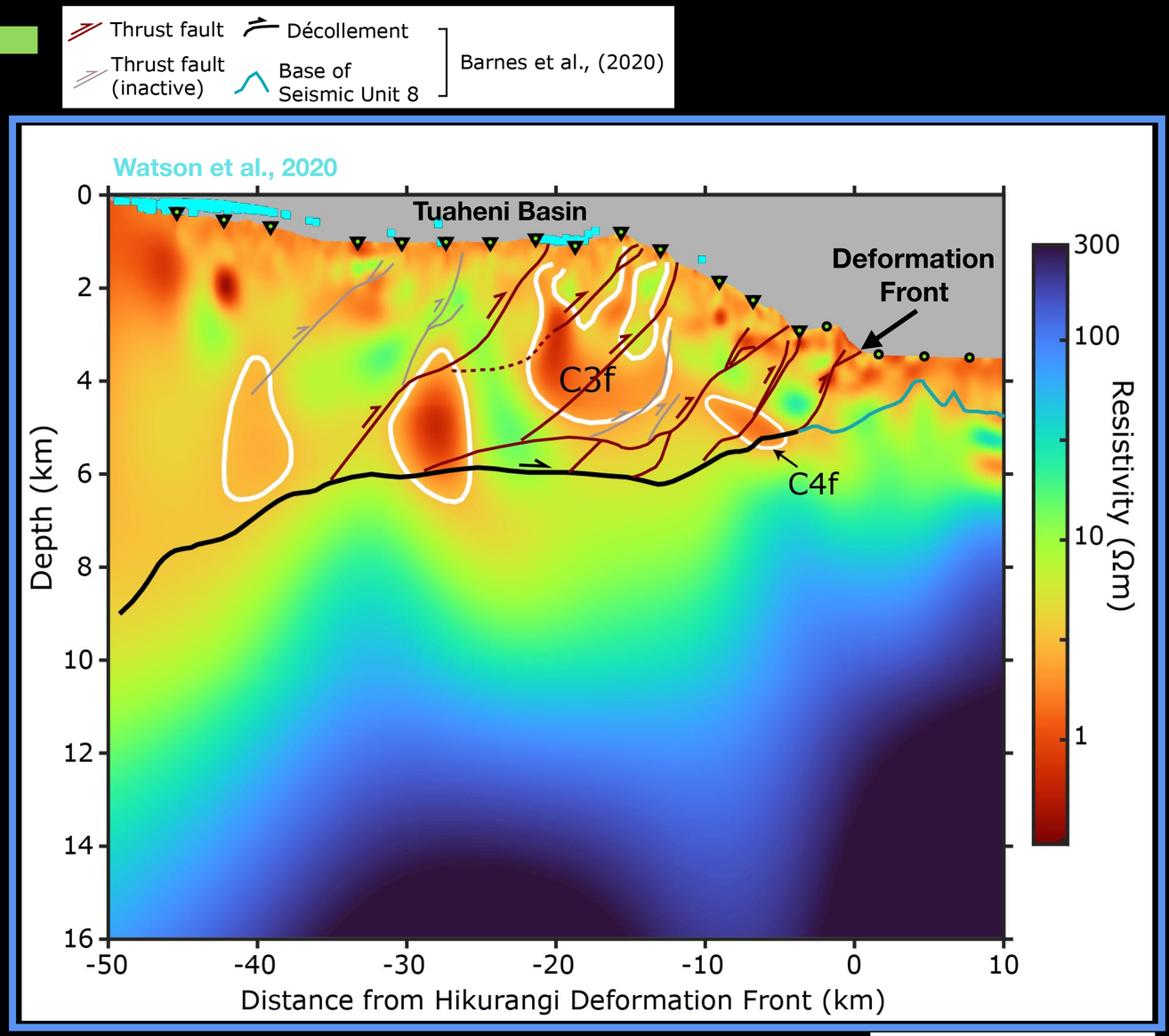
- C4f —> Subducting sediment



Chesley et al., 2021

Forearc Resistivity

- C3f —> Sediment underplating?
- C4f —> Subducting sediment



Chesley et al., 2021

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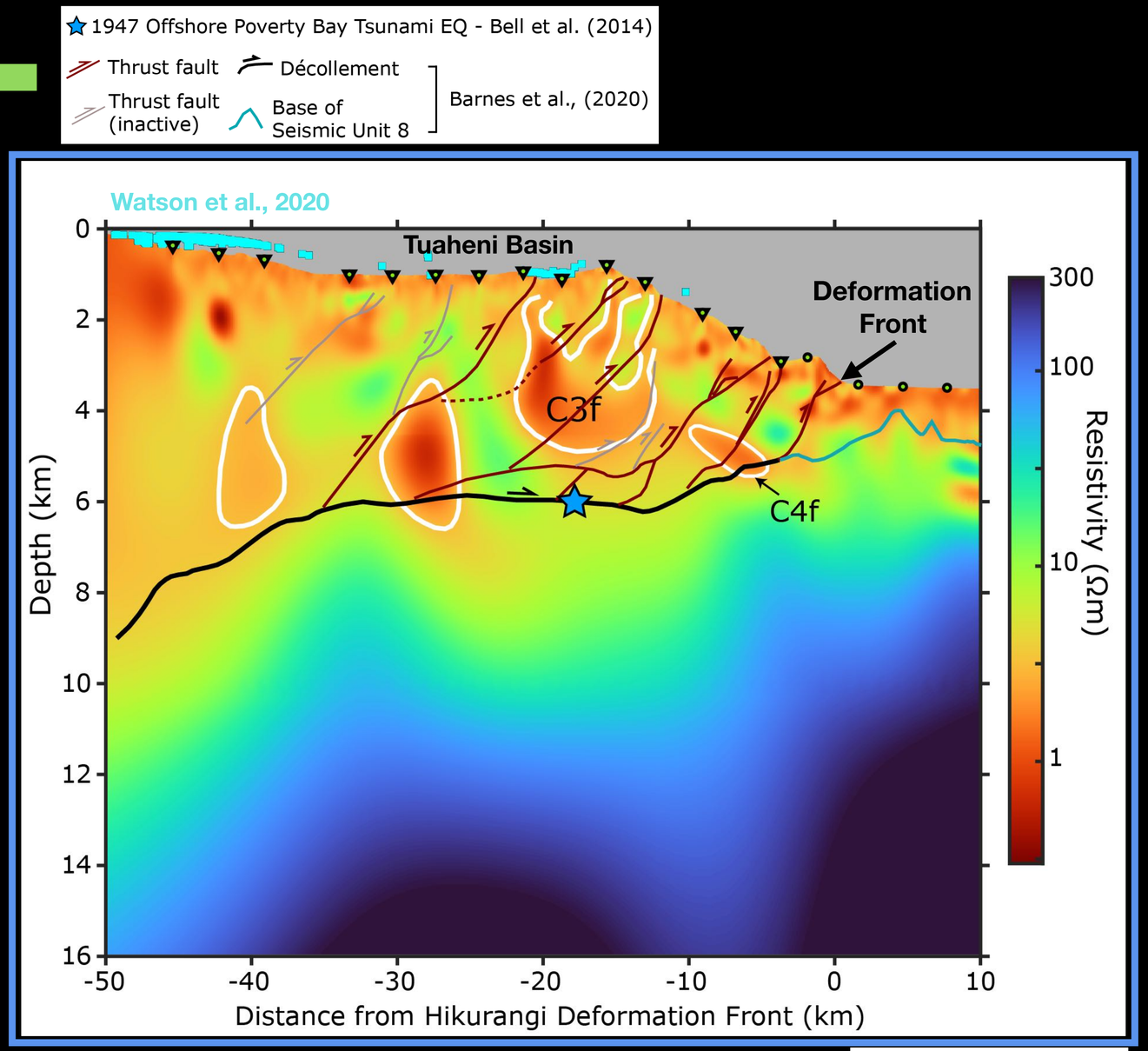

Chesley et al., 2021

Forearc Resistivity

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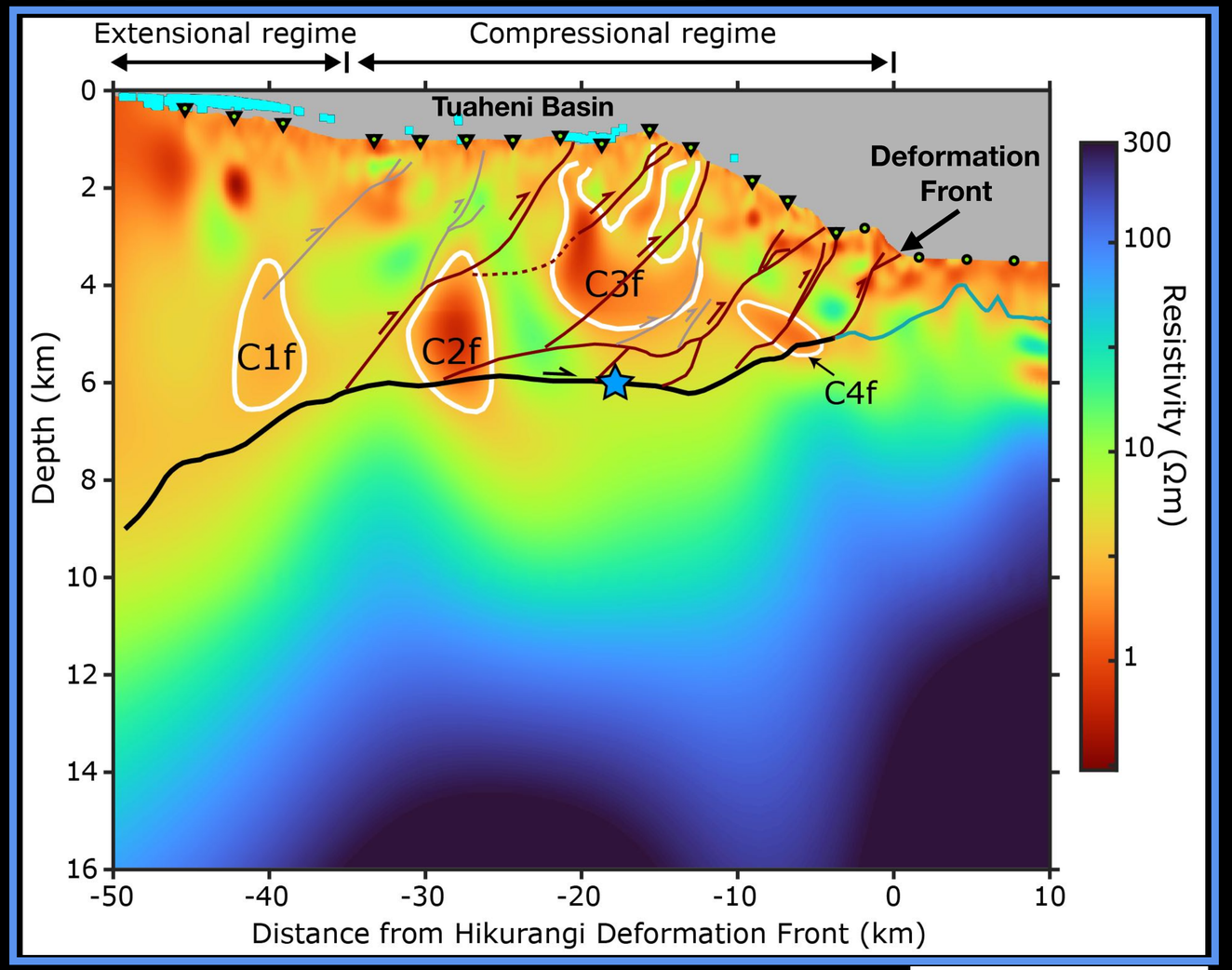

Chesley et al., 2021

Forearc Resistivity

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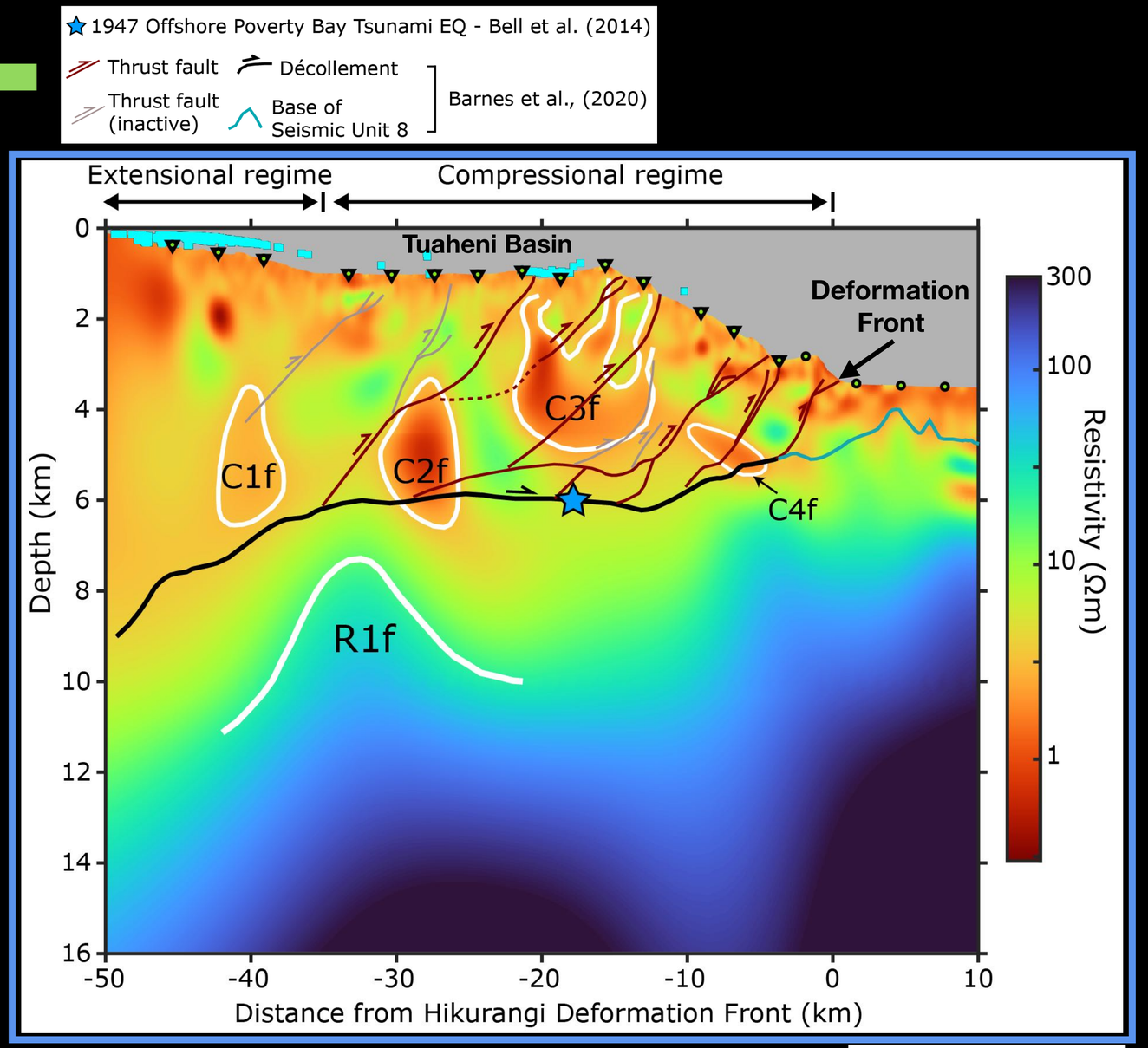
- R1f —> Core of subducting seamount (comparable to R1p)



Chesley et al., 2021

RESIST

Forearc Resistivity

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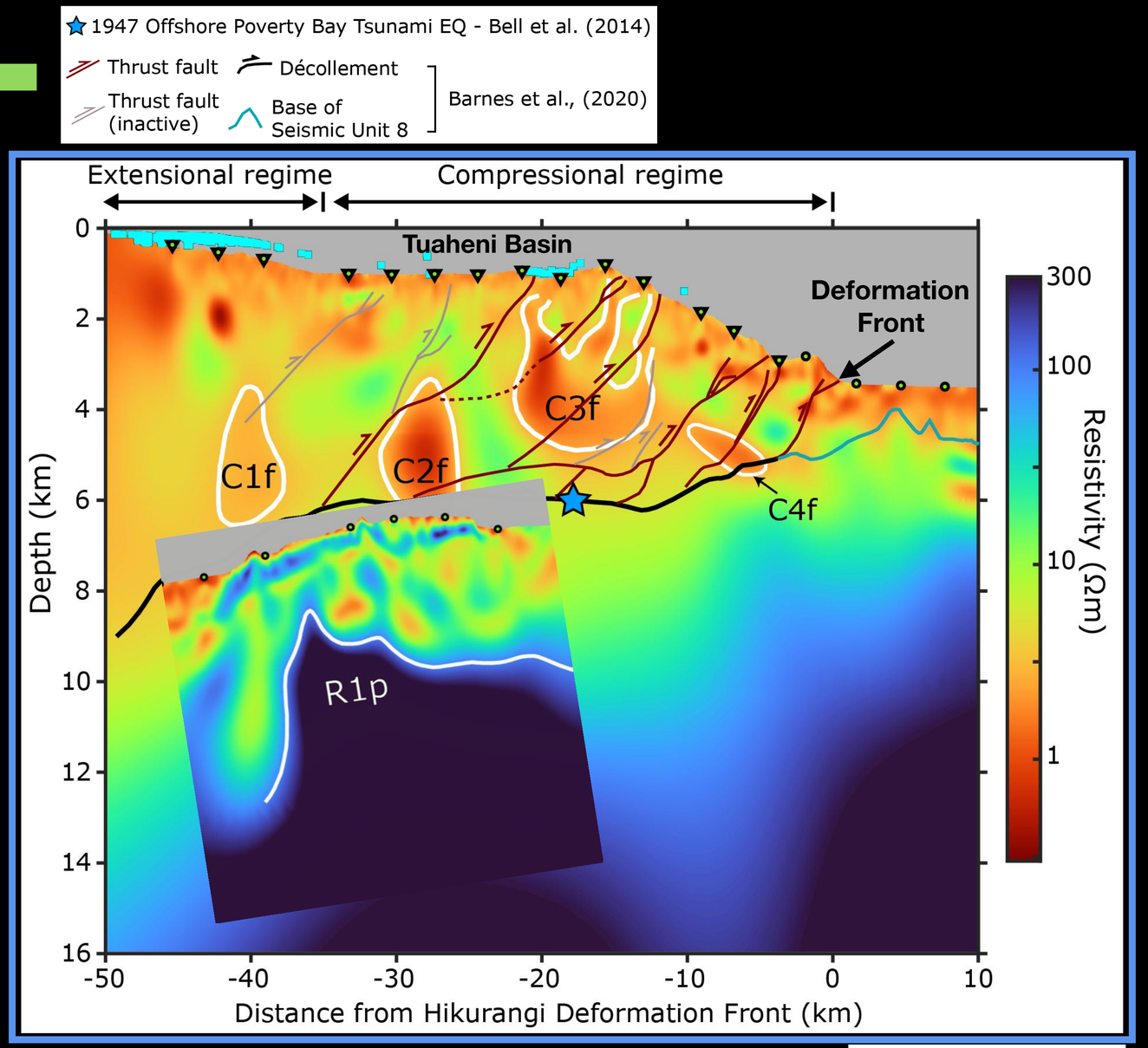
- R1f —> Core of subducting seamount (comparable to R1p)



