Mapping porosity of the Cocos oceanic crust at the Middle America Trench with marine EM

Samer Naif[1*], Kerry Key[1], Steven Constable[1], Rob L. Evans[2]

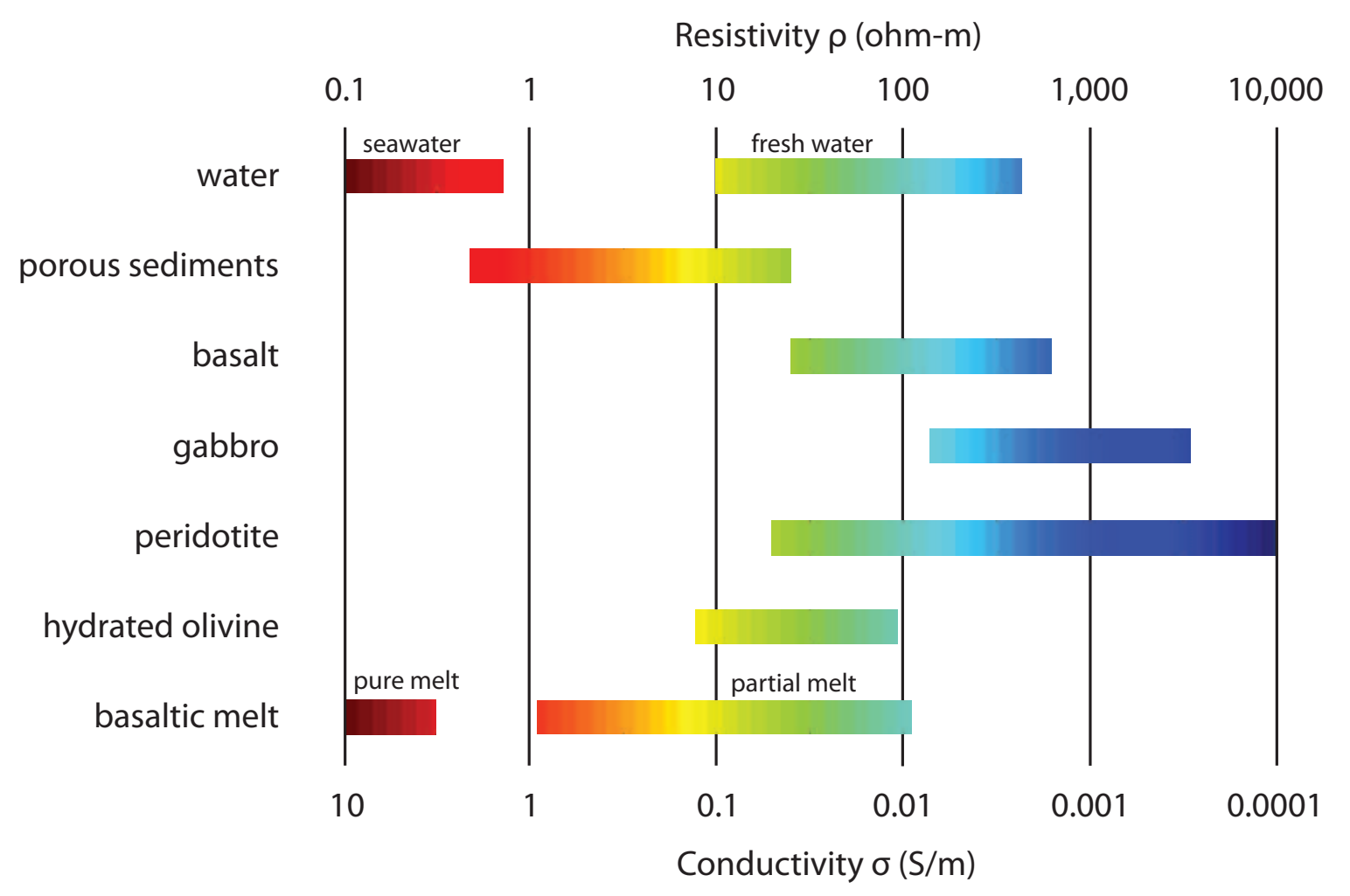
[1]Scripps Institution of Oceanography, University of California, San Diego [2]Department of Geology and Geophysics, Woods Hole Oceanographic Institution

