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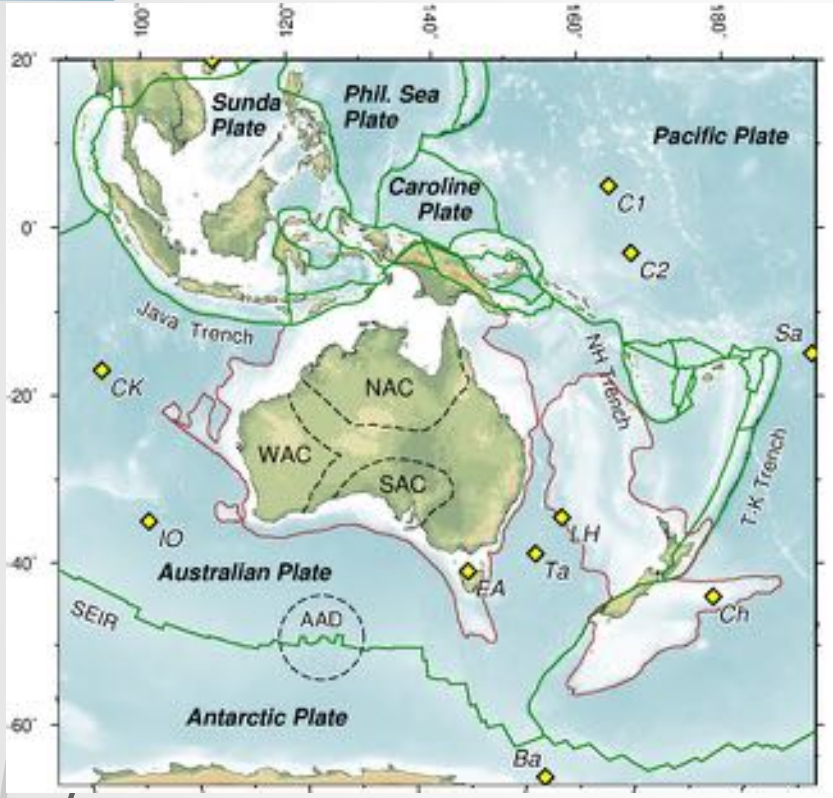
Imaging the Upper Mantle of The Australian Plate from Waveform Tomography with Massive Datasets.

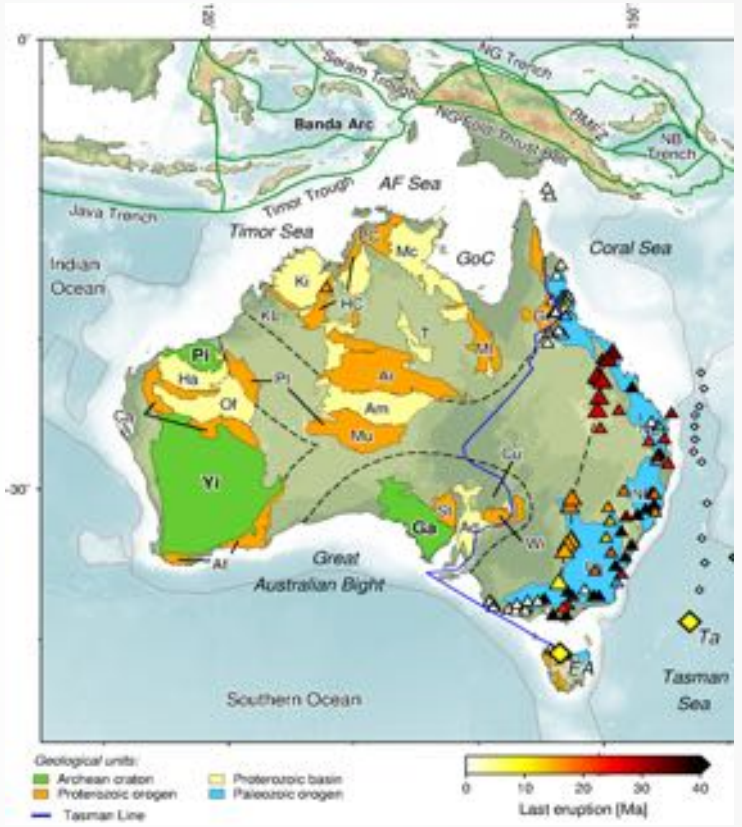
Janneke I. de Laat, Sergei Lebedev, Bruna Chagas de Melo, Nicolas L. Celli, Raffaele Bonadio