Chesley et al., 2021

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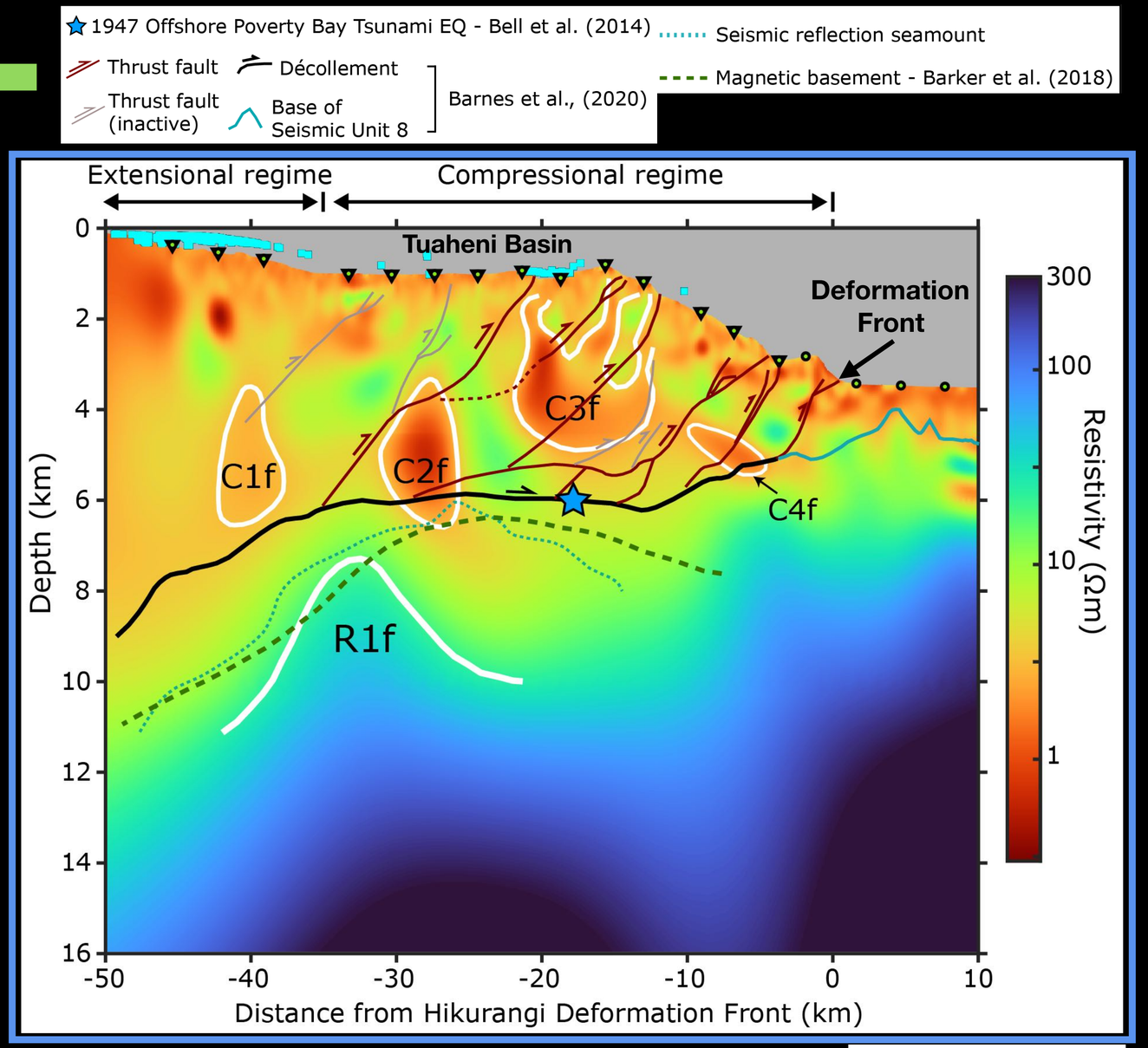

Chesley et al., 2021

Forearc Resistivity

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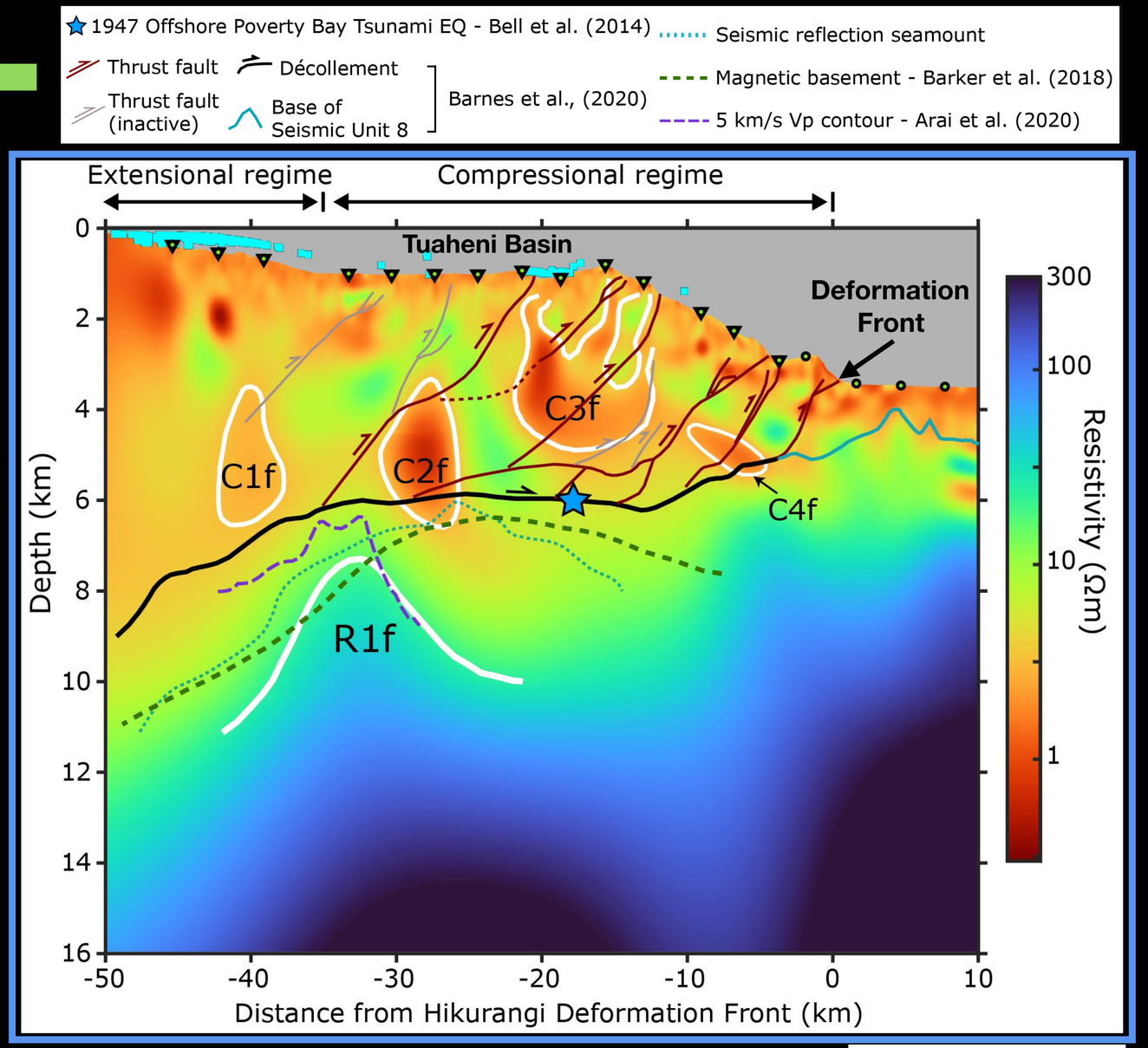

Chesley et al., 2021

Forearc Resistivity

- C1f —> Related to stress regime? Sediment underplating? Seamount damage zone?
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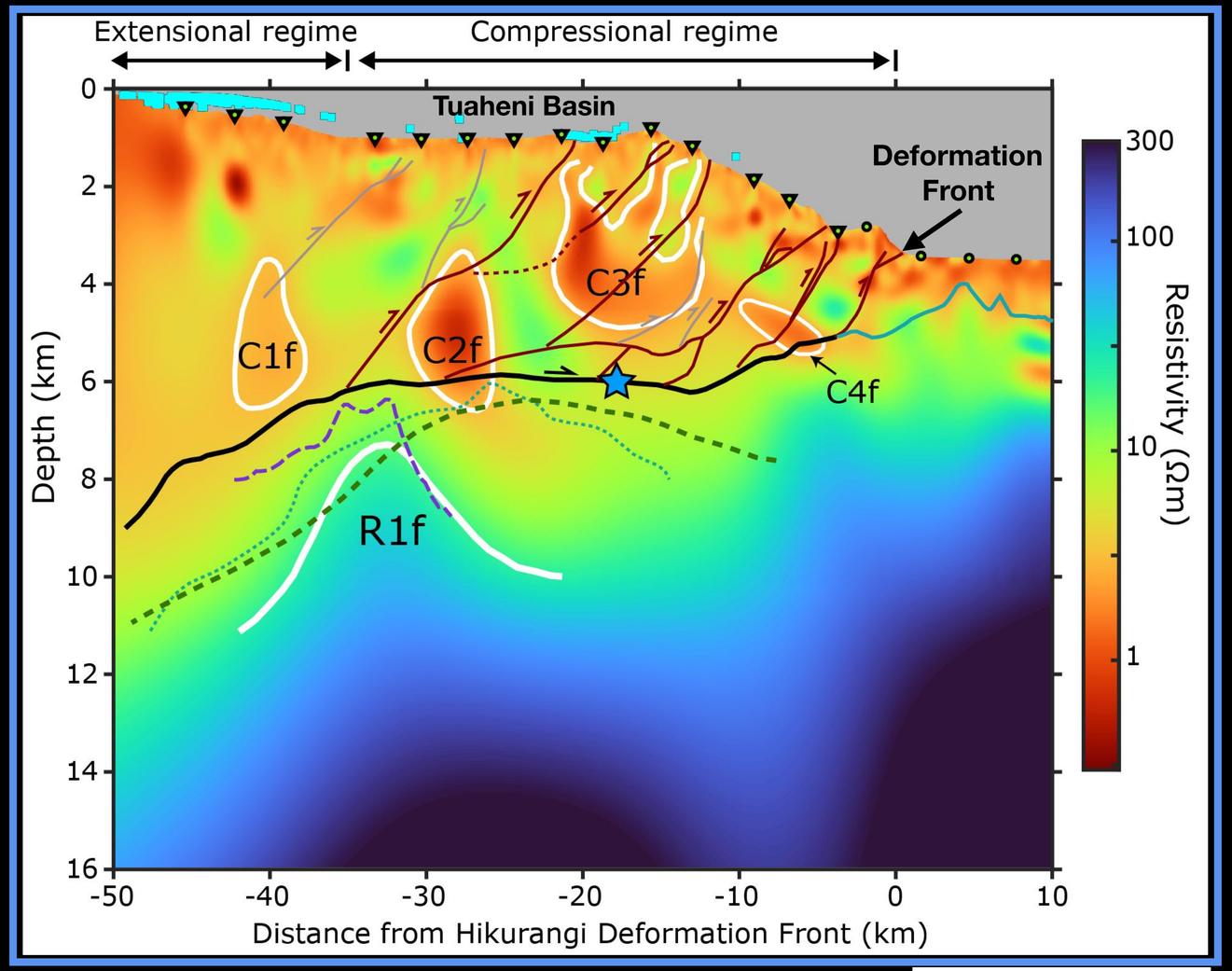

Chesley et al., 2021

RESIST

Forearc Resistivity

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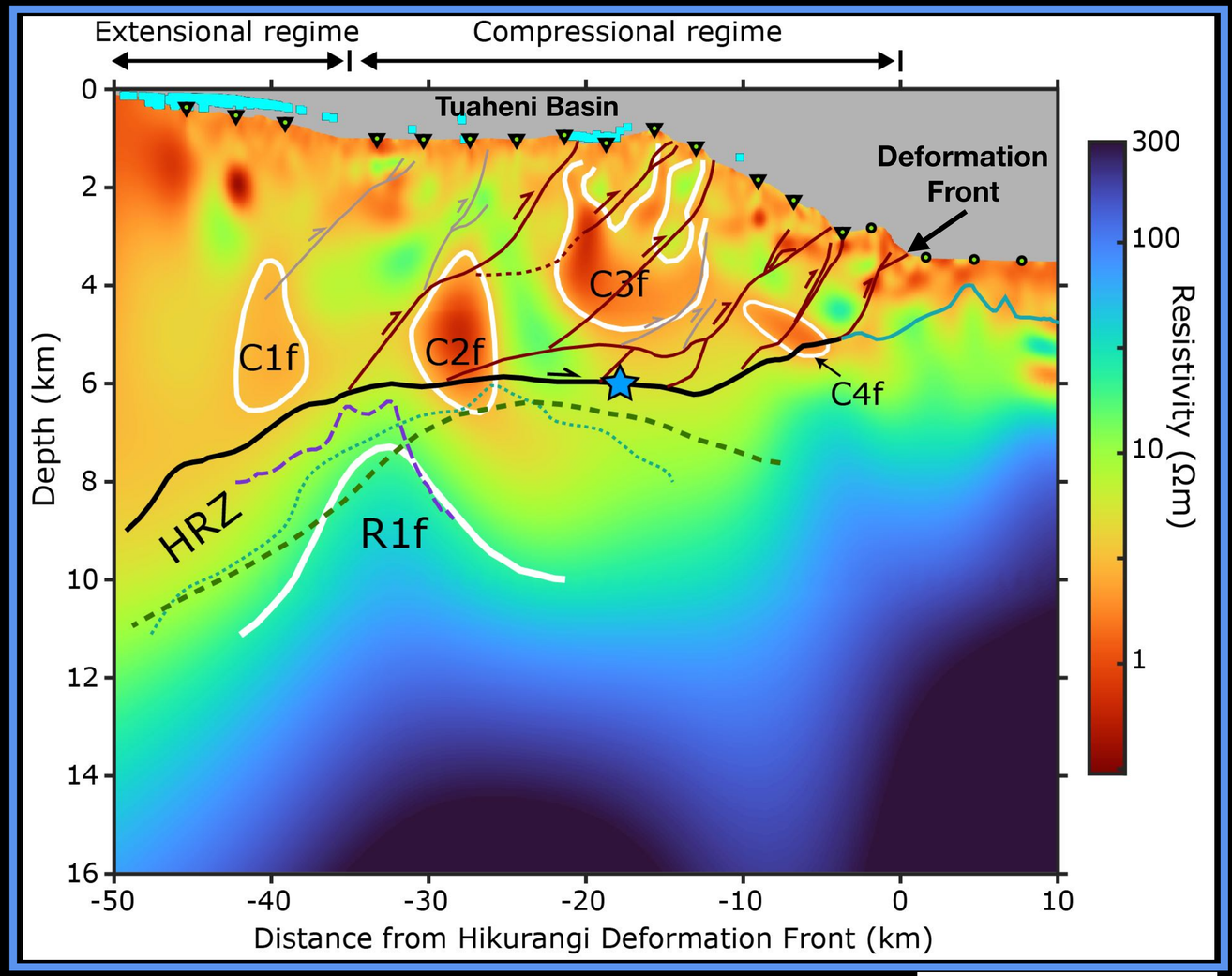
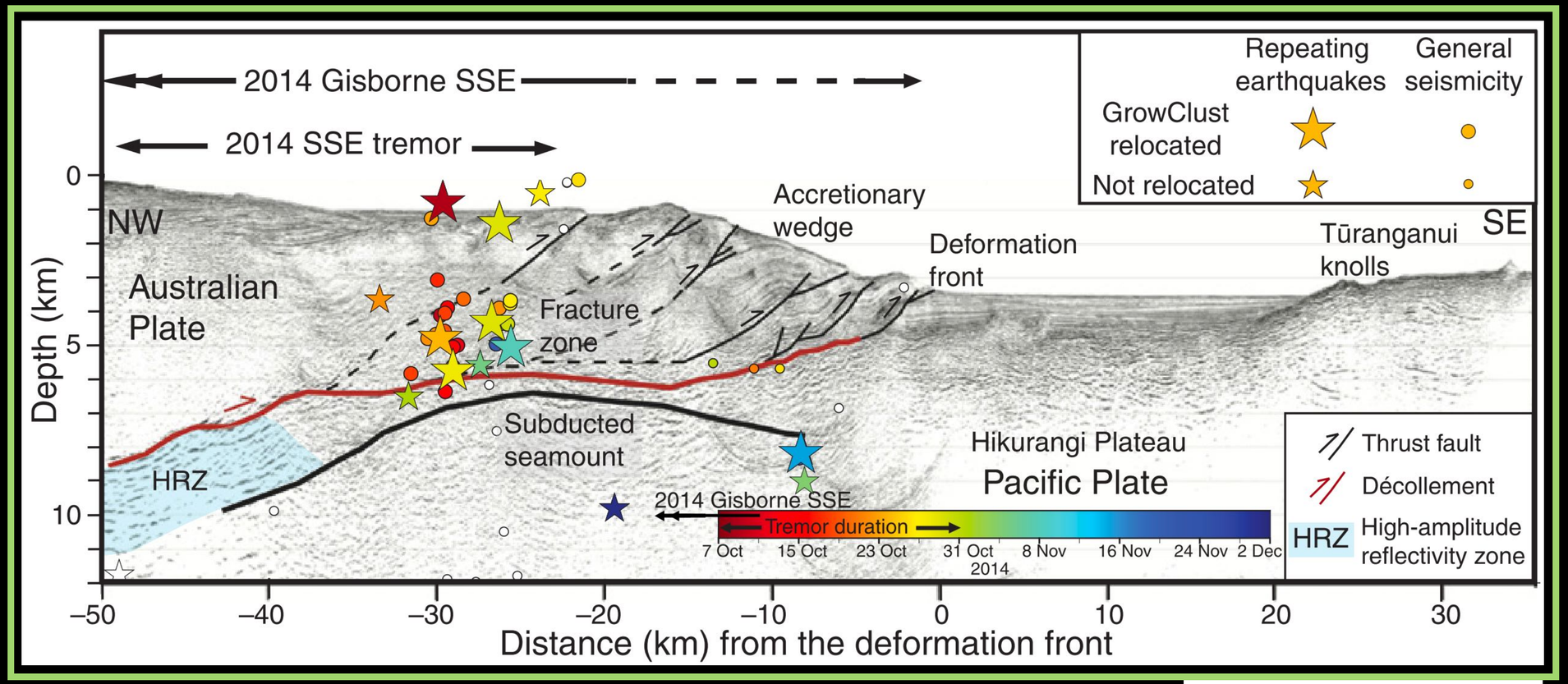