[*]Now at Lamont-Doherty Earth Observatory Email: snaif@ldeo.columbia.edu

1. Introduction

Water that cycles through subduction zones regulates fundamental tectonic processes, including the stress state of the megathrust fault at the plate interface[1], but the volume of pore and mineral-bound water that is subducted with the downgoing oceanic plate is poorly constrained. Here, we use seafloor electromagnetic data to create a comprehensive electrical conductivity image that illuminates a complex system of water-rich faults at the Middle America Trench offshore of Nicaragua.

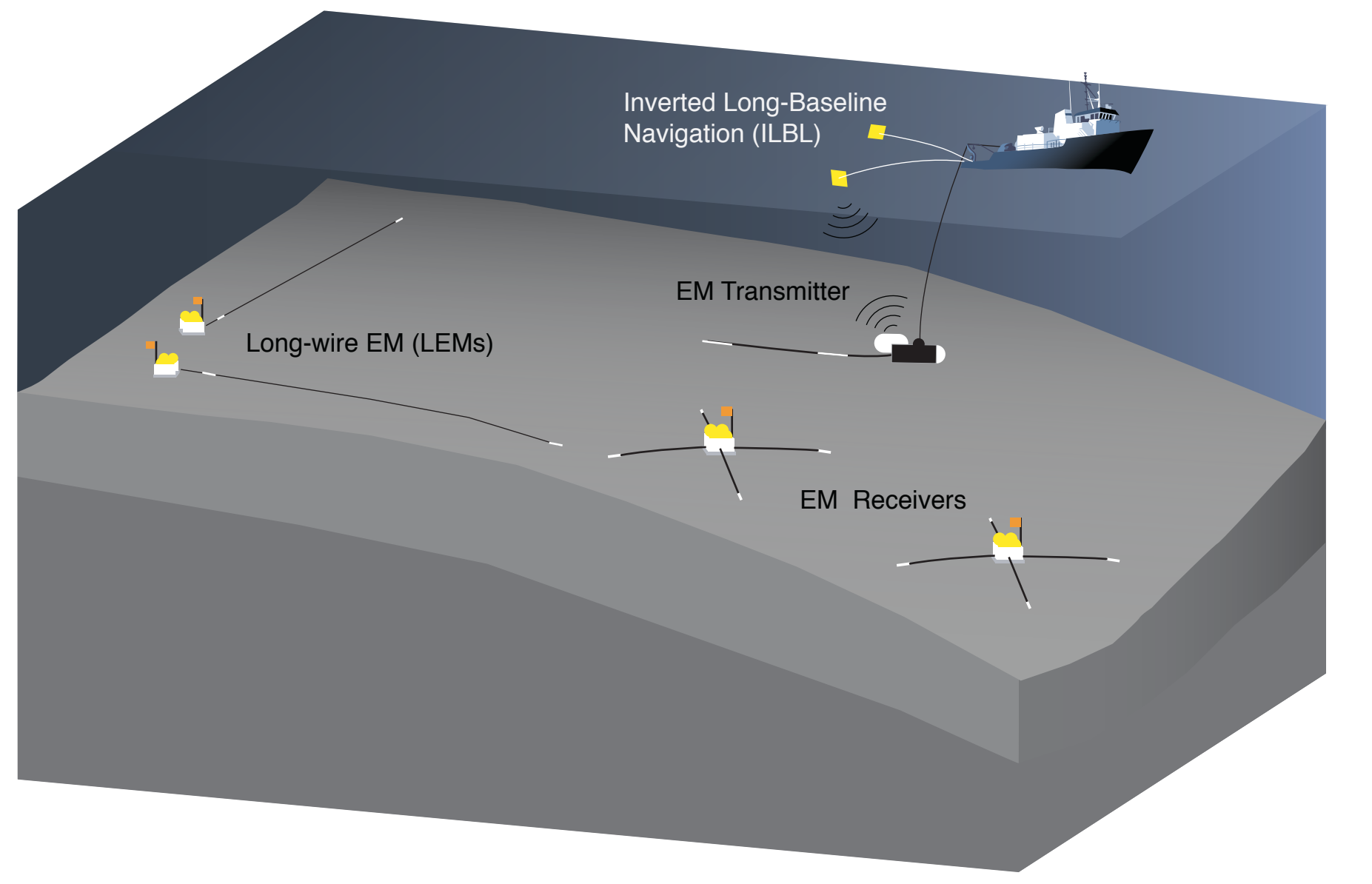
2. Why EM?