Dublin Institute for Advanced Studies

delaat@cp.dias.ie

Introduction



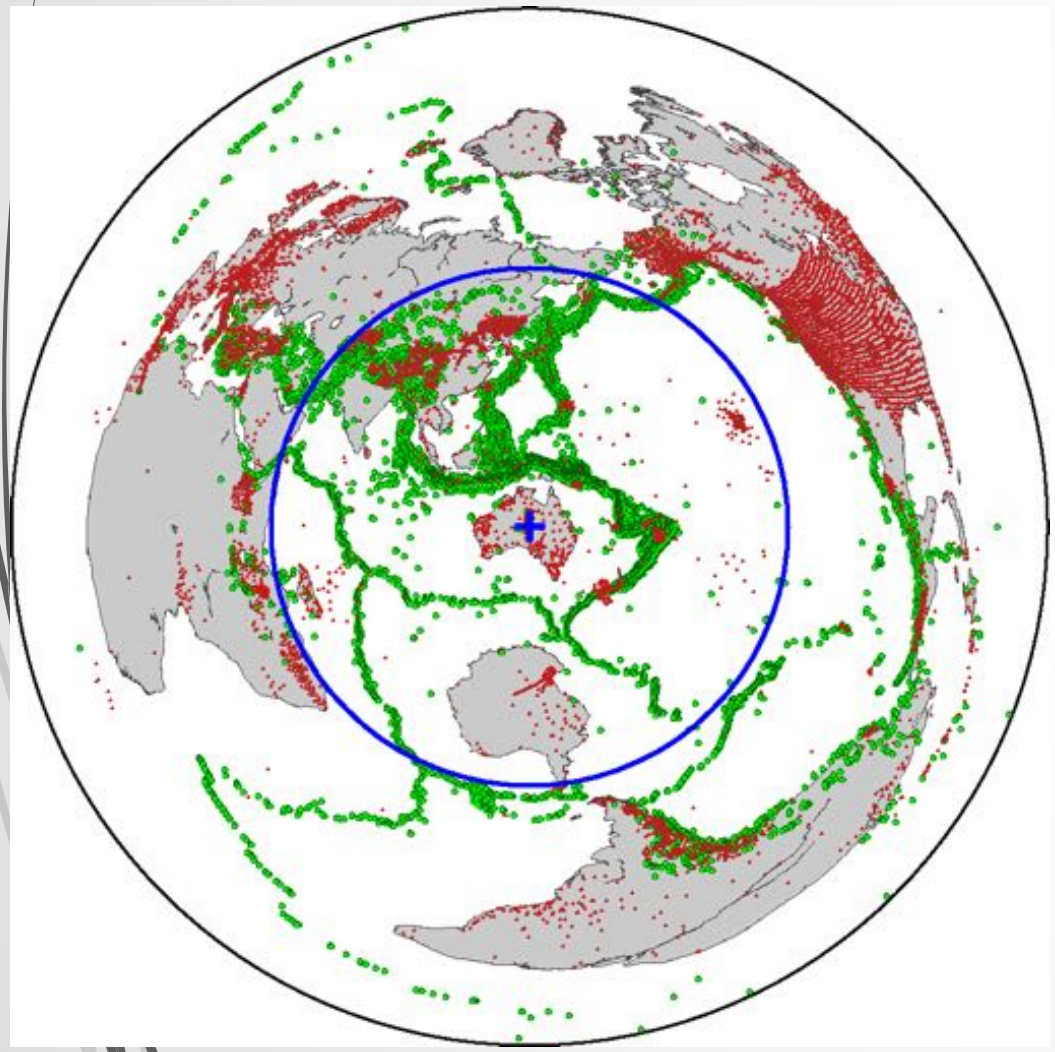


- Australian Plate bounded by a complex configuration of **convergent margins** in the North and East and the South East Indian Ridge (SEIR) in the South.
- Australian continent contains some of the **oldest** rocks on Earth and many poorly understood intraplate **volcanoes**.
- **Many questions** remain unanswered relating to the structure and evolution of the Australian plate and its margins.

Aim

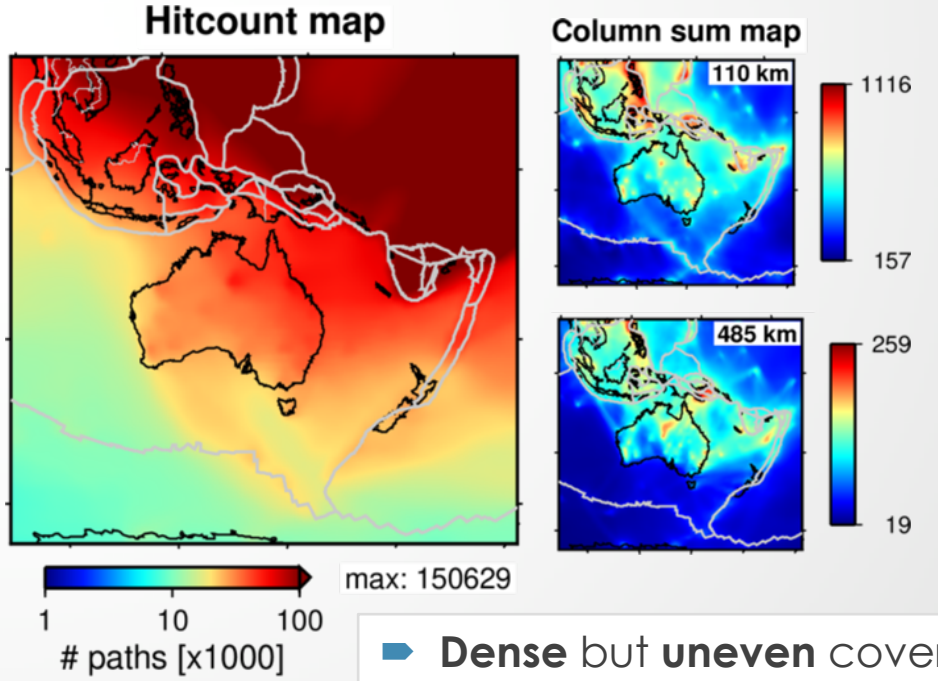
- To provide a detailed image of the upper mantle of the entire Australian Plate and its boundaries,
- To gain better insight in the structure and evolution of the entire Australian Plate.

Methods: Dataset



Hemisphere model generated using a dataset of almost **1 million waveforms,** including both local and global datasets.

- **26 thousand** teleseismic **events**
- **9 thousand** broadband **stations** (including NSN, ANU, SKIPPY, MOANA).



- **Dense** but **uneven** coverage,
- Covering the entire Australian Plate.

Methods: Inversion Procedure

Lebedev et al., (2005), Lebedev and Van der Hilst (2008)

- **1. Automated Multimode waveform Inversion (AMI):**
  - fits surface, S- and multiple S-wave phases from the waveforms to computed synthetic waveforms.
  - Generates a set of linear independent equations that describe the 1D average perturbations in the P- and S- wave velocities within the sensitivity volume between the source and receiver.
  - Perturbations relative to a 3D crust and 1D mantle velocity profile.

- **2. 3D Tomographic inversion**:
  - Combines all the AMI equations into one large linear system,
  - Solves it for the 3D distributions of P- and S-wave velocities and the S-wave azimuthal anisotropy with LSQR.
  - Regularization is applied by lateral and vertical smoothing and gradient damping, tuned per depth knot (18 for S and 10 for P-waves).

- **3. Outlier analysis**:
  - Selects the mutual consistent data by automatically
  - and manually removing outliers in the obtained tomographic model.
  - Rerun step 2 with reduced dataset.