Chesley et al., 2021

RESIST

Burst-type Repeating EQs

- Associated w/aseismic slip or fluid migration



Shaddox & Schwartz, 2019

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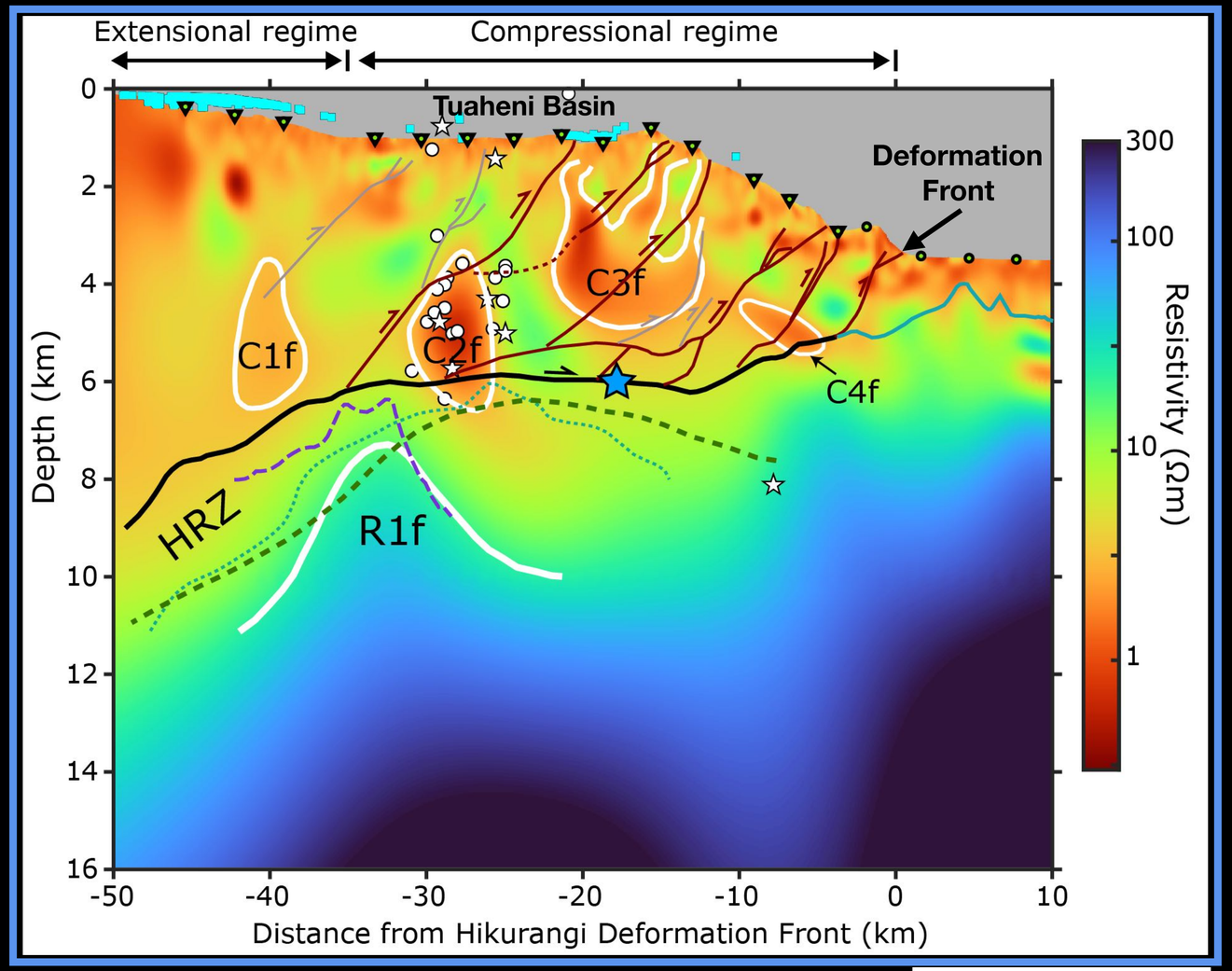
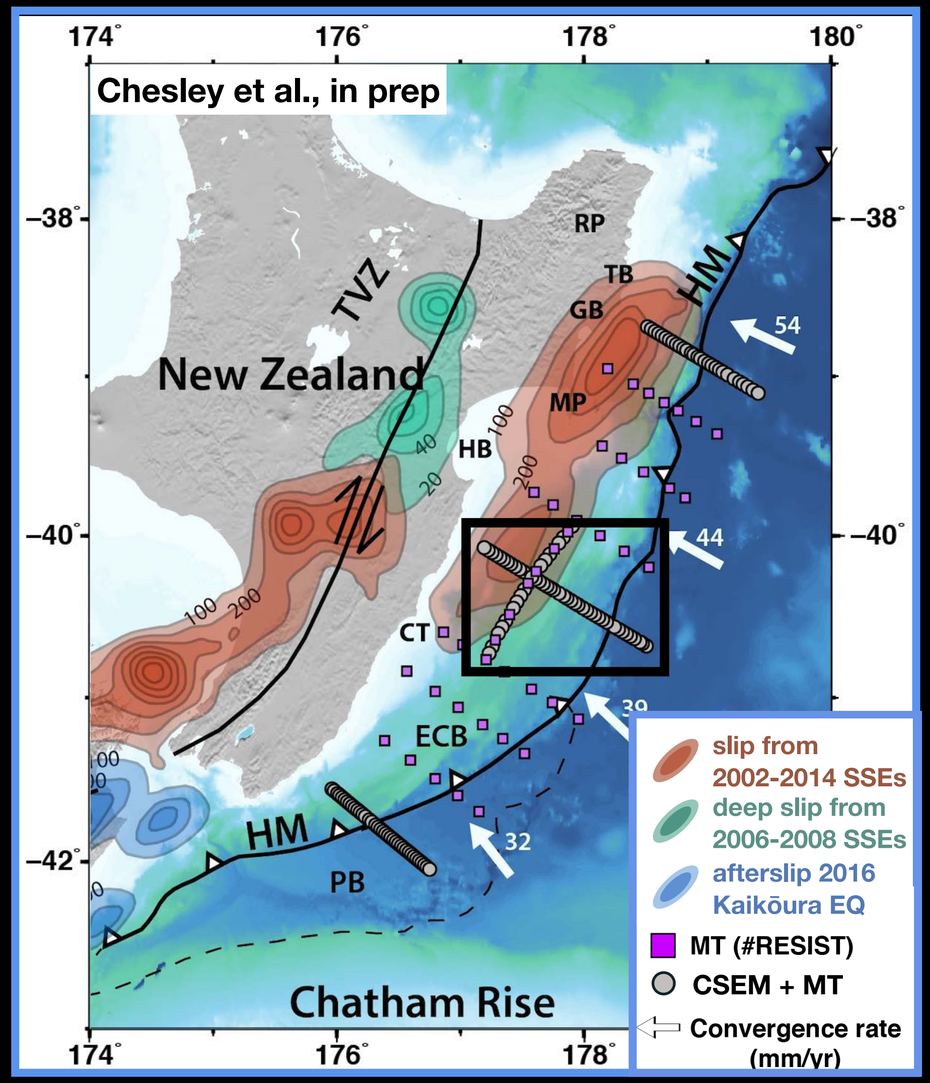
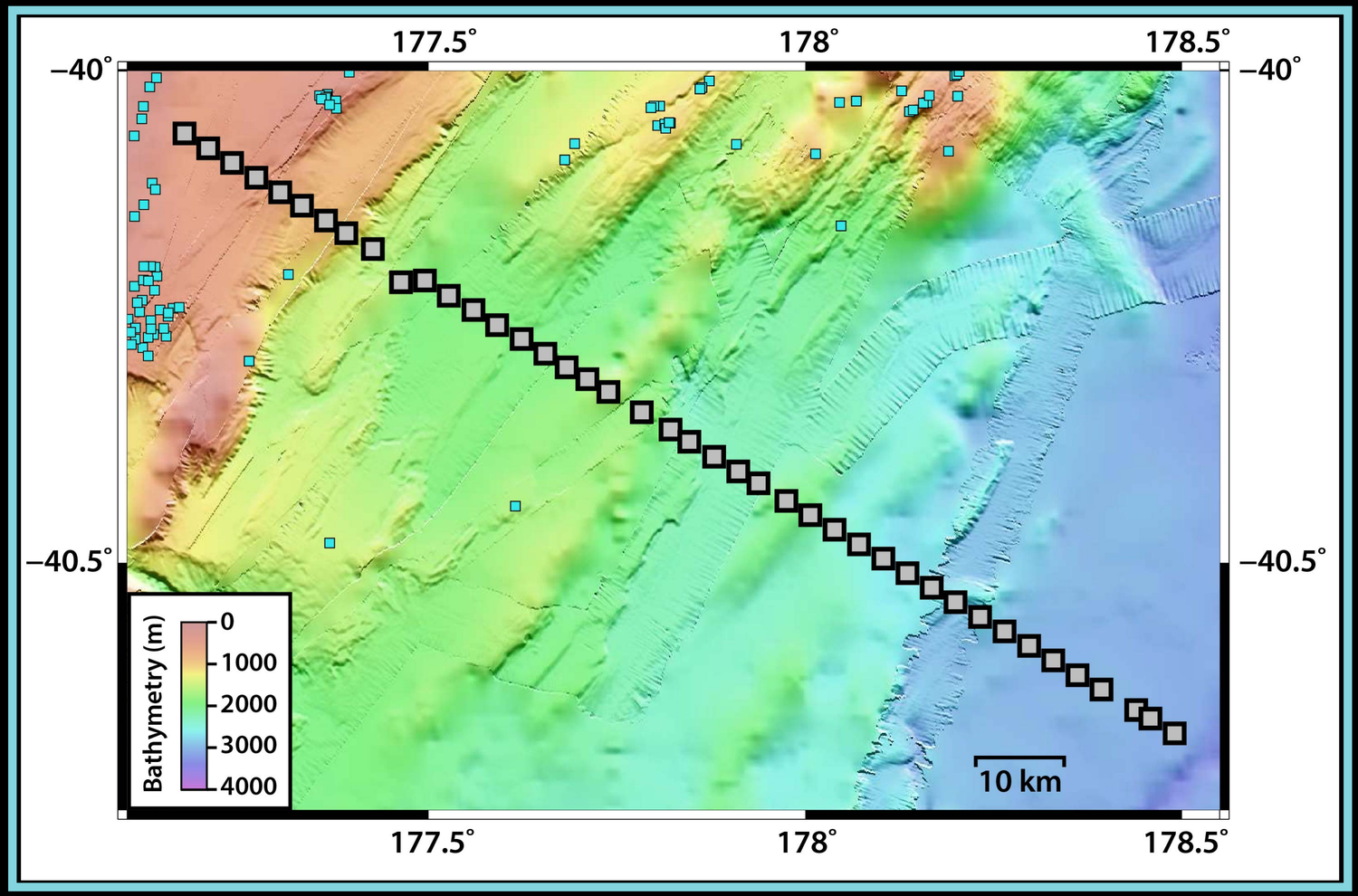


Chesley et al., 2021

Resistivity of the Central Hikurangi Margin





RESIST

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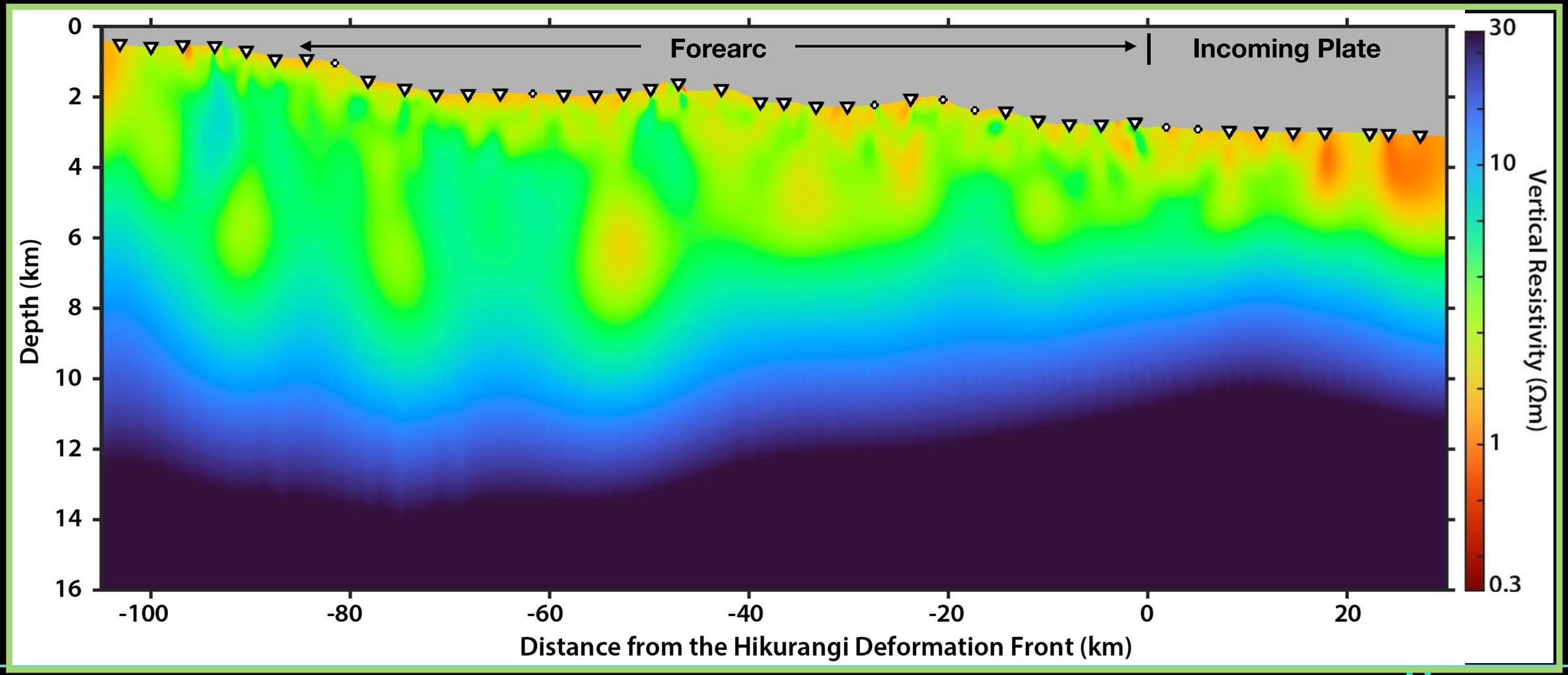
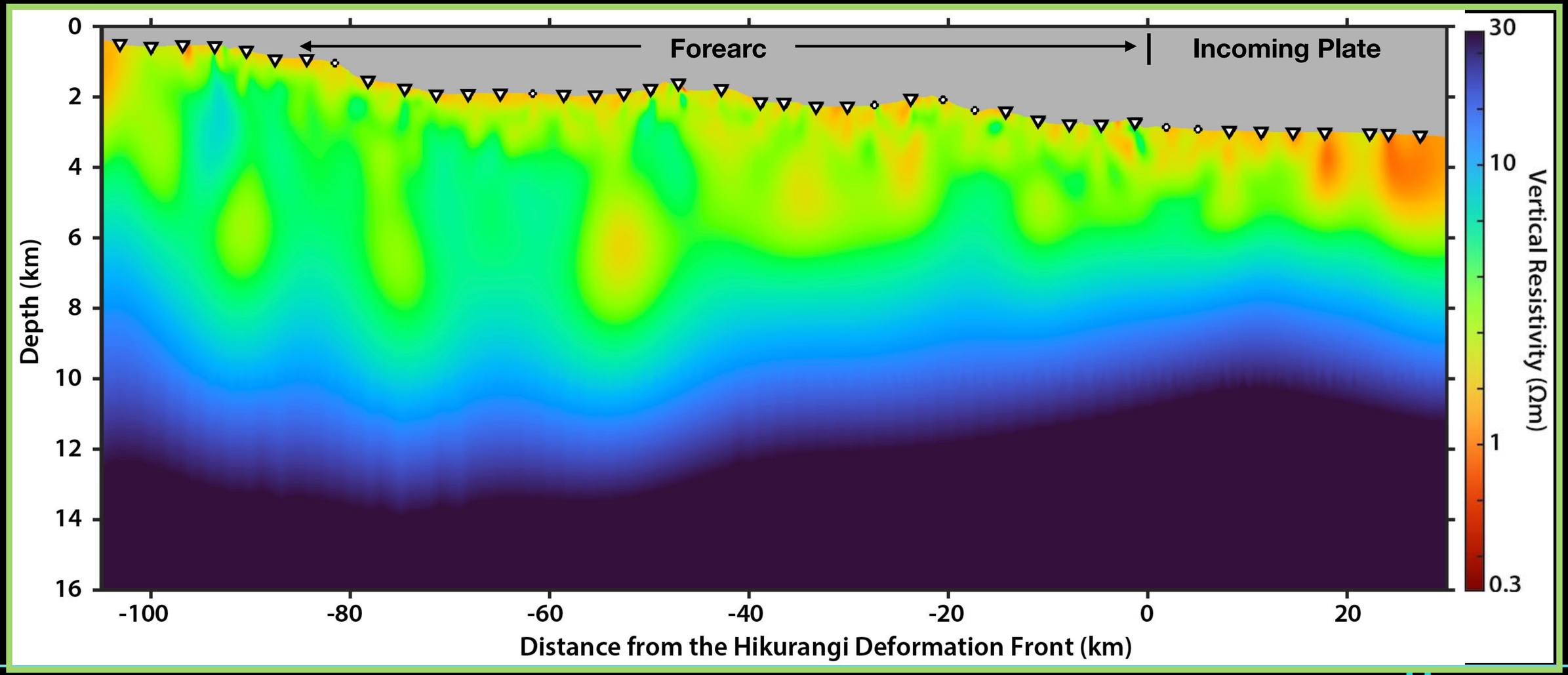