Electrical conductivity is a physical parameter that is primarily sensitive to the presence of fluids and partial melts. With models of conductivity, we can detect fluid migration pathways and estimate porosity of the subsurface to constrain the cycling of water between the surface and the deep Earth.

3. Marine electromagnetic methodology

- EM receivers are deployed onto the seafloor and record horizontal electric and magnetic fields
- Natural oscillations of passive EM fields provide low frequency energy to probe deep crustal and upper mantle structure (magnetotelluric method)
- High frequency energy attenuated by seawater is injected through a towed EM transmitter with a dipole source (controlled-source EM method)



Marine EM survey operations. Broadband ocean bottom EM receivers (OBEM) are deployed from a ship and record electric and magnetic fields on the seafloor. An EM transmitter is towed behind the ship to collect controlled-source data. A typical survey is performed in a single month-long voyage.

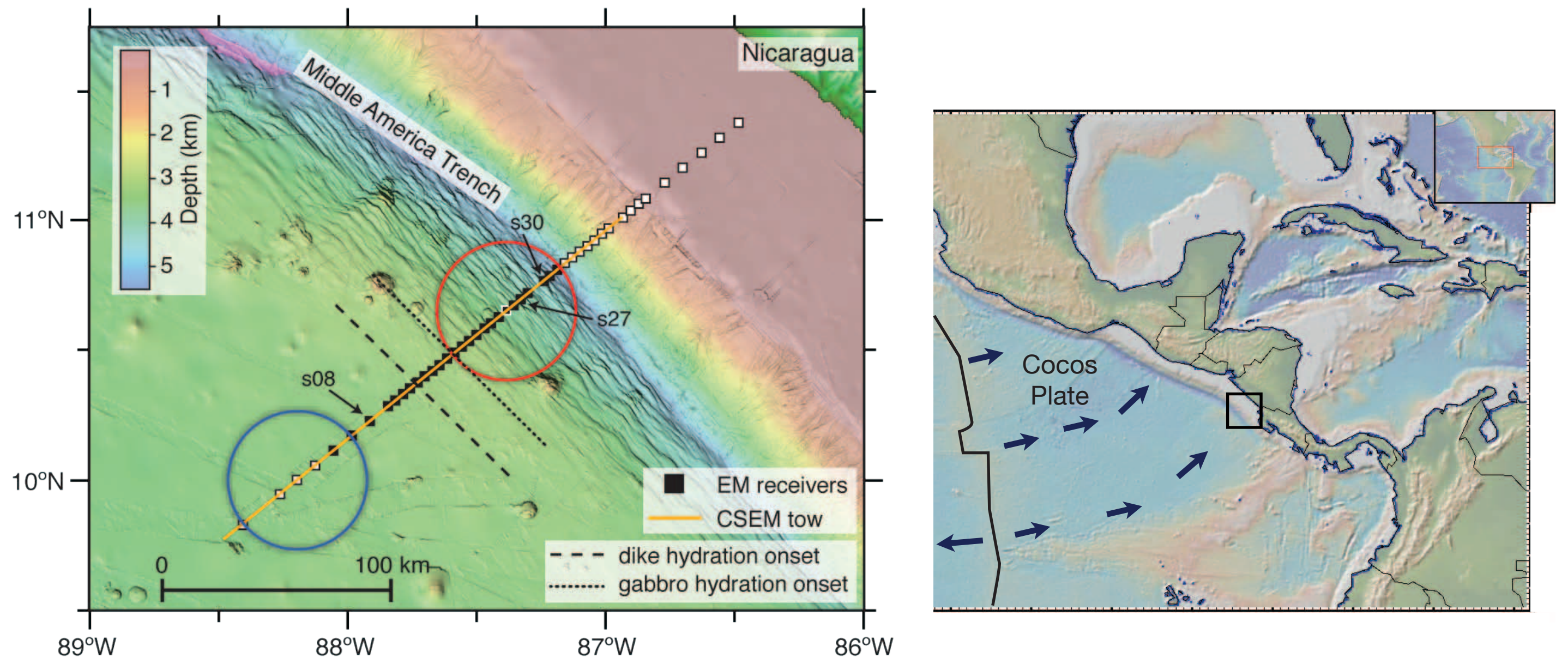
Results from:
Naif et al. (2015), Water-rich bending faults at the Middle America Trench, *Geochem. Geophys. Geosyst.*