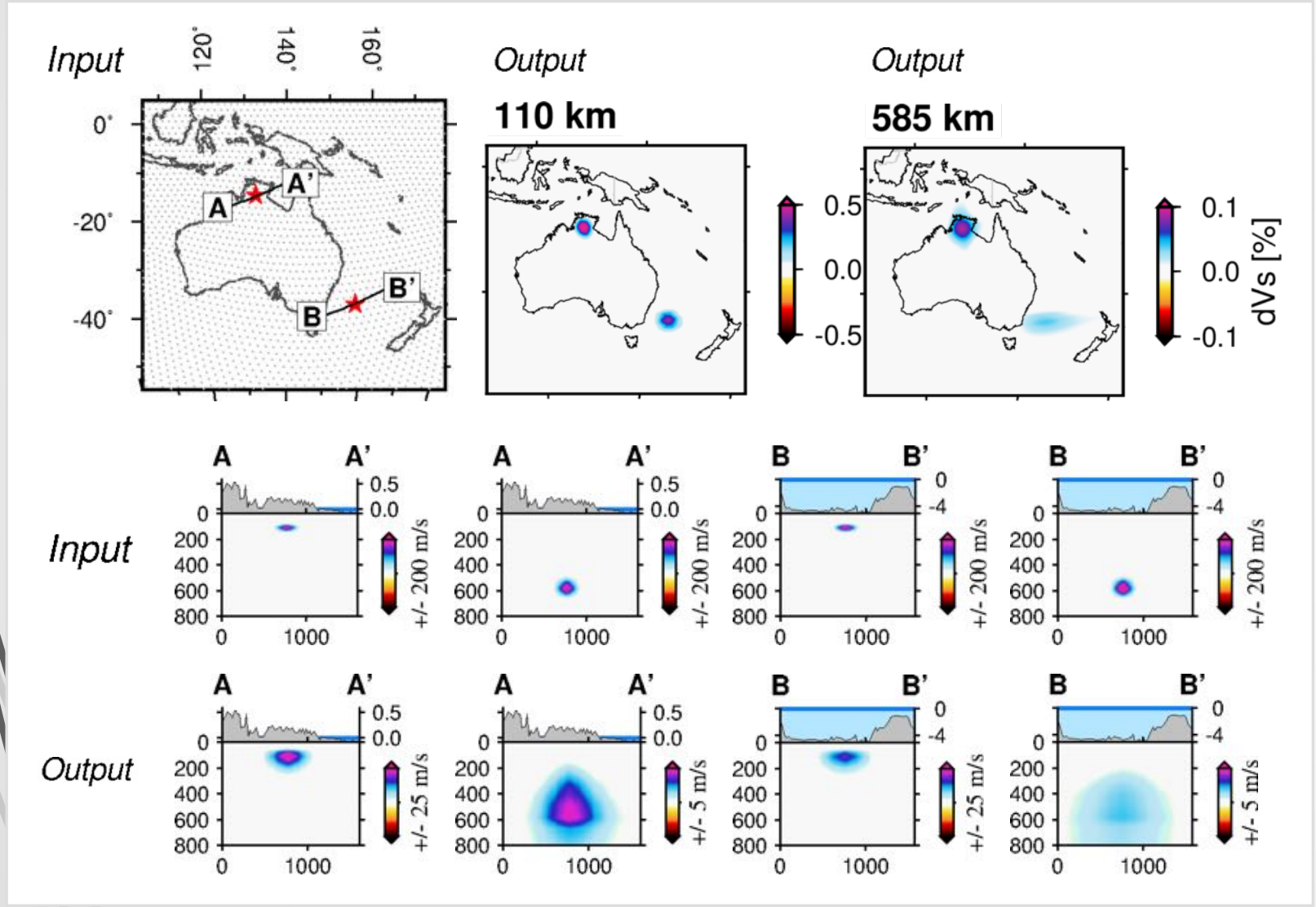
    (Final dataset = 650 thousand waveforms)

Note:

Although the tomographic inversion is performed **globally**, the model is **regional** as:

- Only the waveforms within the hemisphere are included,
- Regularization is optimized for the Australian Plate,
- Outlier analysis is applied focusing on the Australian Plate.