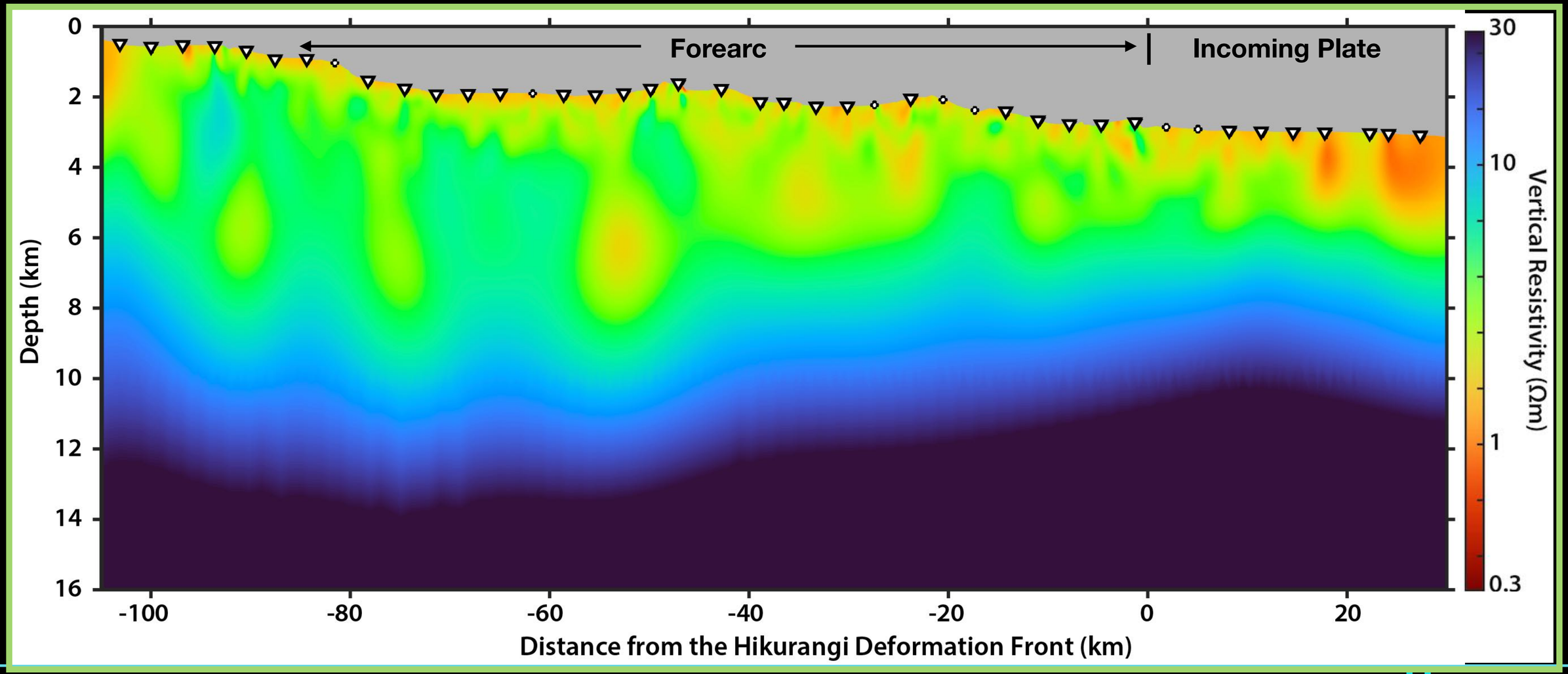
Resistivity of the Central Hikurangi Margin

- Compared to the north…



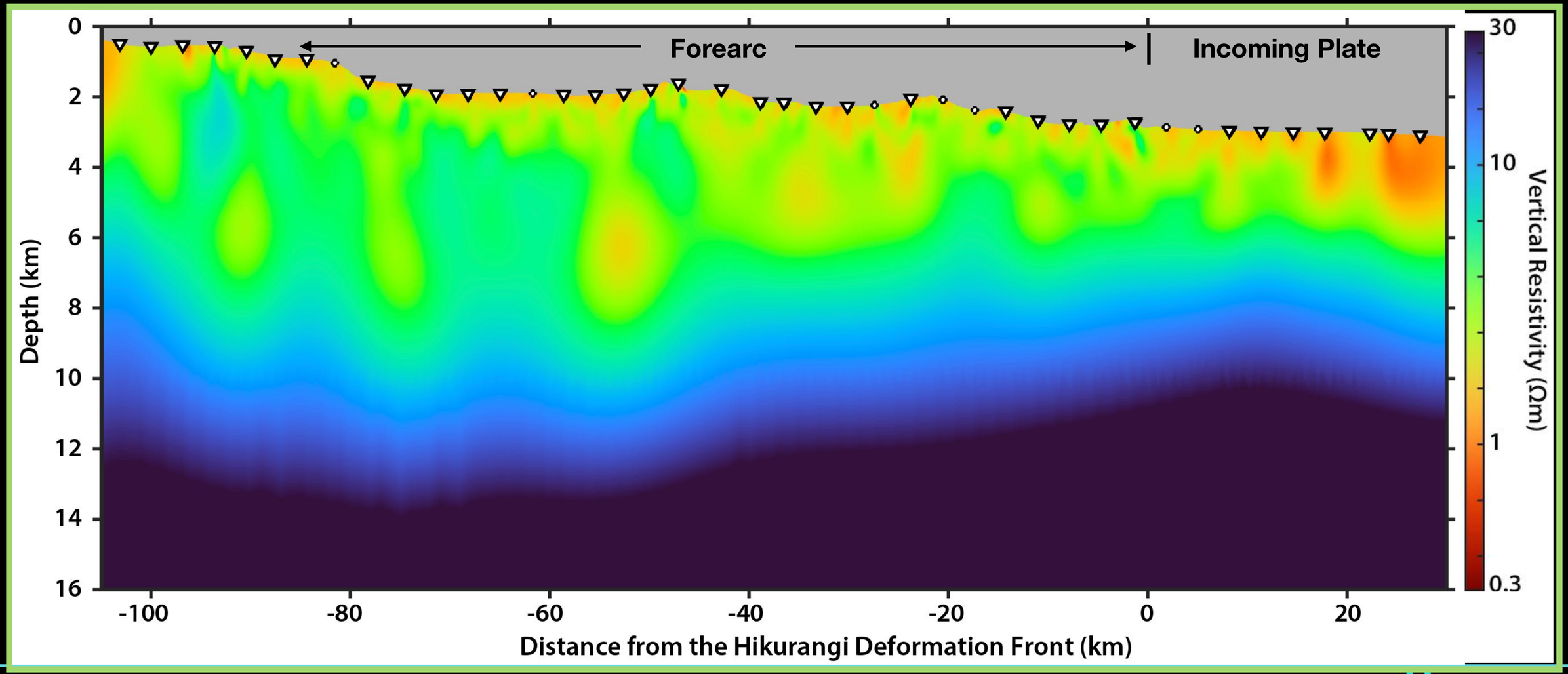
Resistivity of the Central Hikurangi Margin

- Compared to the north…
- Simpler incoming plate and forearc structure



Resistivity of the Central Hikurangi Margin

- Compared to the north…
- Simpler incoming plate and forearc structure
- No evidence of *large* seamounts



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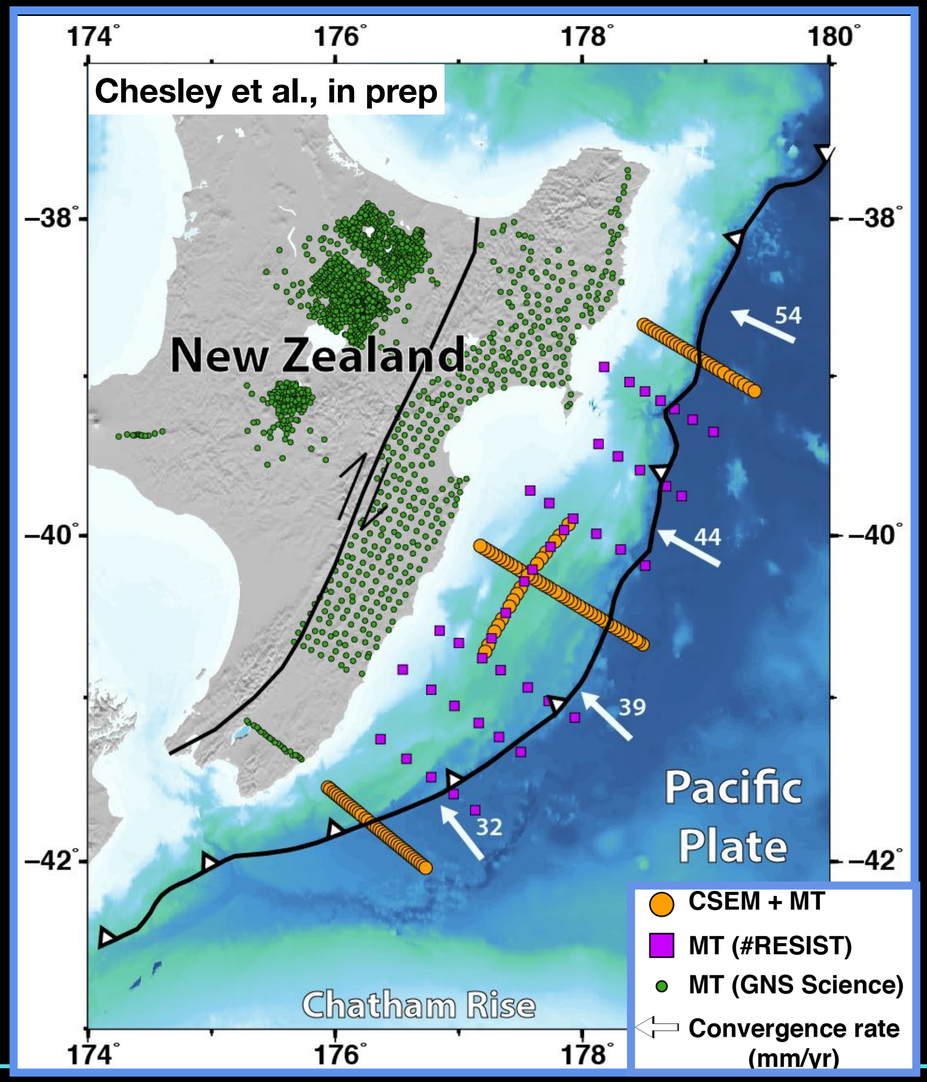