Bibliography

1. Saffer & Tobin (2011), Hydrogeology and mechanics of subduction zone forearcs, *Annu. Rev. Earth Planet. Sci.*
2. Constable et al. (2009), Mapping offshore sedimentary structure using EM methods and terrain effects in marine MT data, *GJI.*
3. Jarrard (2003), Subduction fluxes of water, carbon dioxide, chlorine, and potassium, *Geochem. Geophys. Geosyst.*
4. Bach et al. (2006), Unraveling the sequence of serpentinization reactions, *GRL.*

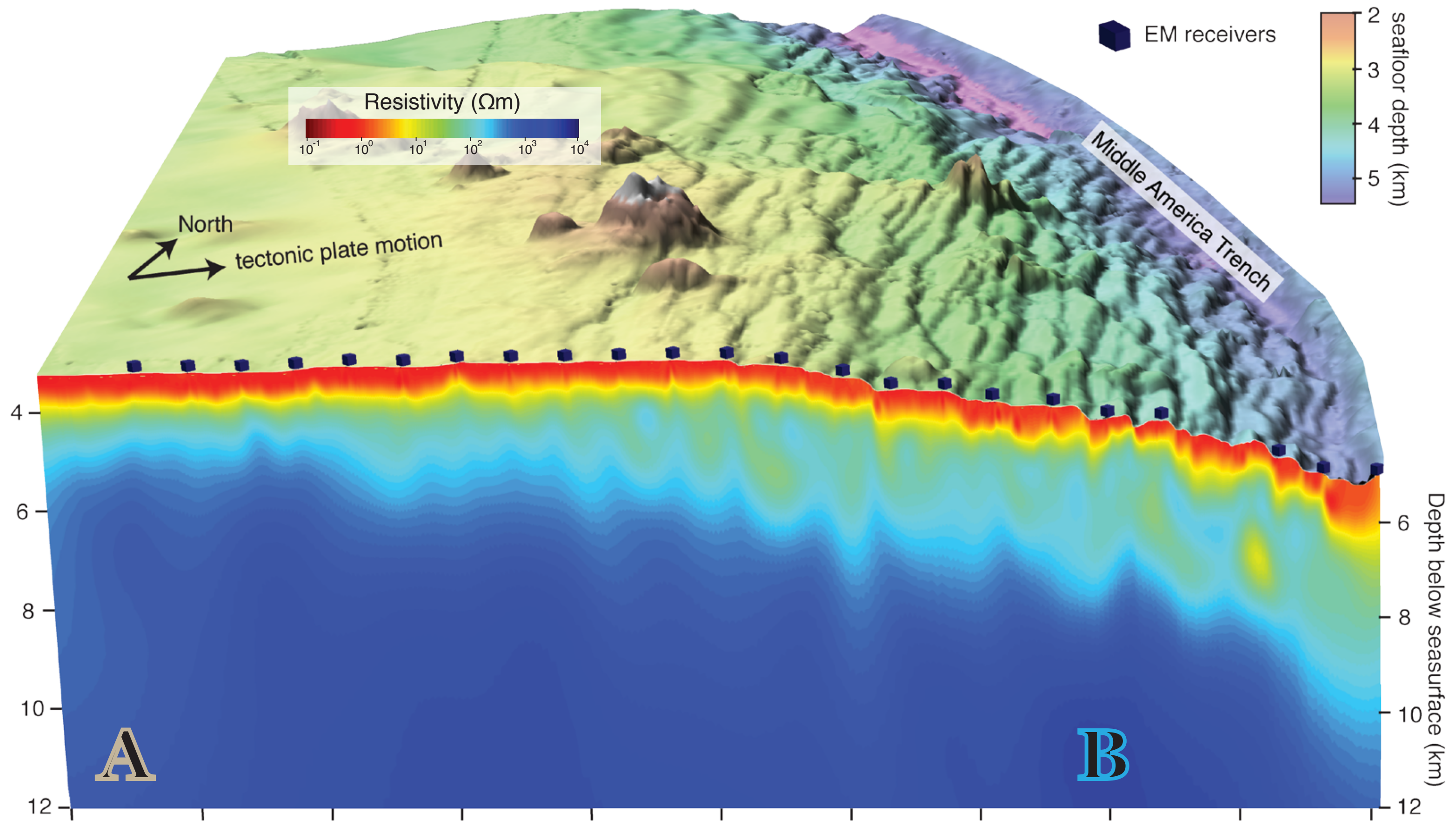
4. Marine EM Survey of the MAT

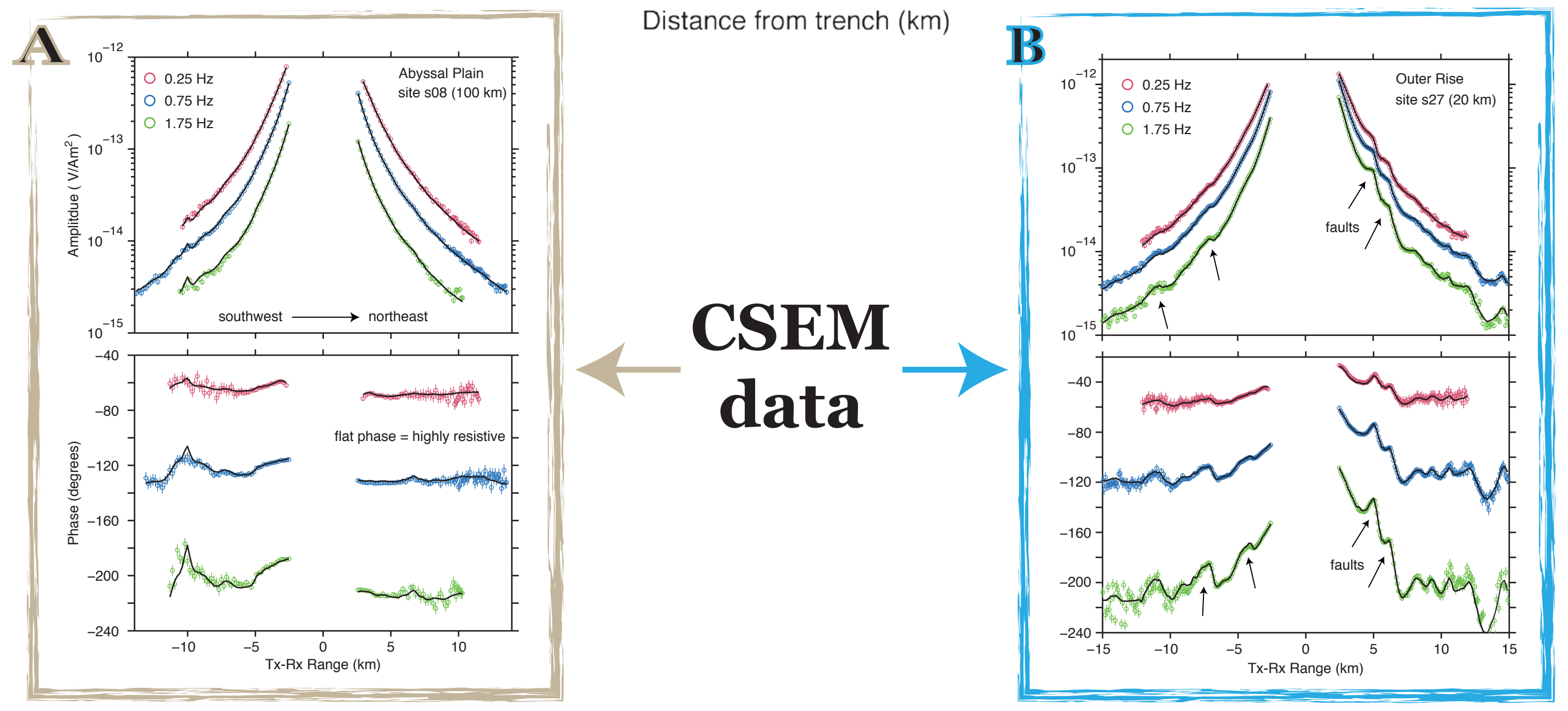
- EPR-sourced Cocos plate (24 Ma) subducts offshore of Nicaragua
- Spreading fabric parallel to trench; trench flexure reactivates abyssal faults
- Total of 50 Rx deployed along 280 km transect spaced 10 and 4 km apart