Validation (I): Spike Test

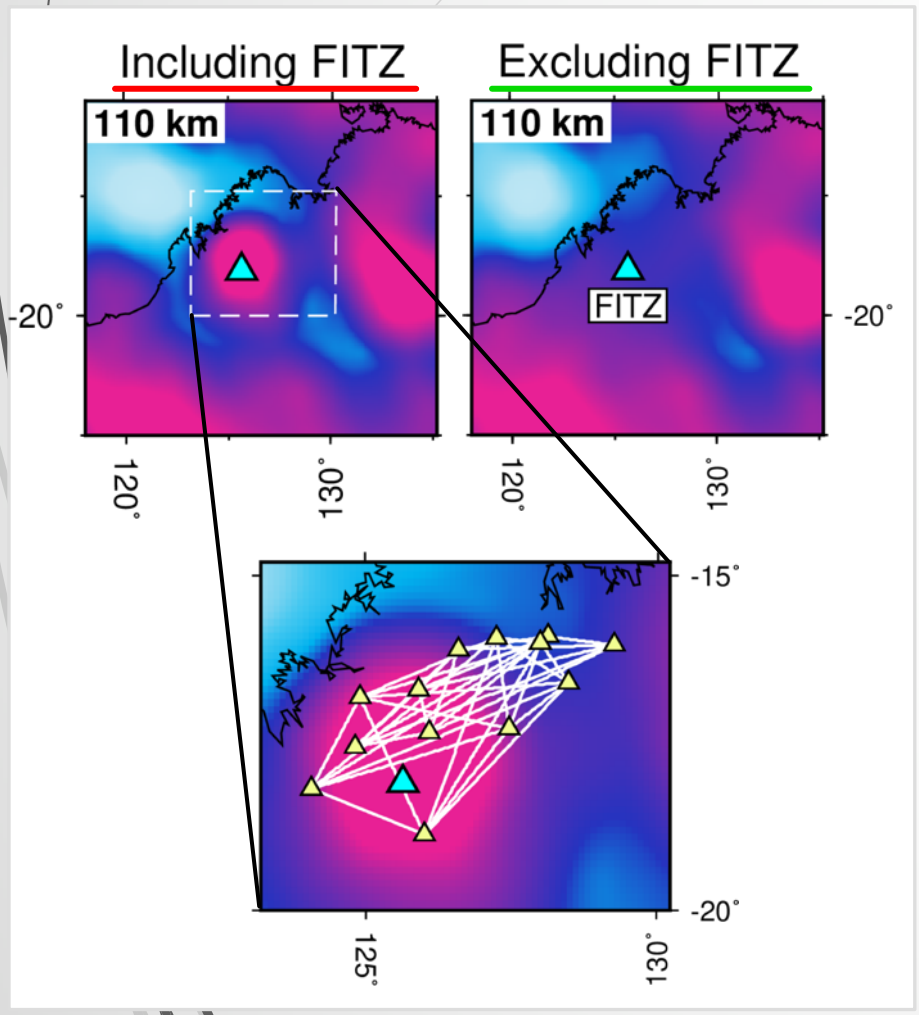


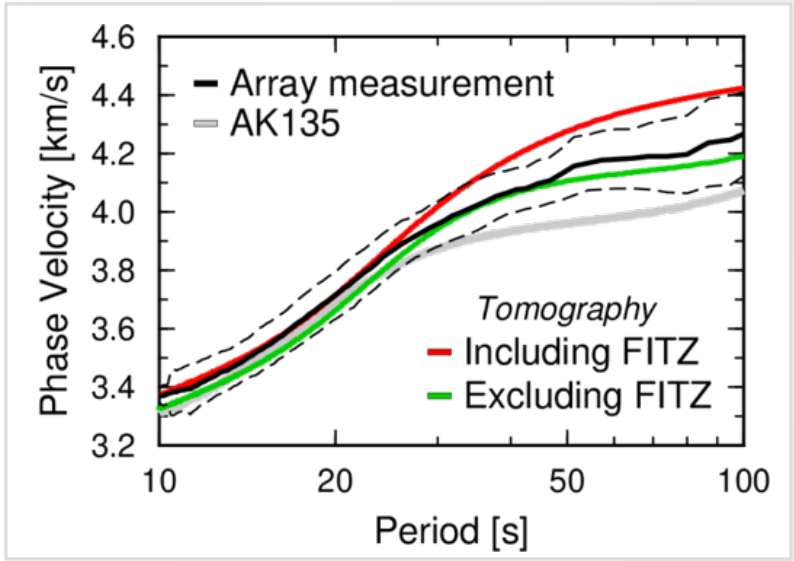
- Used to get a better understanding of the **resolution** of the model.
- Due to the **uneven** data coverage, Aus21 **varies** in resolution **laterally** and with **depth**.
- Important to take into account when **tuning** the tomographic inversion and interpreting the results.

Validation (II): Interstation Method

= **Independent** method to verify the lithospheric properties beneath an array of stations

(Soomro et al., 2016)



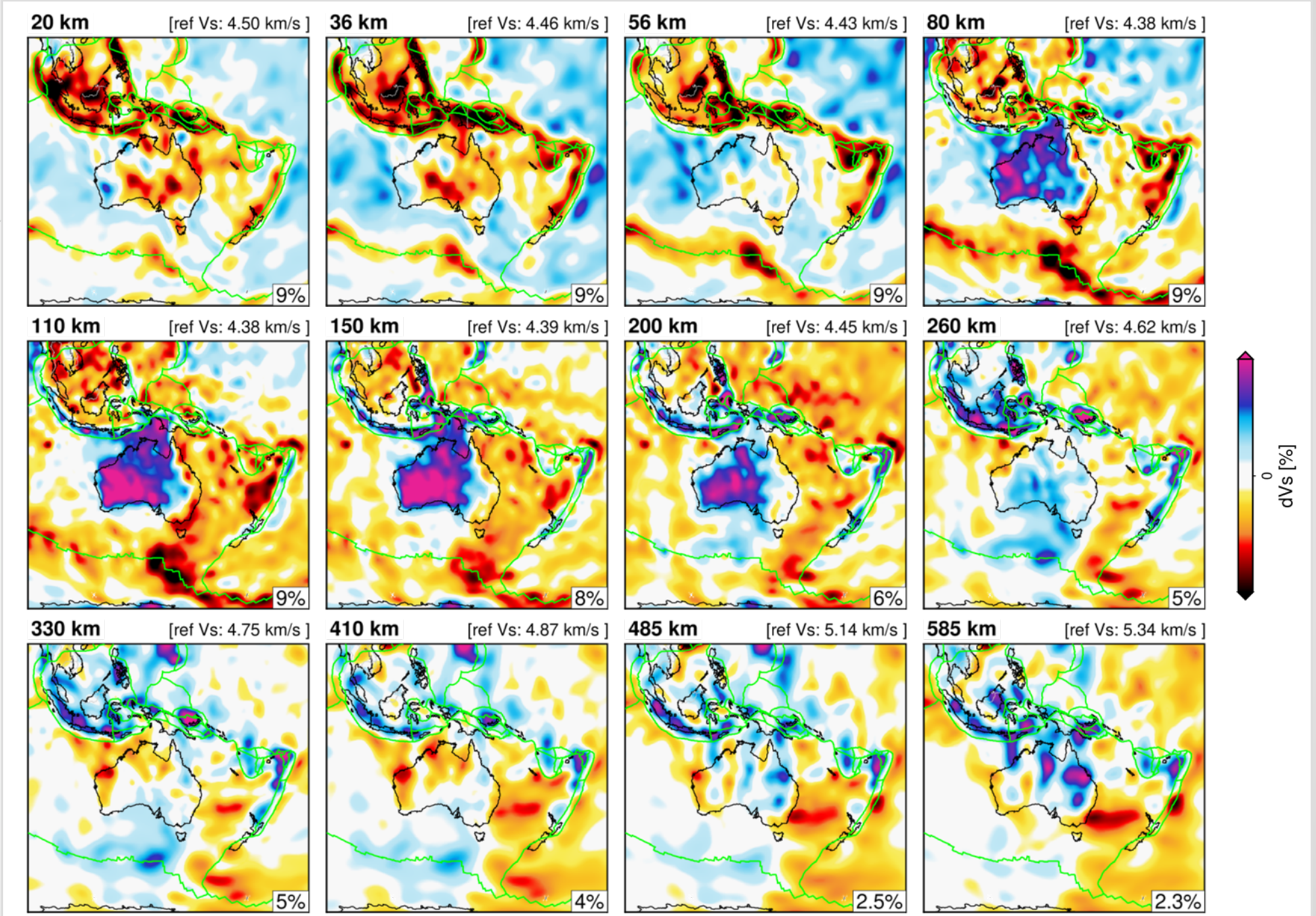


Used to identify possible **errors** in the model:

- Left: The phase velocity profiles obtained from the tomographic model **including** and **excluding** the data from station FITZ is compared o the phase velocity profile obtained by applying the **interstation method** to the surrounding array.
- Top: The phase velocity profile obtained when **excluding** the data from station FITZ is confirmed by the interstation method.
- Result: the data from FITZ is **excluded** from the input of the inversion.

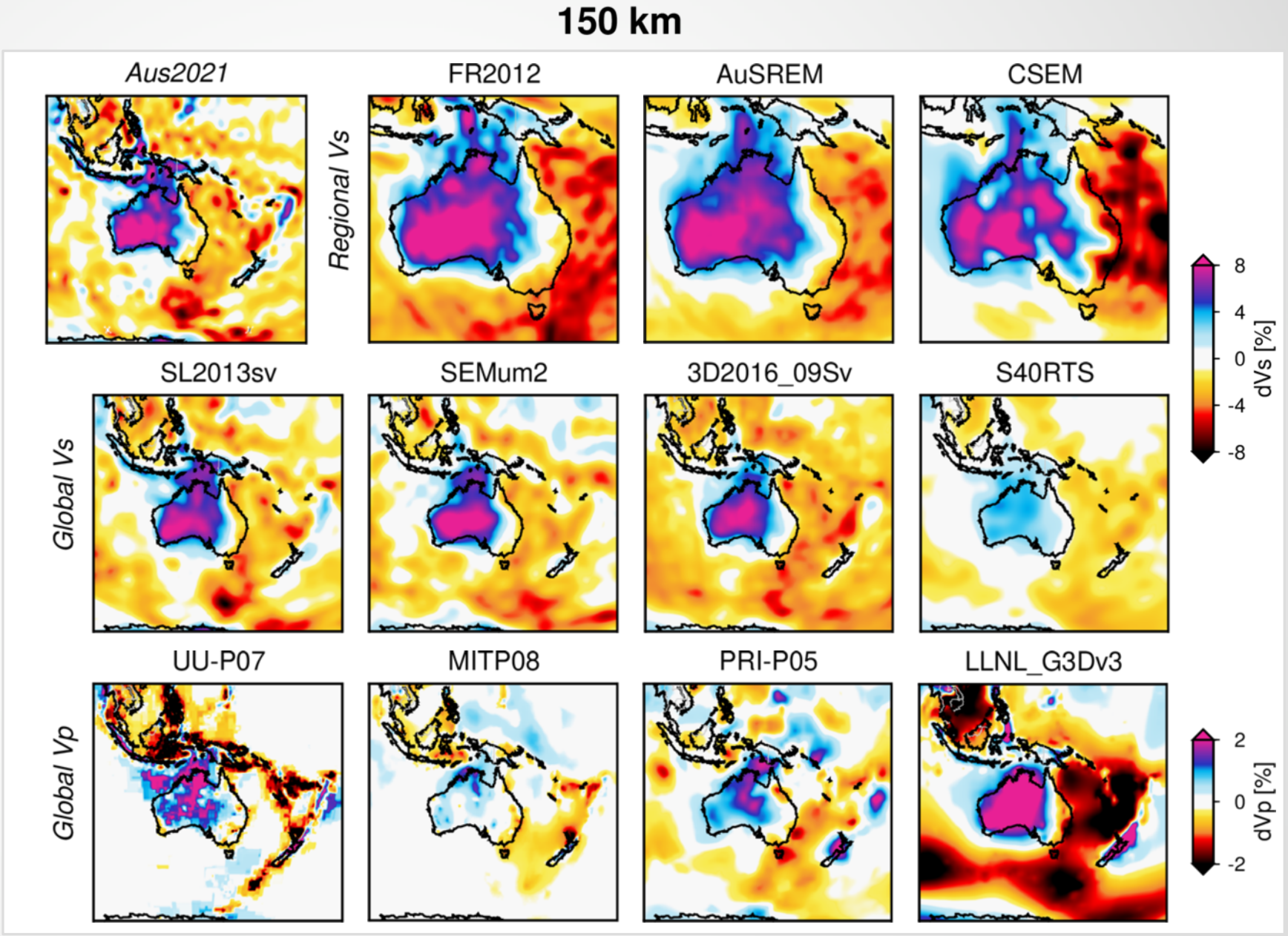
The Model:

Aus21



Comparison

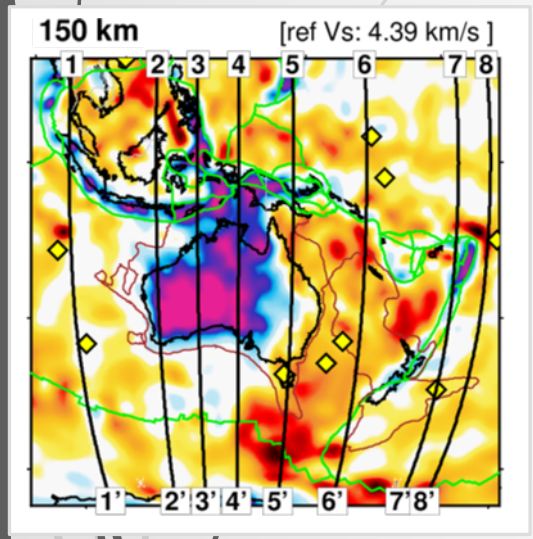
- Regional Vs
- Global Vs
- Global Vp

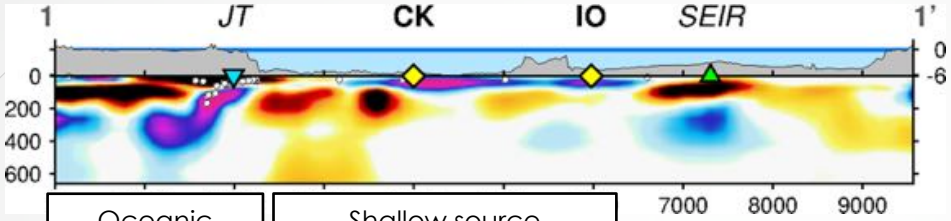


FR 2012 = Fishwick and Rawlinson (2012), AusREM = Kennett et al. (2013), CSEM = Fichtner et al. (2010), SL2013sv = Schaeffer and Lebedev (2013), 3D2016_09Sv = Debayle et al (2016), SEMum2 = French and Romanowicz (2014), S40RTS = Ritsema et al. (2011), UU-P07 = Amaru (2007), MITP08 = Li et al. (2008), PRI-P05 = Montelli et al. (2006), LLNL_G3Dv3 = Simmons et al. (2012).

Observations & Interpretations

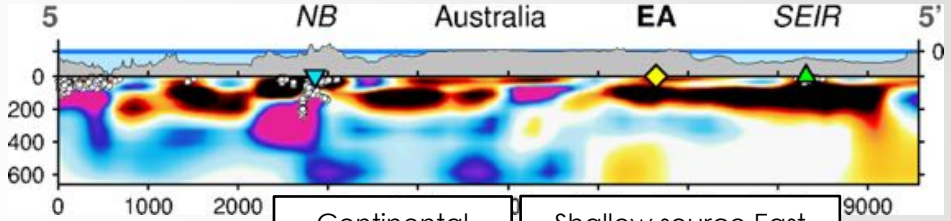
N-S X-sections





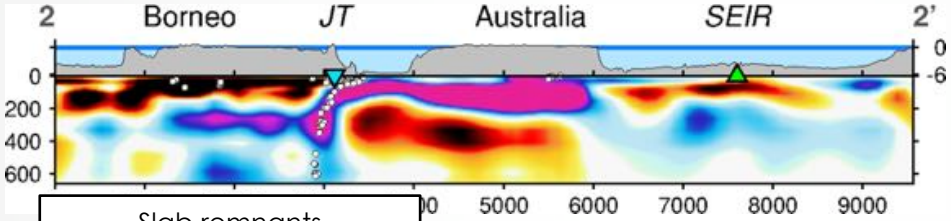
Oceanic subduction.

Shallow source Cocos-Keeling hotspot.

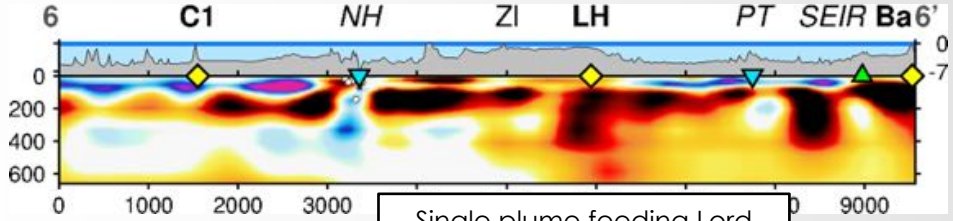


Continental slab remnants?

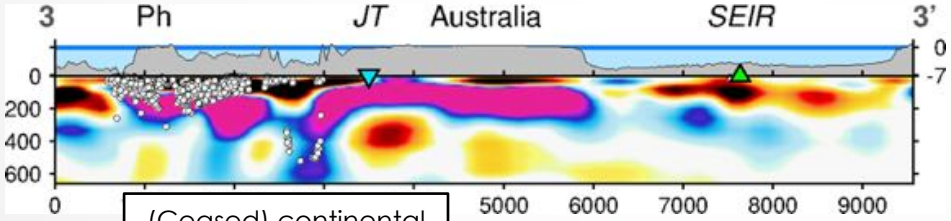
Shallow source East Australia hotspot?



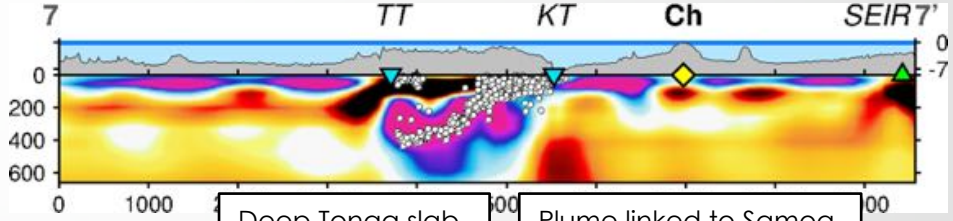
Slab remnants -> Proto South China Sea?



Single plume feeding Lord Howe & Tasmanid hotspot.

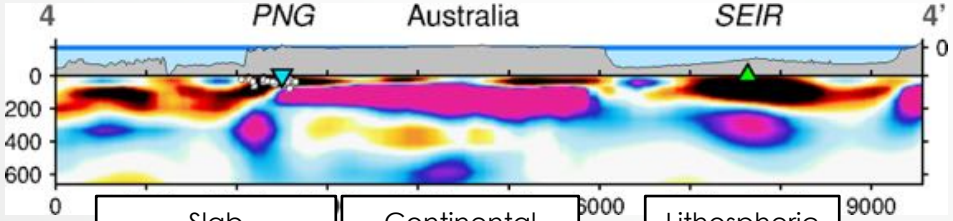


(Ceased) continental subduction.



Deep Tonga slab

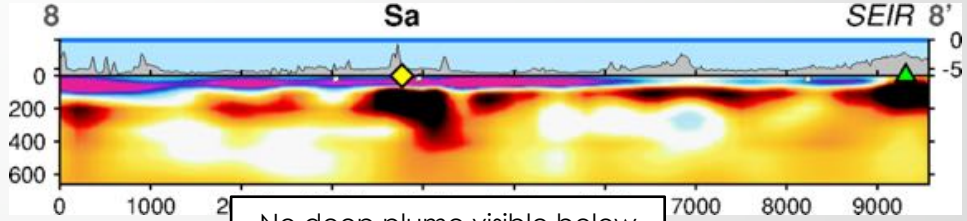
Plume linked to Samoa hotspot?