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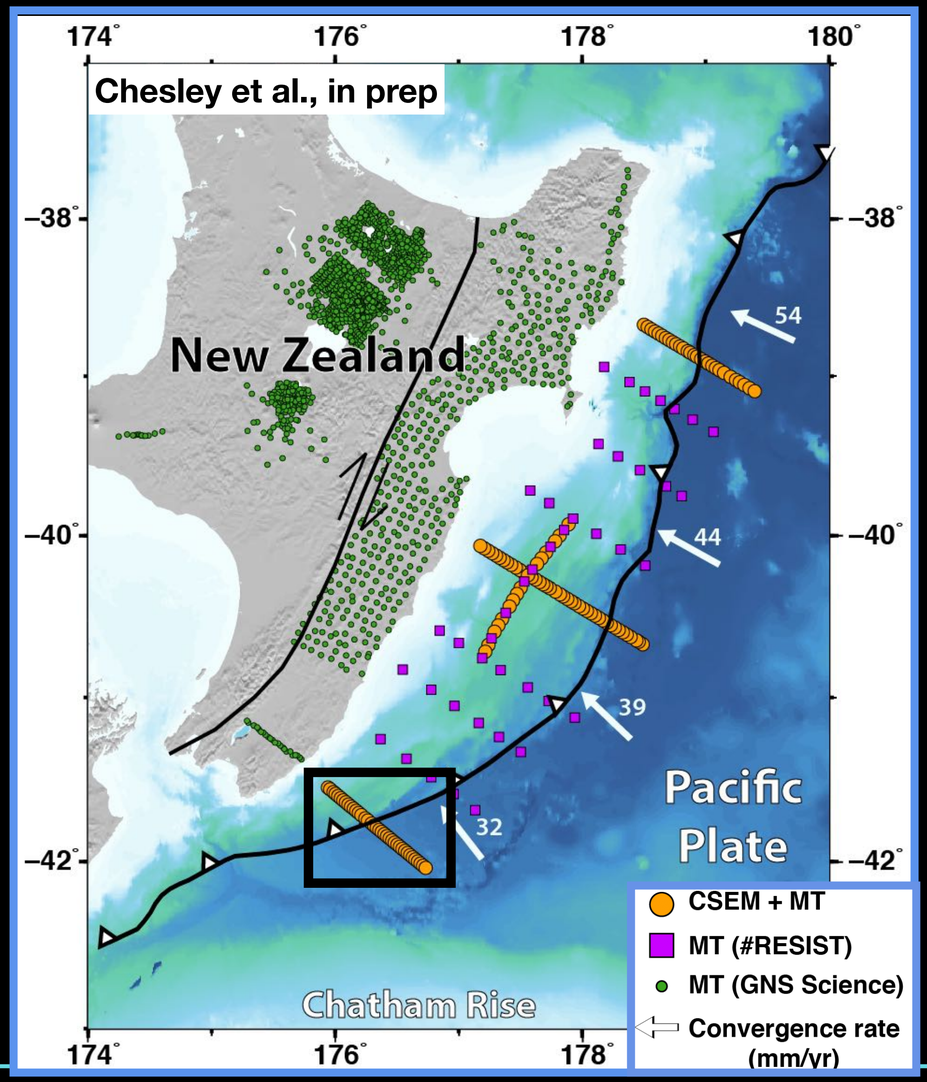
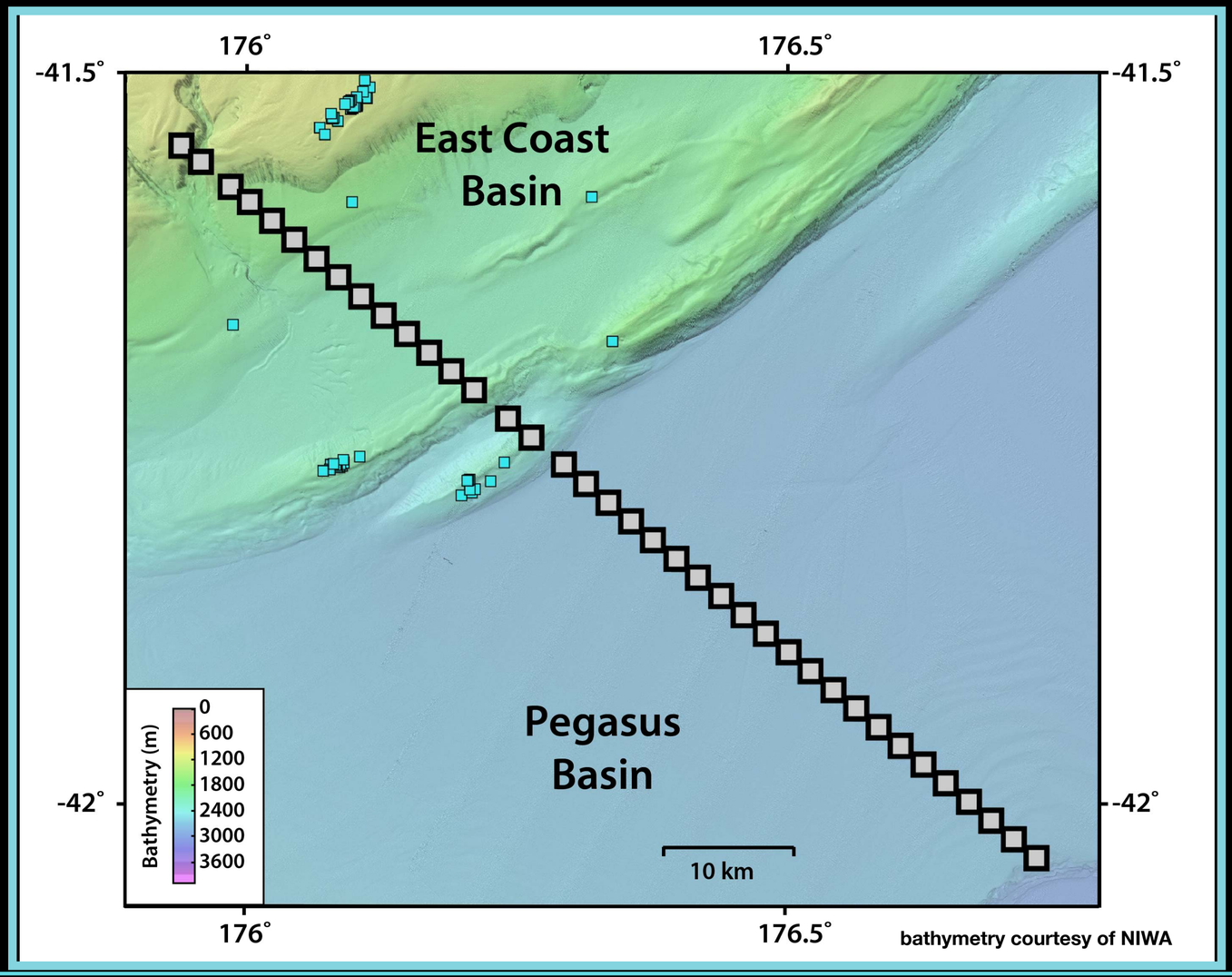
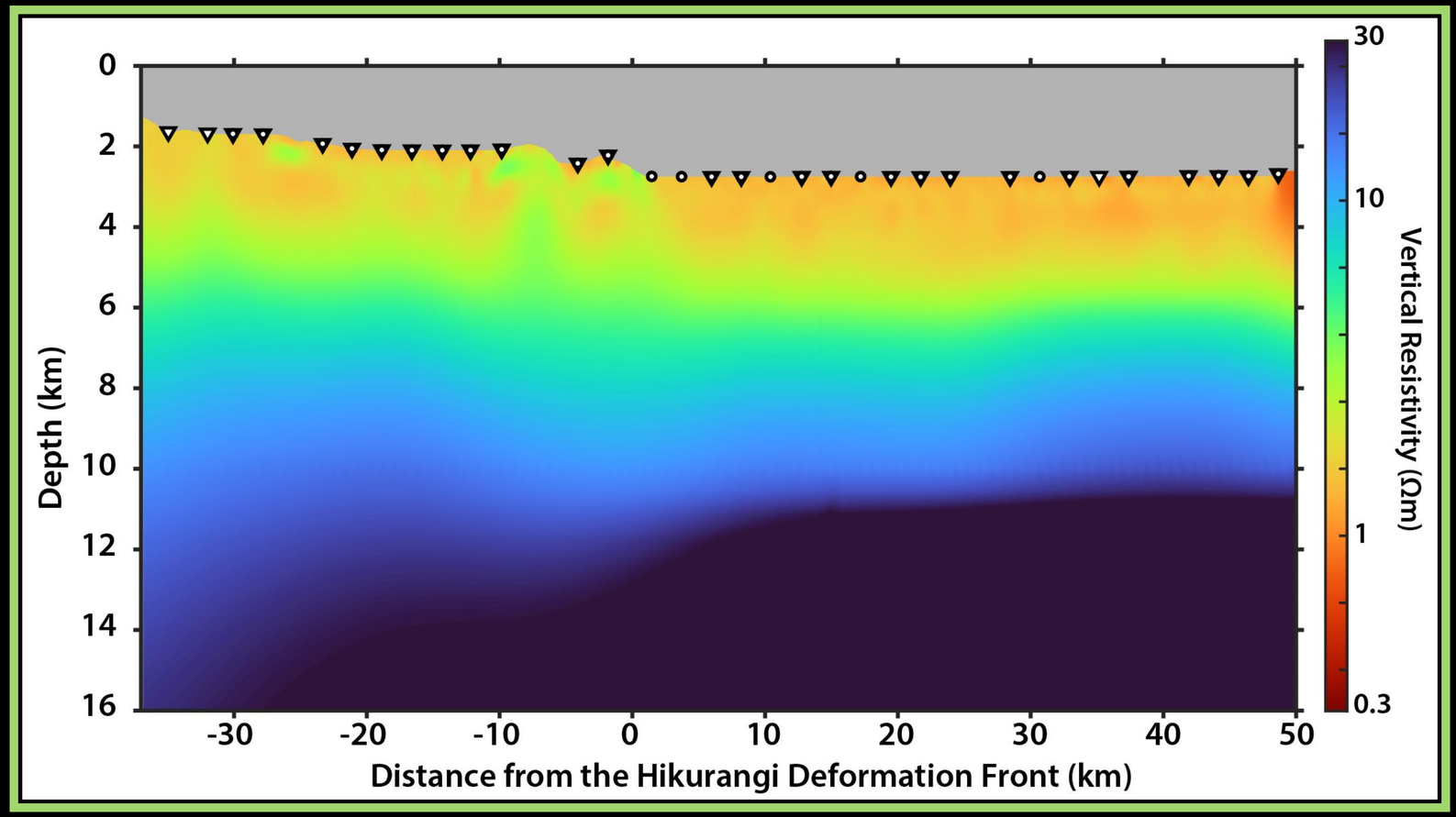




RESIST

Resistivity of the Southern Hikurangi Margin

- Compared to northern and central…
  - Much thicker sediments on incoming plate



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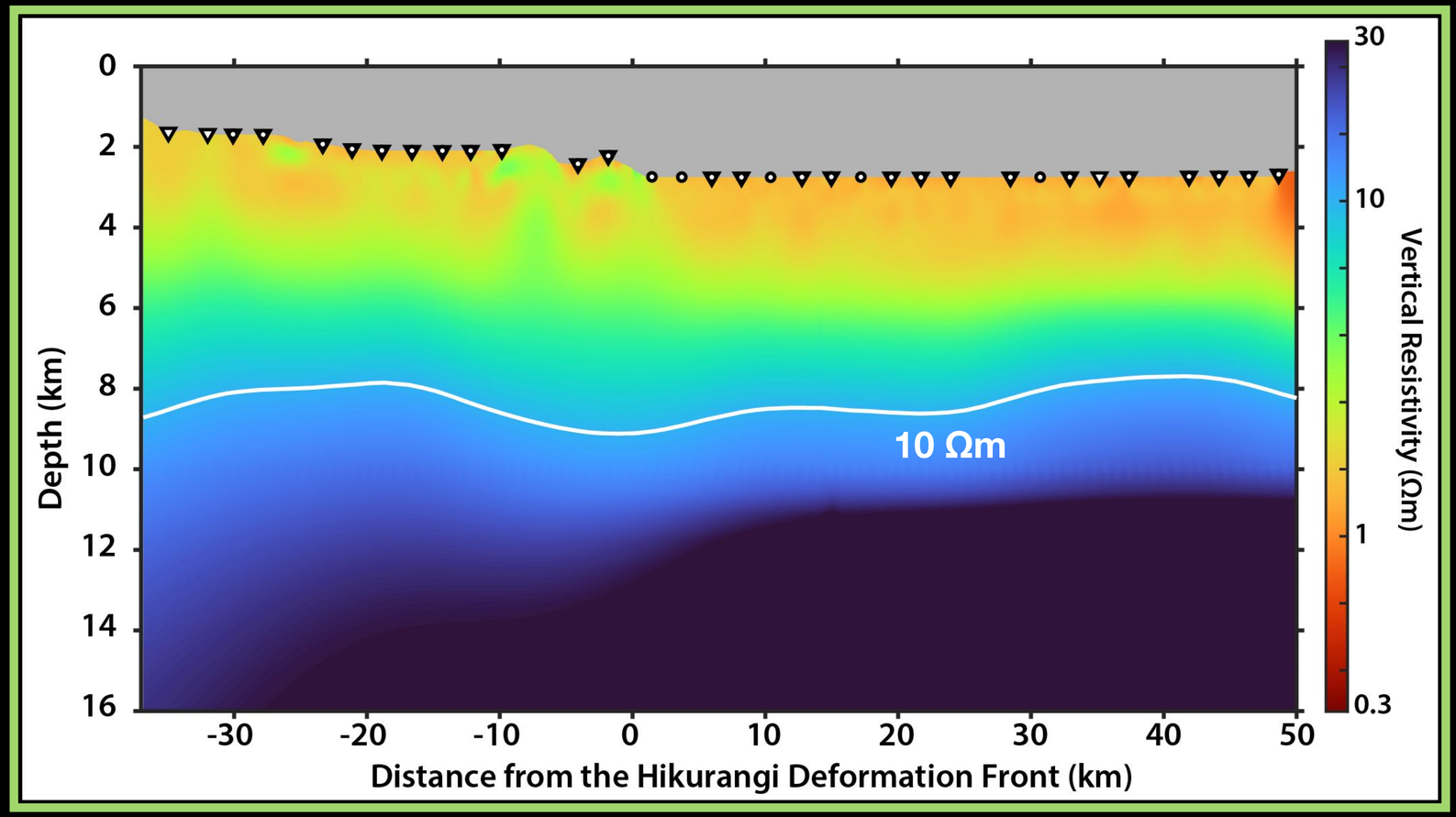

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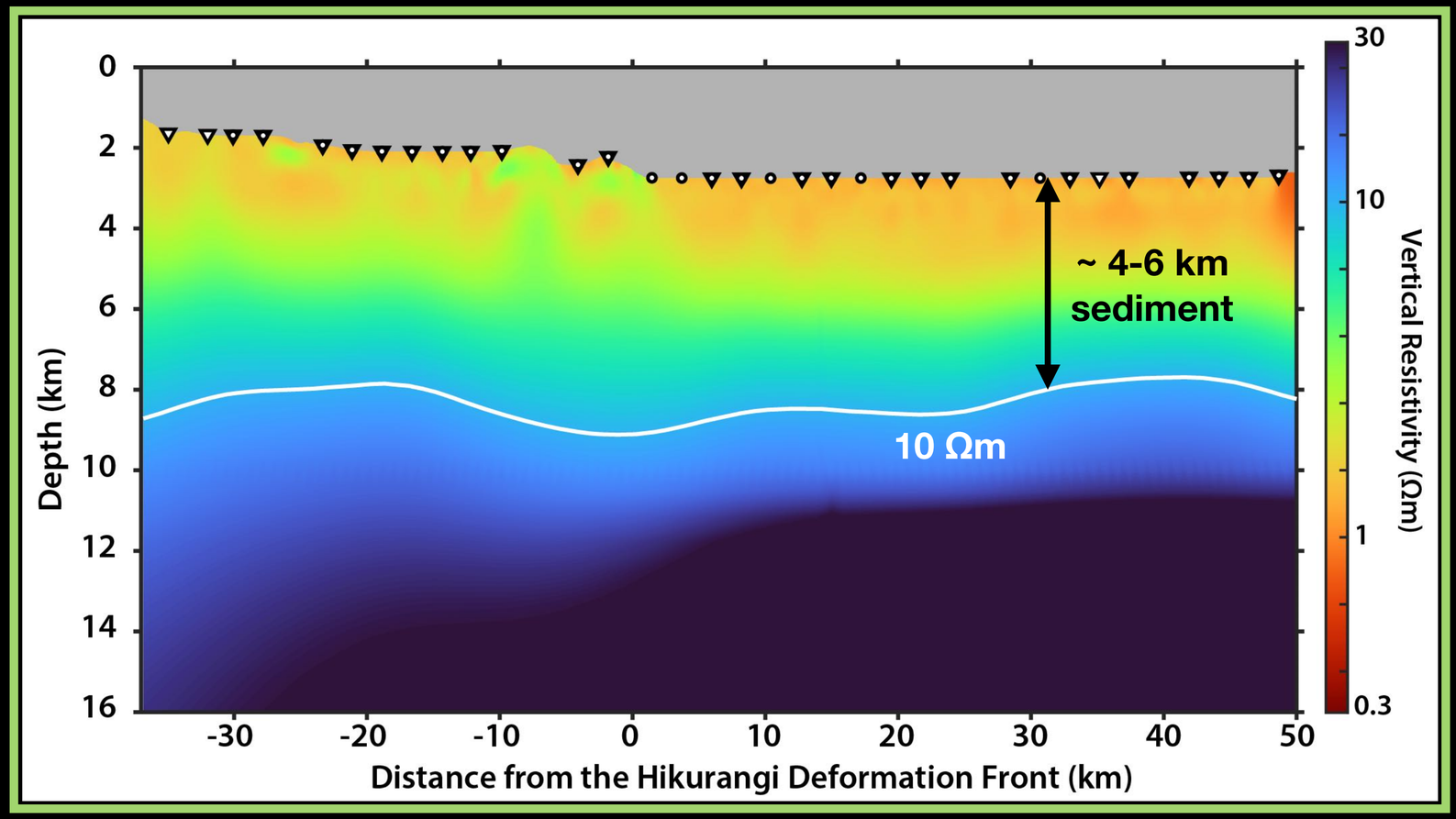