Map of EM survey. Black squares show OBEM receivers. Solid orange line is the Tx tow path. A total of 44 receivers recorded CSEM data, and all 50 recorded MT data. The results presented here consider receivers deployed on the incoming plate and trench.

5. 2D Inversion Results





Conclusions

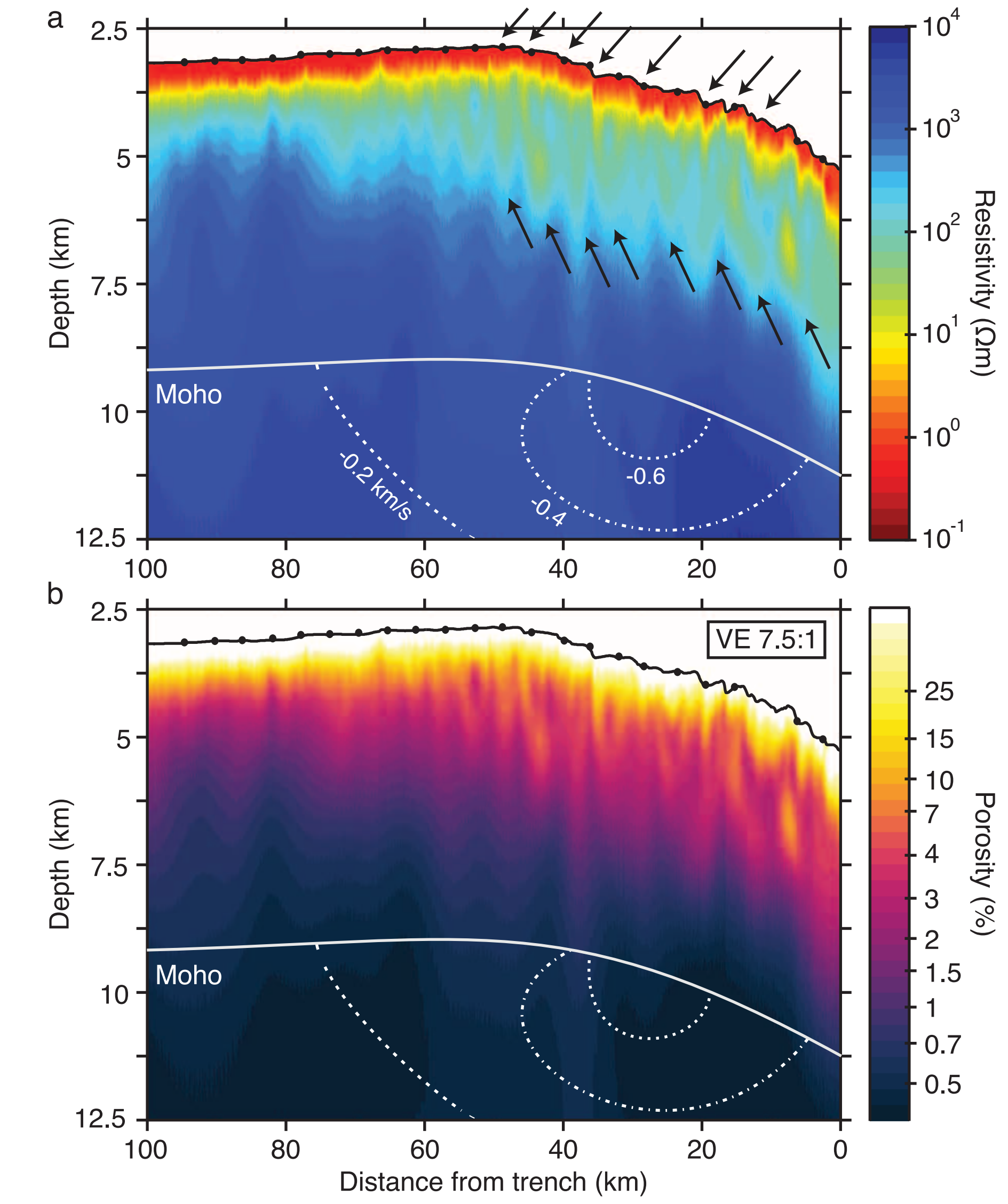
- **Outer rise faults** provide **porous/permeable pathways** that hydrate the incoming oceanic crust
- Lower crust **porosity** is **doubled**. Significantly **more pore water is subducted** than previous estimates[3]
- **Mantle** stays **resistive**, suggests **less than 20%** serpentinization[4]. Favors a **closed, low-fluid-flux** system