Slab delamination.

Continental slab remnant?

Lithospheric Remnant?



No deep plume visible below Samoa hotspot

Abbreviations:

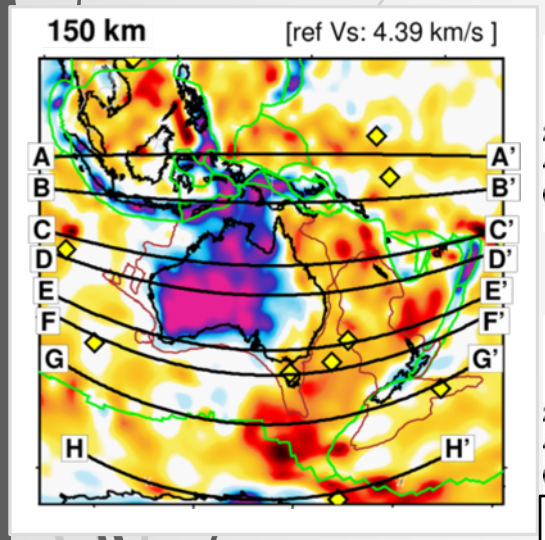
Plate boundaries: JT = Java Trench, KT = Kermadec Trench, NB = New Britain, NH = New Hebrides trench, PT = Philippine Trench, SEIR= South East Indian Ridge, TT = Tonga Trench.

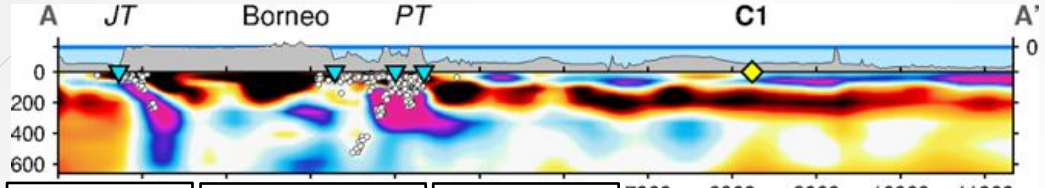
Hotspots: Ba = Baleny, C1&2: Caroline 1&2, Ch = Chatam, CK = Cocos-Keeling, EA = East Australia, IO = Indian Ocean, LH = Lord Howe, Sa = Samoa.

Continents: Ph = Philippines, PNG = Papua New Guinea, Zl = Zealandia.

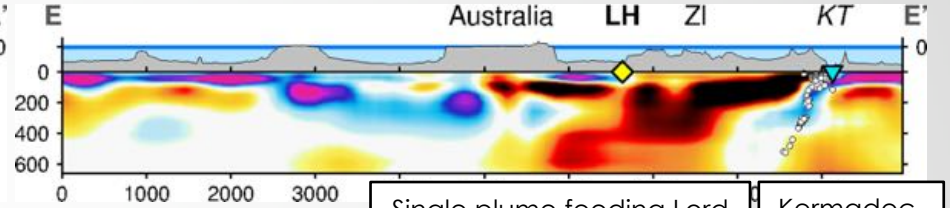
Observations & Interpretations

E-W X-sections

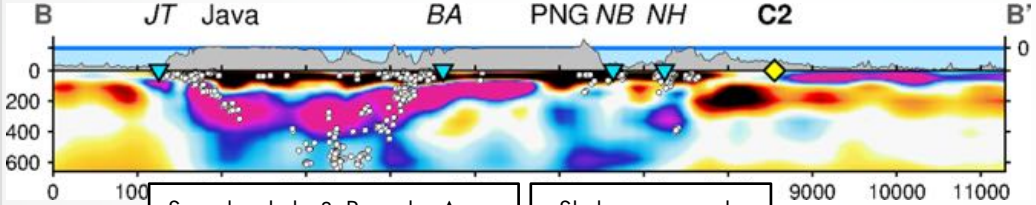




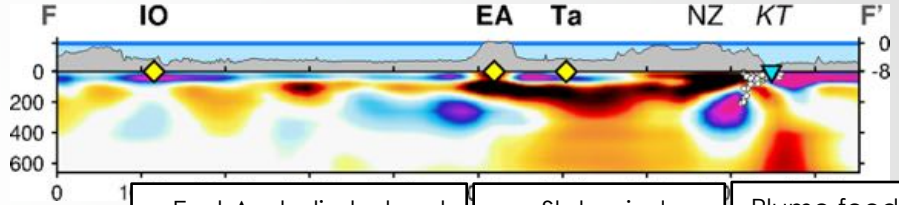
Sunda slab | Slab remnants | Molucca Sea slabs



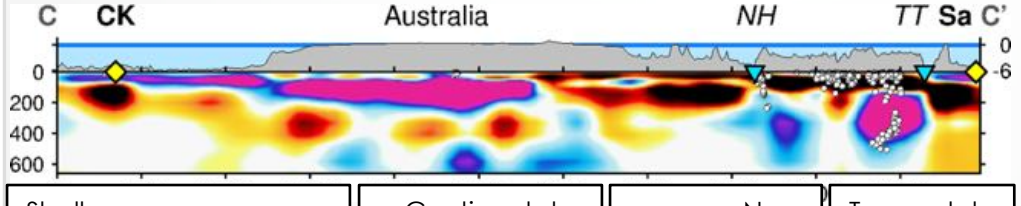
Single plume feeding Lord Howe & Tasmanid (& EA?) | Kermadec Slab