Resistivity of the Southern Hikurangi Margin

- Compared to northern and central…
  - Much thicker sediments on incoming plate
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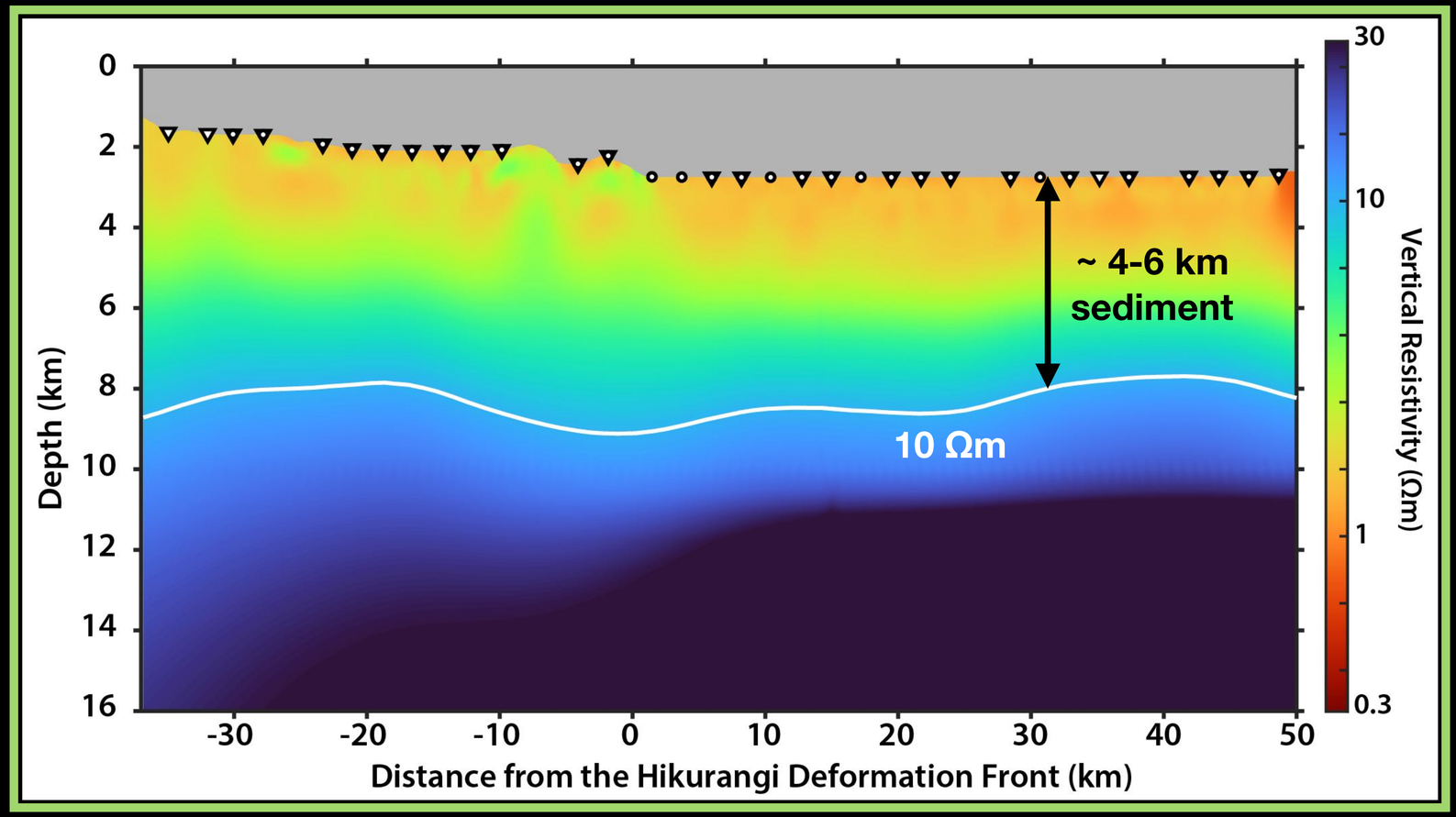
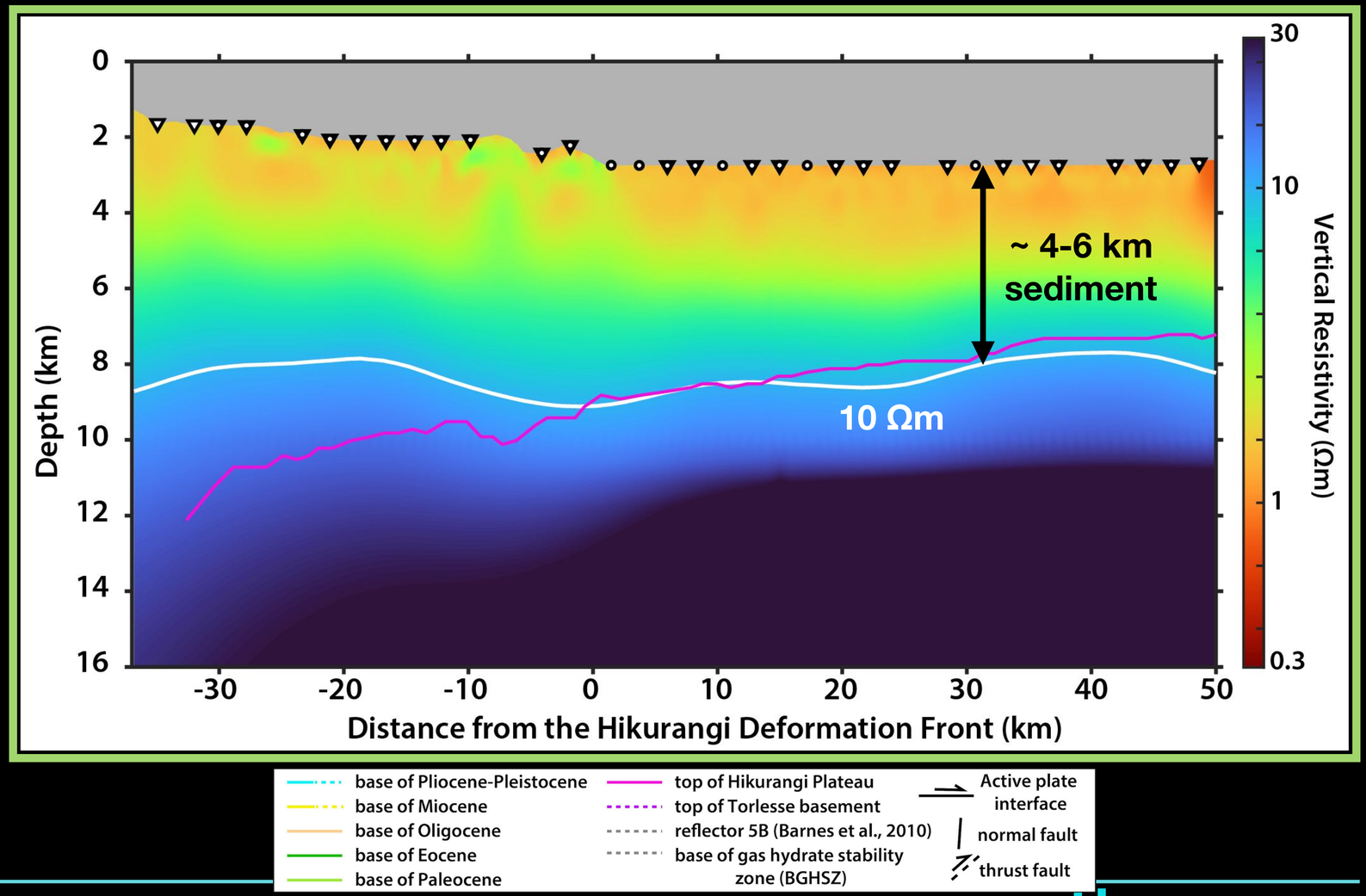


Comparisons with seismically interpreted boundaries

Bland et al., 2015 & Mochizuki et al., 2019

- 10 Ωm contour on incoming plate in agreement w/seismic top of Hikurangi Plateau



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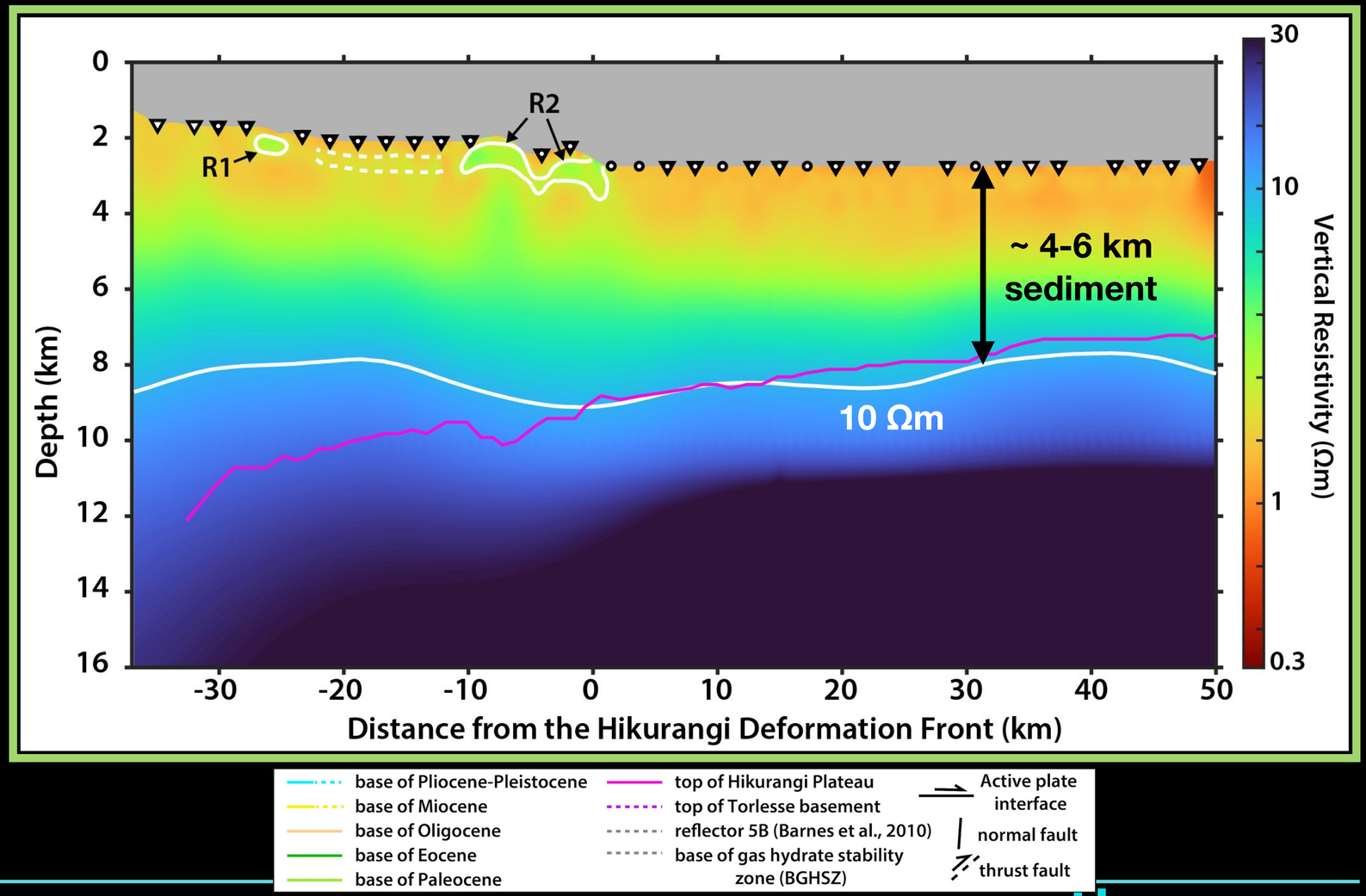

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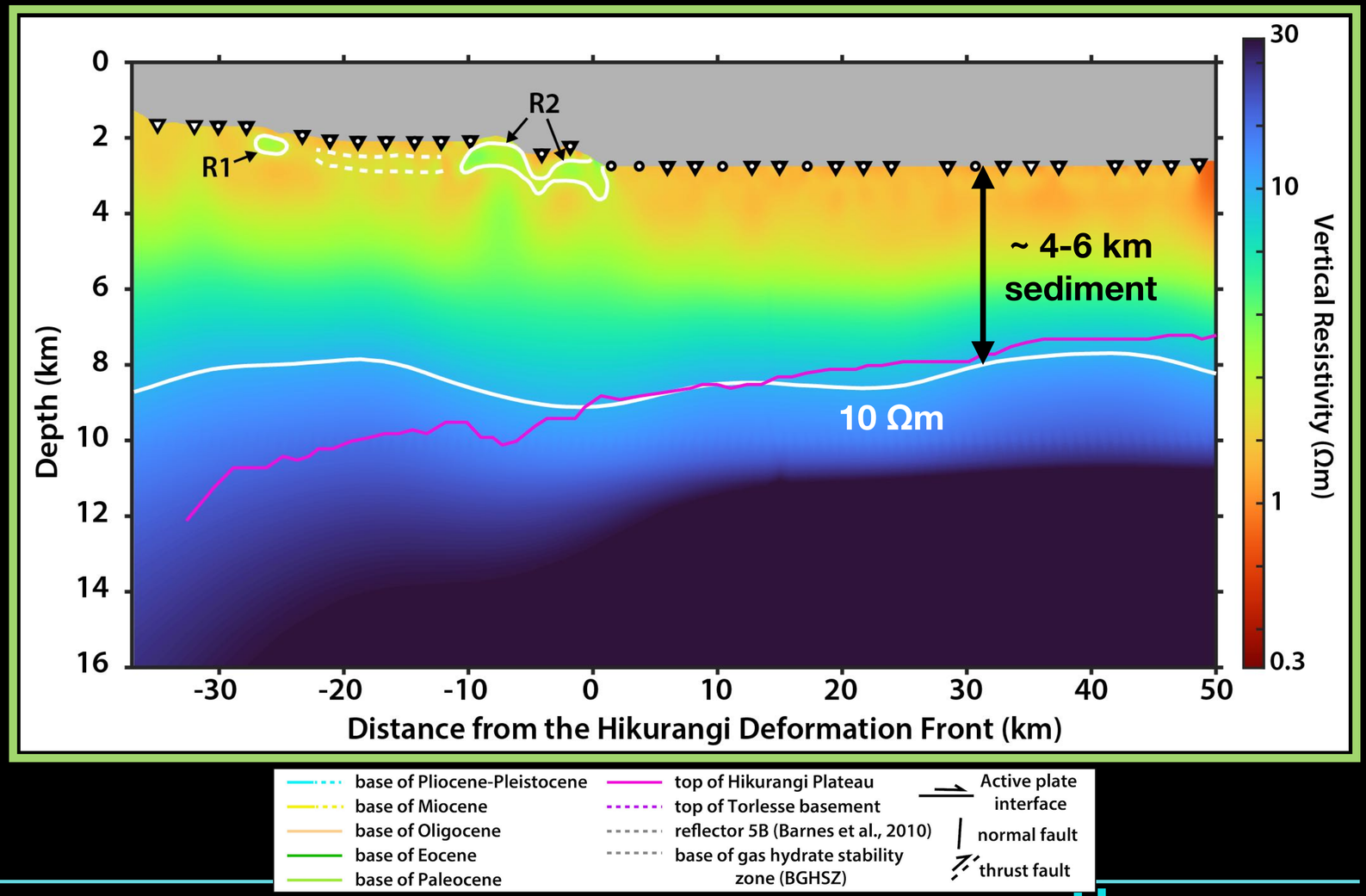

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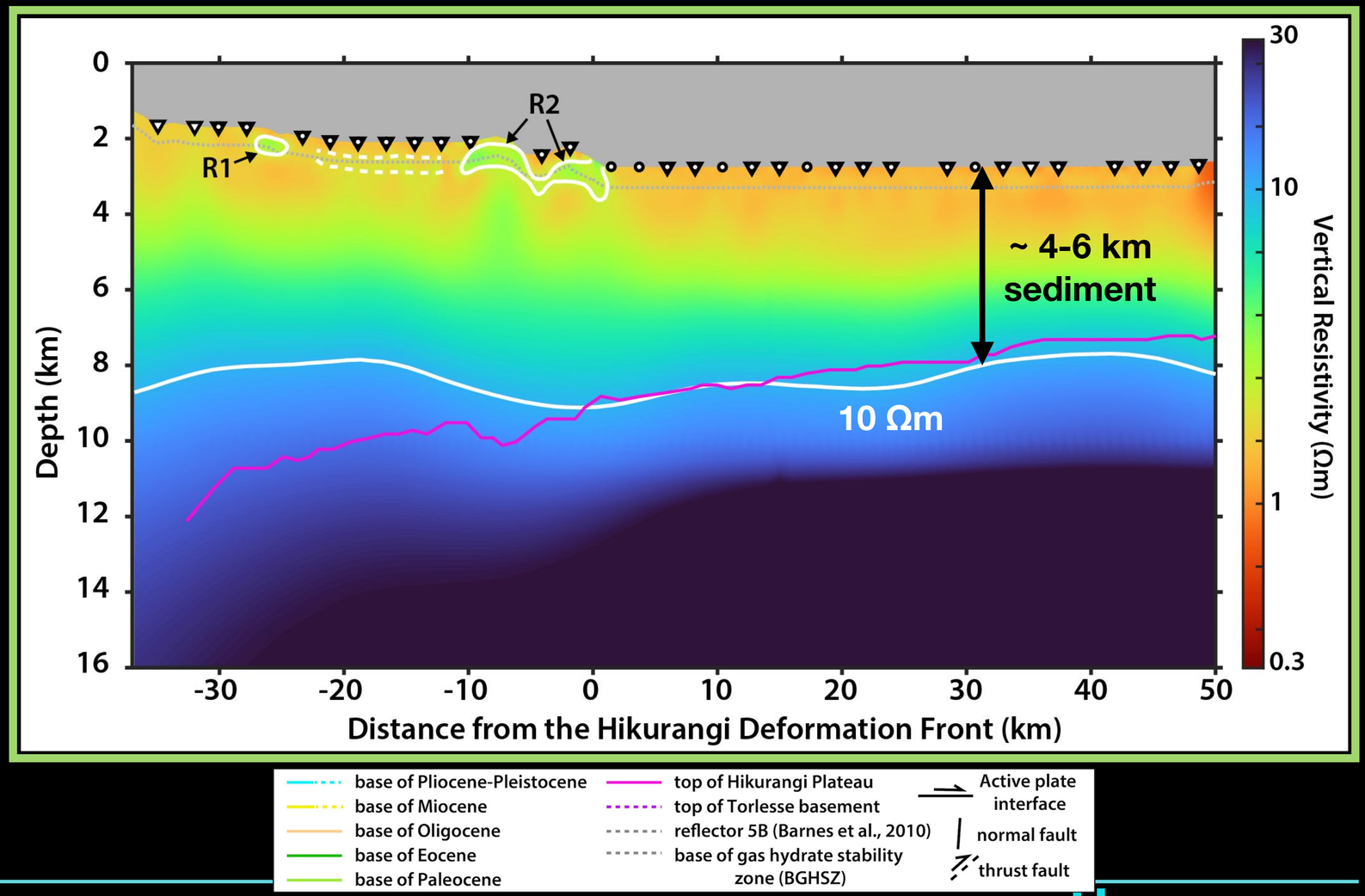
- R1 and R2 occur above base of GHSZ