6. Porosity

Archie's Law $\rho=\rho_f\varphi^{-m}$

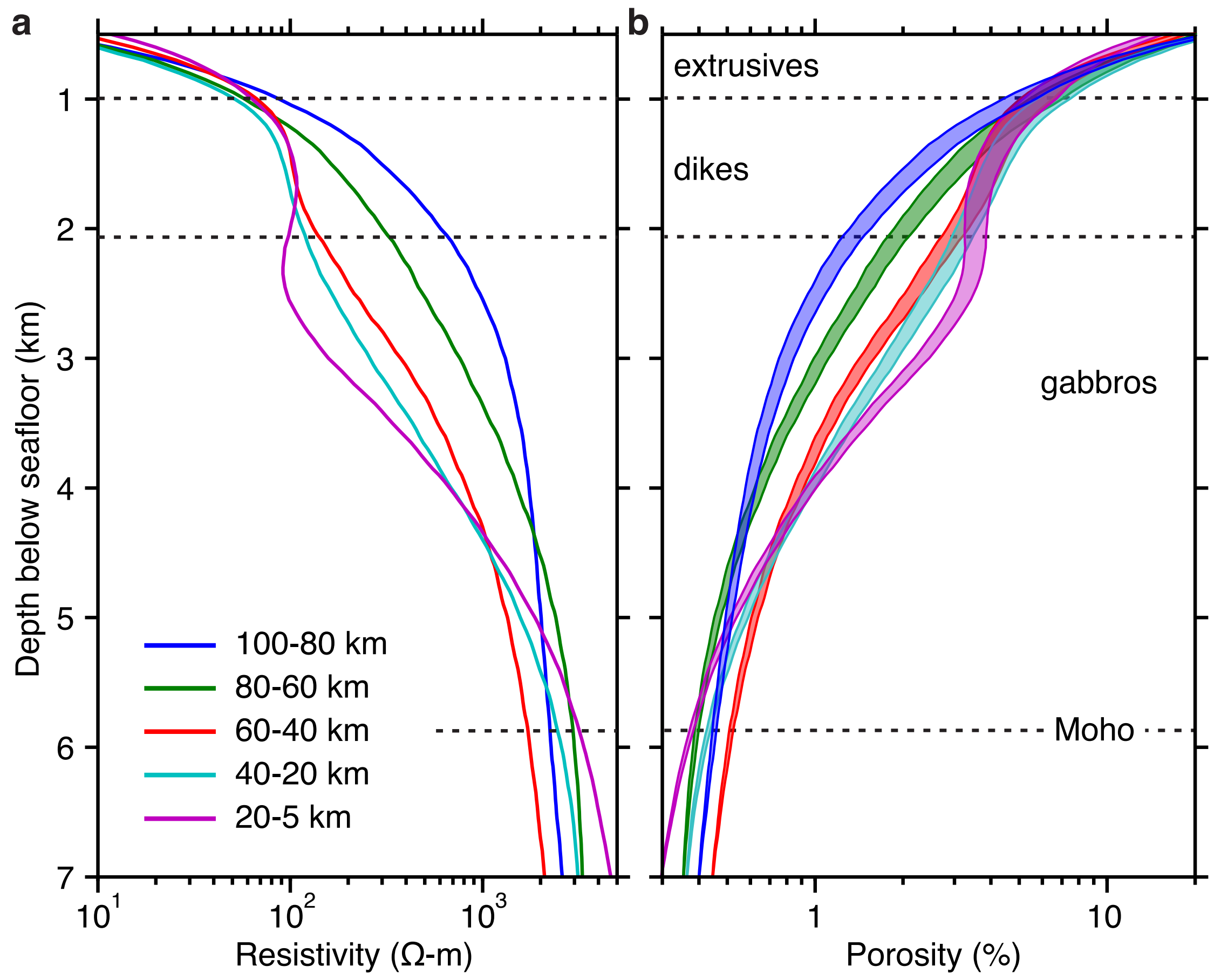
bulk resistivity, fluid resistivity, porosity, cementation exponent

- Fluid resistivity is strongly temperature dependent[2]
- Cementation exponent is related to pore geometry



Close up of outer rise electrical structure.

a, showing significant subvertical conductive channels below fault scarps. **b,** crustal bulk porosity estimates from Archie's law (m=2).



Increasing crustal porosity with proximity to the trench

a, Lines show the averaged bulk resistivity as a function of depth of five 20 km wide sections from the trench to 100 km seaward. **b,** bulk porosity of **a**.

Porosity of oceanic crustal layers with proximity to the trench

Window, dist. from trench	Extrusives (600m), m= 1.6, 2	Dikes (1km), m= 2	Gabbros (4km), m= 2
24 Ma crust*	10.4	3	0.7
80-100 km	7.5, 12.2	2.7	0.7
40-60 km	8.5, 13.5	4.7	1.3
5-20 km	**9.1, 14.3**	**4.8**	**1.7**

*from Jarrard (G-cubed, 2003)

7. Synthetic tests

- Model responses w/ and w/o faults are inverted; demonstrate sensitivity of CSEM data
- Porosity inferred from forward and inverse models demonstrate resolution of CSEM data
- Data sensitivity good to 6-8 km depths; Resolution begins to fade around 3.5 km below seafloor
- Mean porosity is conserved