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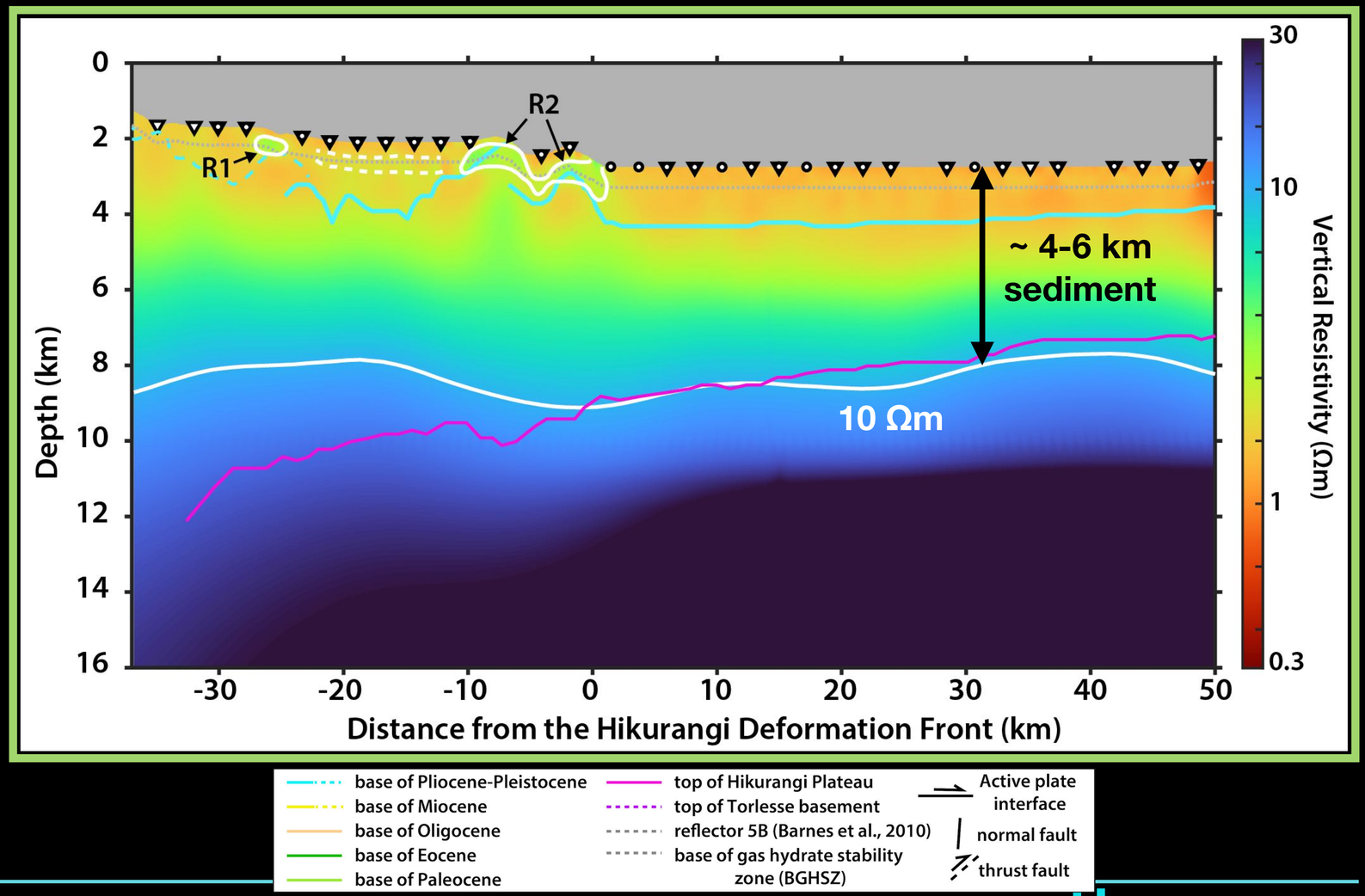
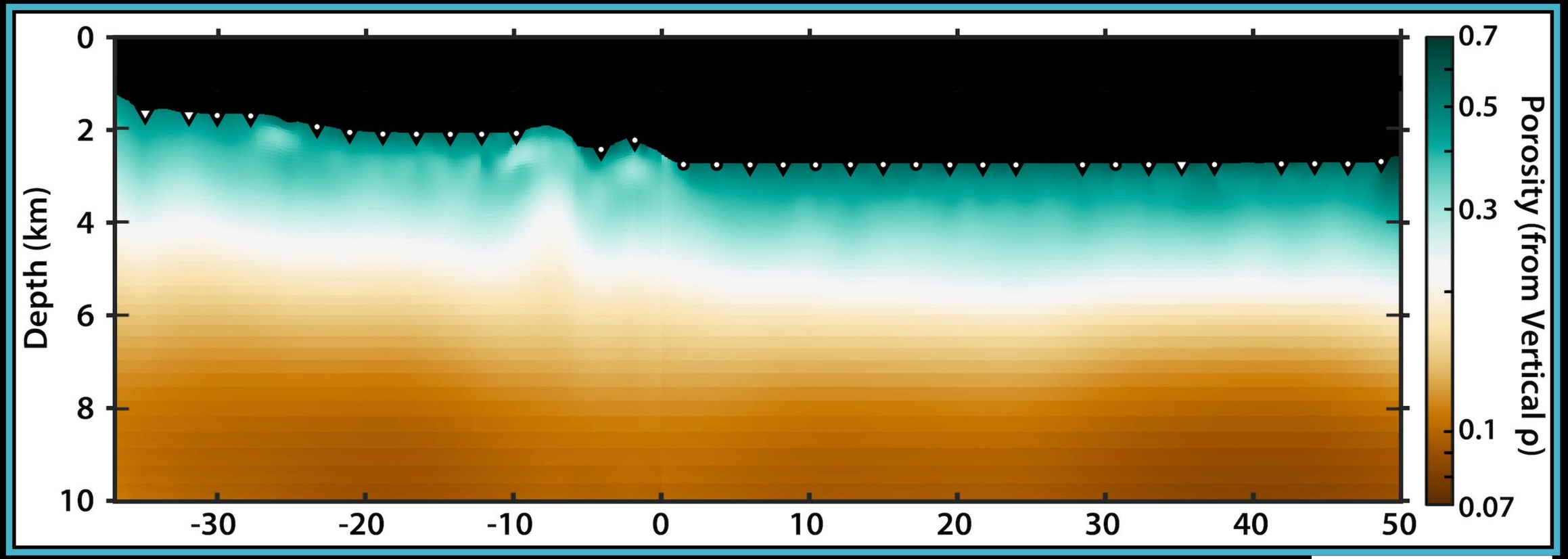
- R1 and R2 occur above base of GHSZ
  - Concentrate at ridges/ paleo-ridges



Resistivity-Derived Porosity



Chesley et al., in prep

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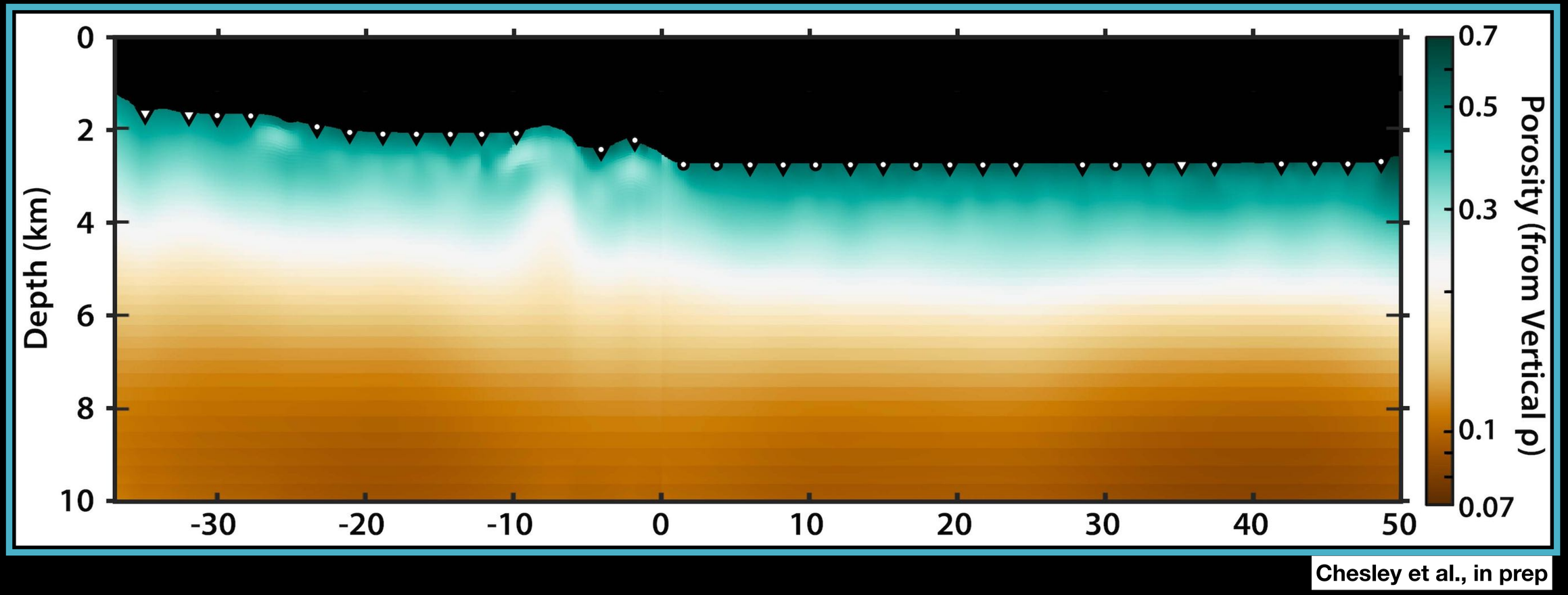

Chesley et al., in prep

- First-order trend: Porosity decreases with depth

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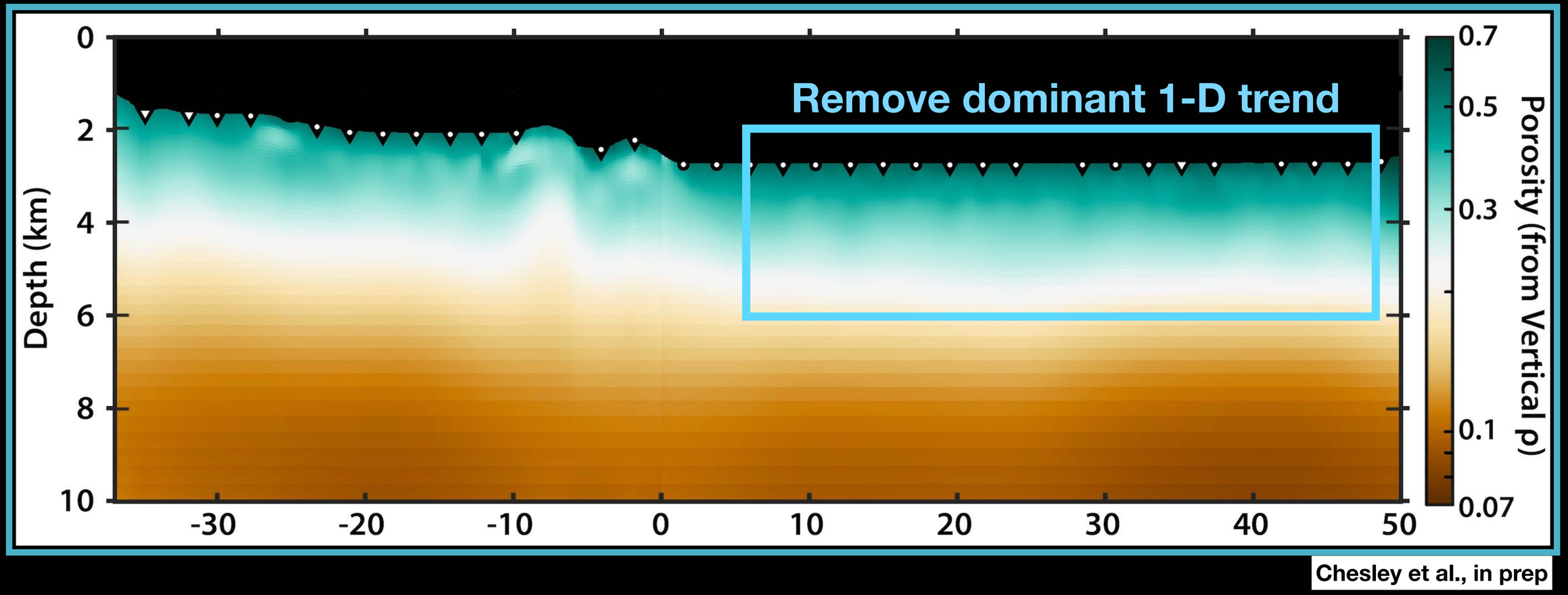
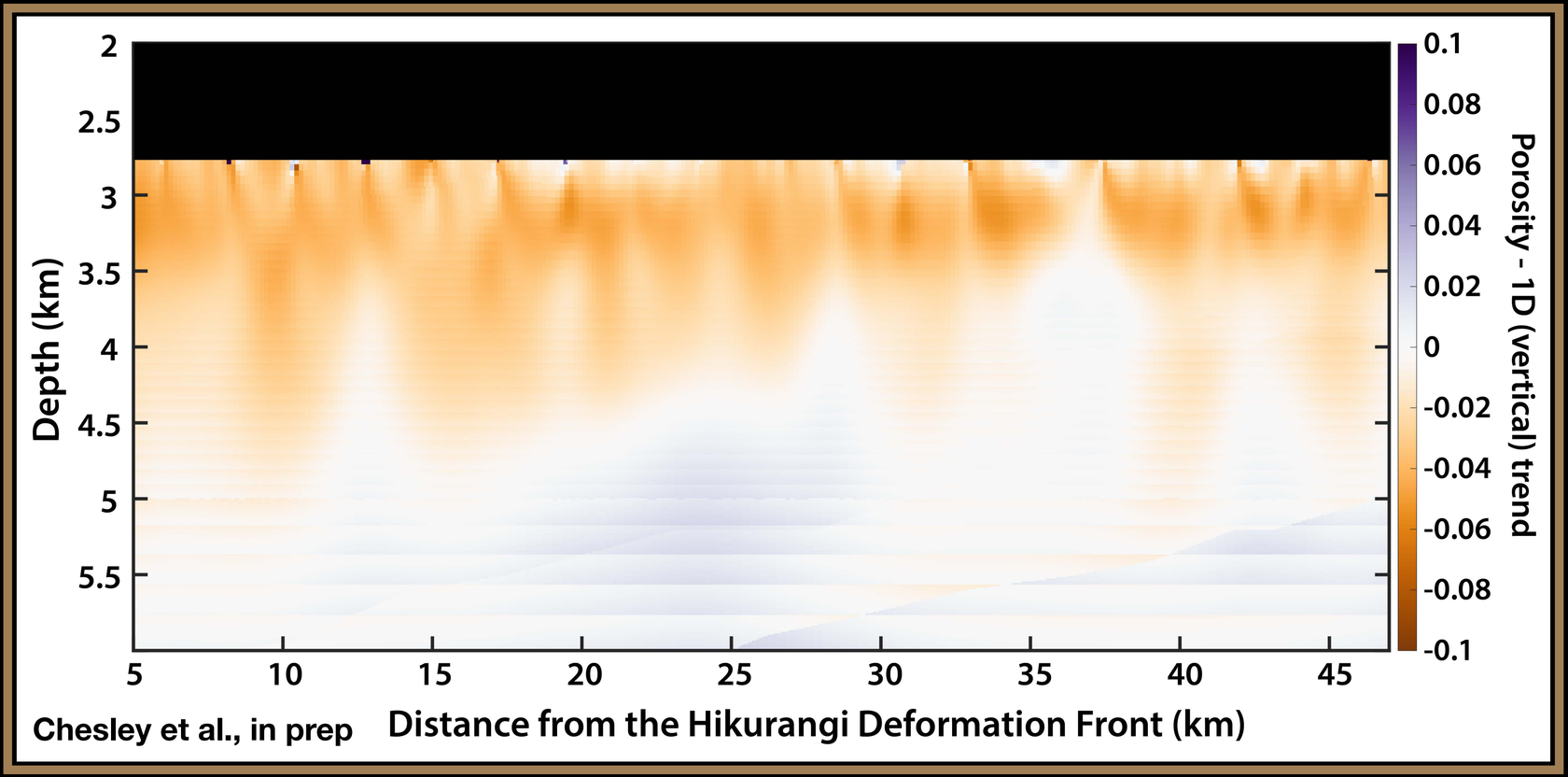


- First-order trend: Porosity decreases with depth

Porosity Anomaly



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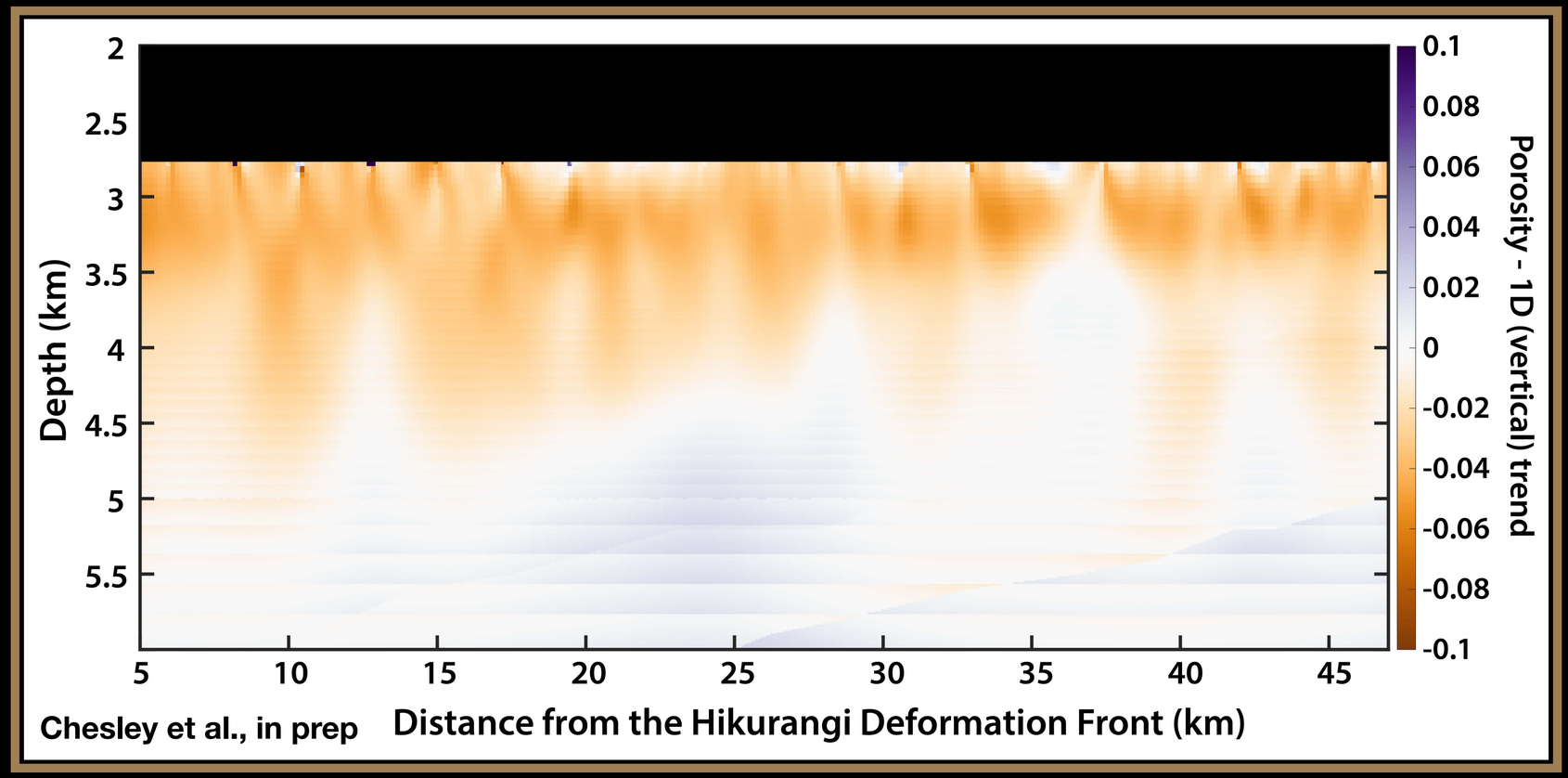
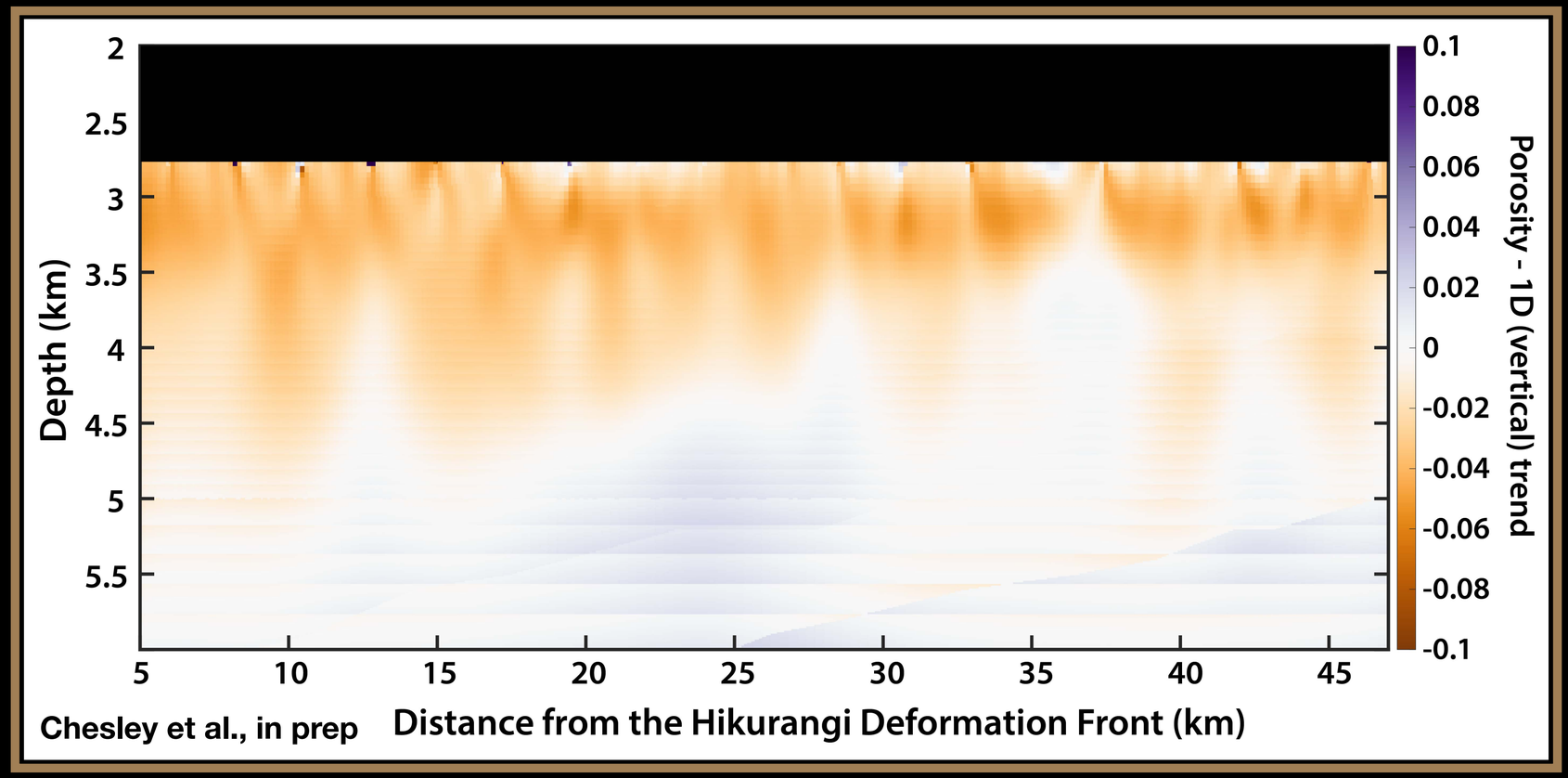


More porous than vert. compaction would predict

Porosity Anomaly



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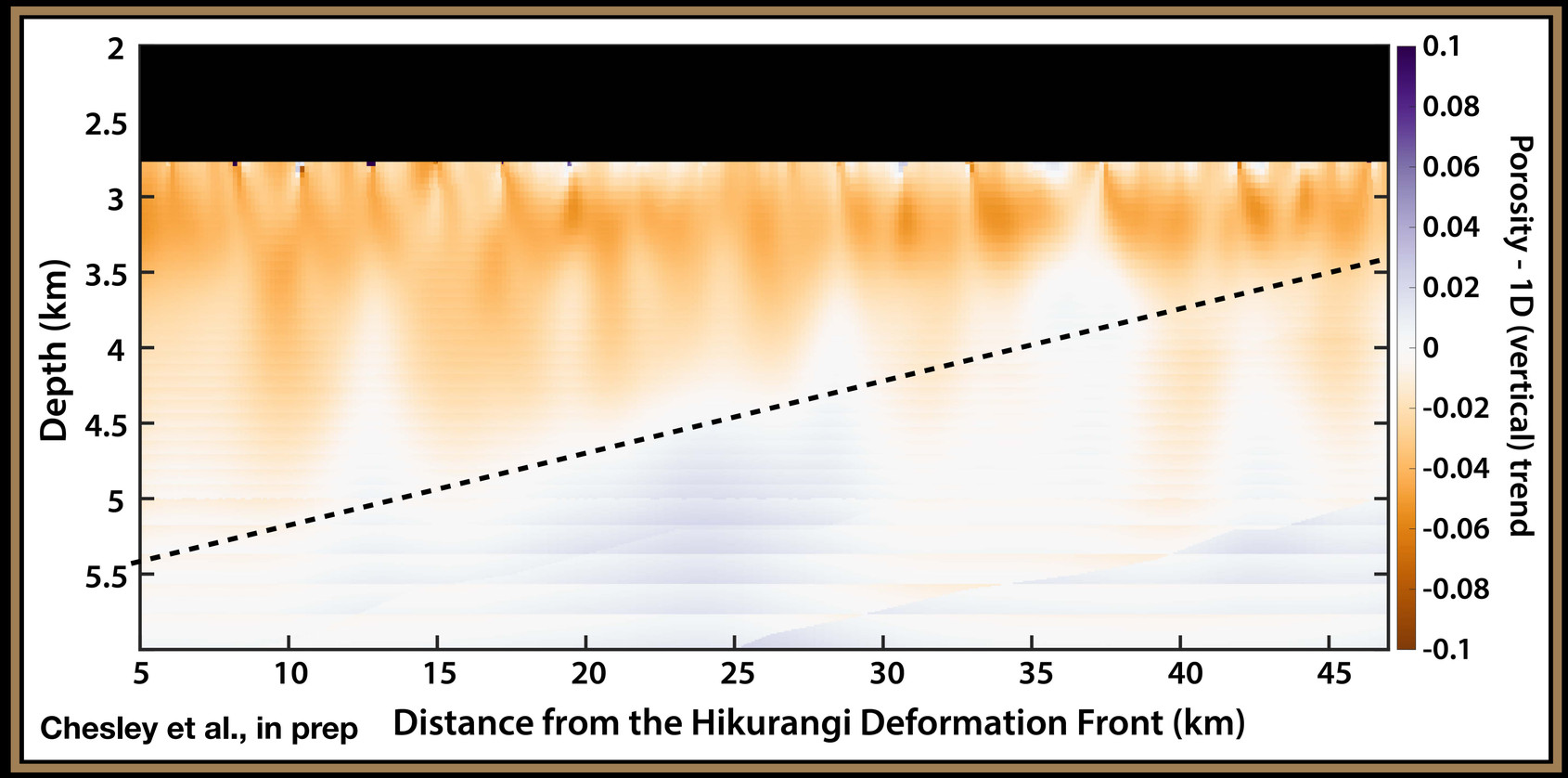
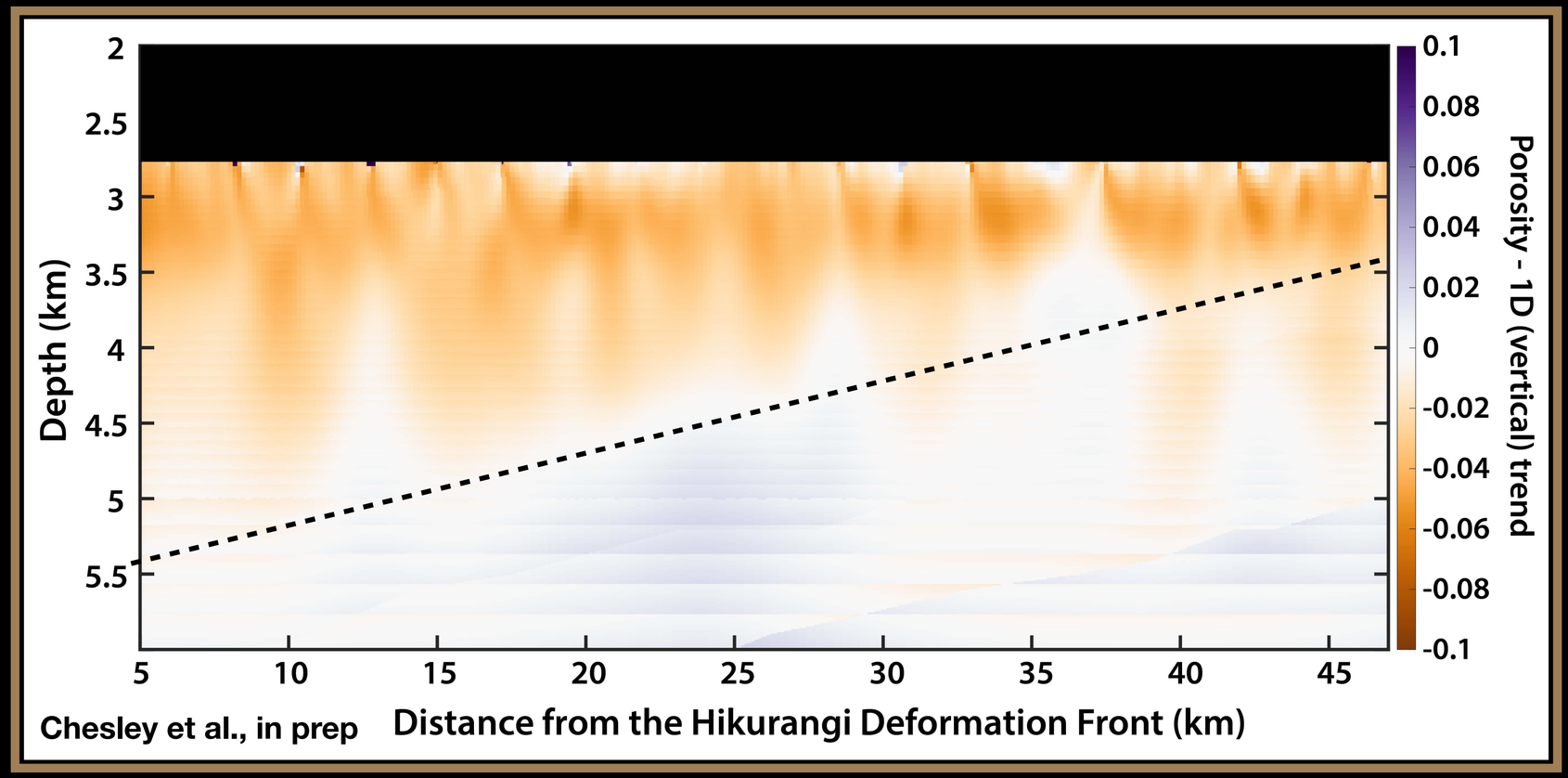


- Negative porosity anomaly deepens as seds approach trench

Porosity Anomaly

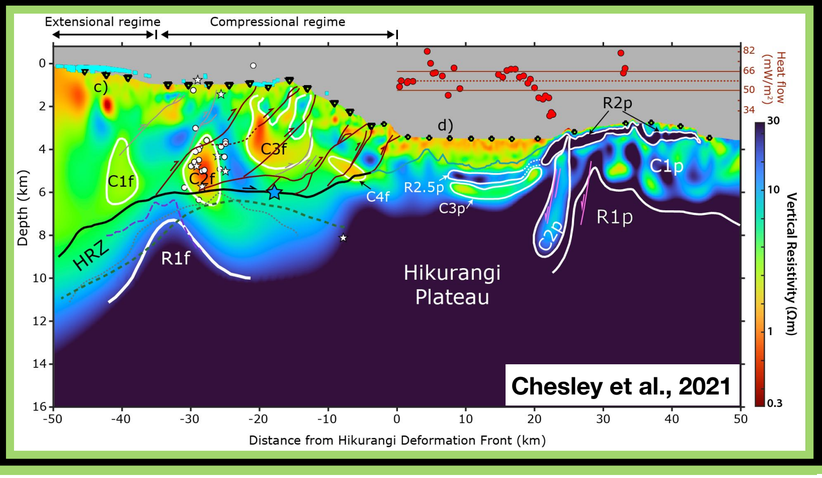


- Negative porosity anomaly deepens as seds approach trench
- Early stages of protothrust zone

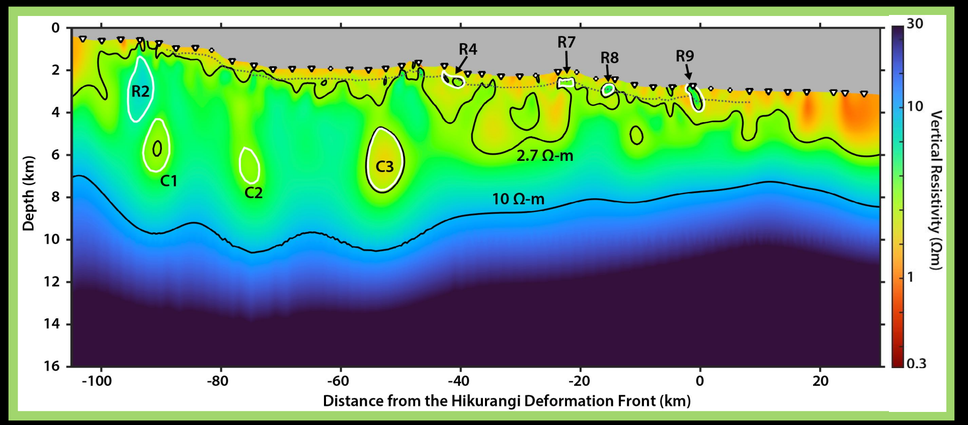
Conclusions

- First EM image of subducting topography
- Seamounts carry an underappreciated volume of H_2O to SZs
- Heterogeneity of resistivity along Hikurangi Margin likely related to seamount exposure
- Subducting seamounts/rough seafloor seems to be linked to shallow SSEs
- EM is a powerful tool for studying SZs

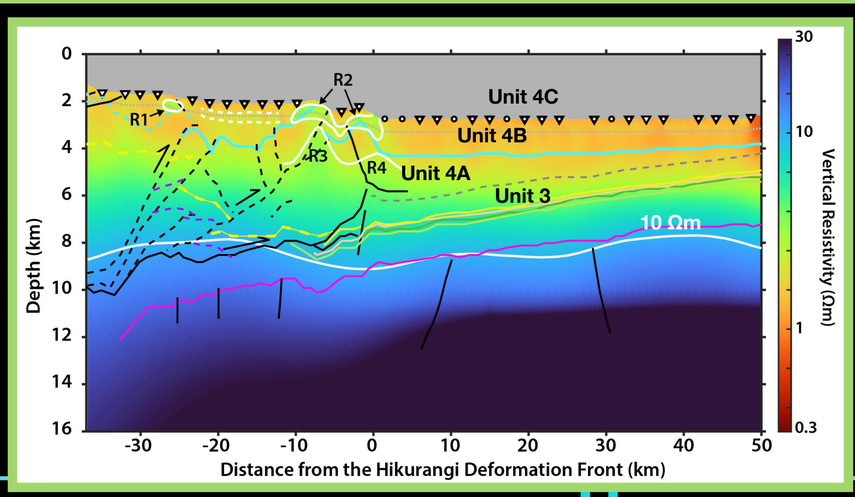
North



Central



South



RESIST