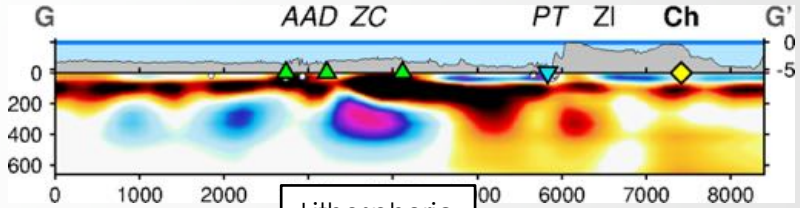
Sunda slab & Banda Arc | Slab remnants



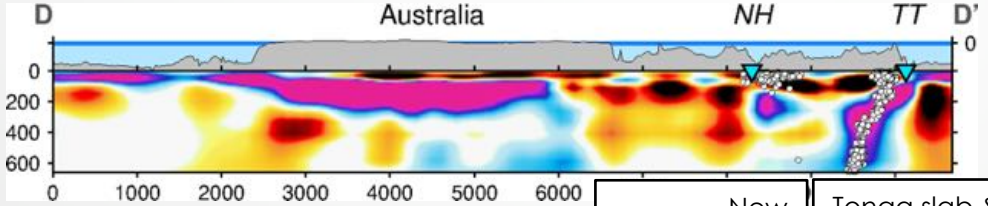
East Australia hotspot linked to LH & TA? | Slab window Kermadec slab? | Plume feeding Samoa?



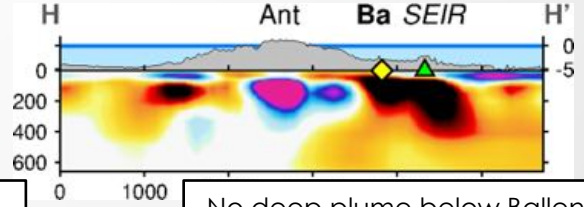
Shallow source Cocos-Keeling hotspot | Continental slab remnants? | New Hebrides slab | Tonga slab



Lithospheric remnant?



New Hebrides slab | Tonga slab & Samoa plume



No deep plume below Balleny? Or too low resolution?

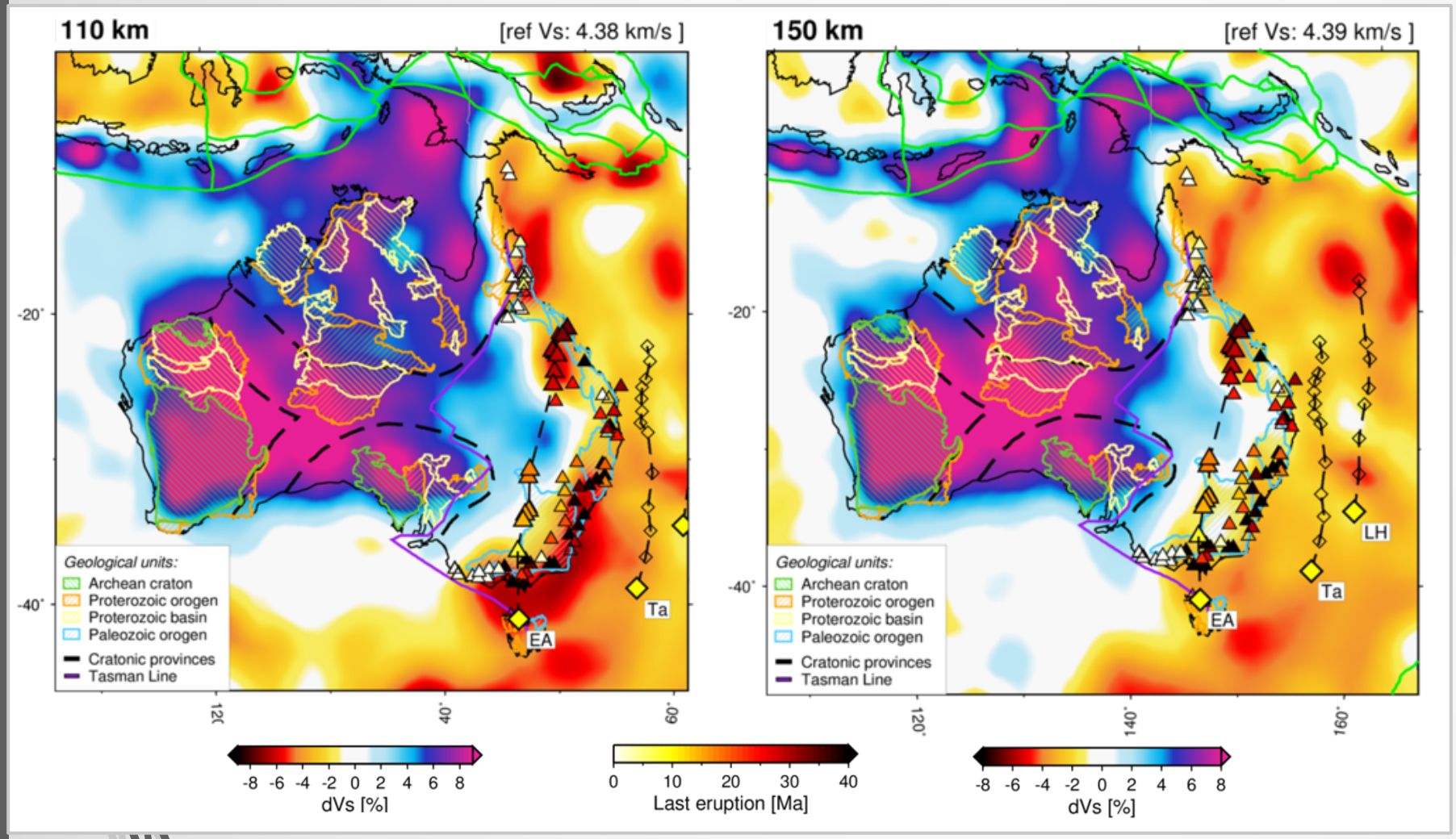
Abbreviations:

Plate boundaries: BA = Banda Arc, JT = Java Trench, KT = Kermadec Trench, NB = New Britain Trench NH = New Hebrides Trench, PT = Philippine Trench, SEIR= South East Indian Ridge, TT = Tonga Trench.

Hotspots: Ba = Baleny, C1&2: Caroline 1&2, Ch = Chatam, CK = Cocos-Keeling, EA = East Australia, IO = Indian Ocean, LH = Lord Howe, Sa = Samoa.

Continents: Ant = Antarctica, PNG = Papua New Guinea, Zl = Zealandia.

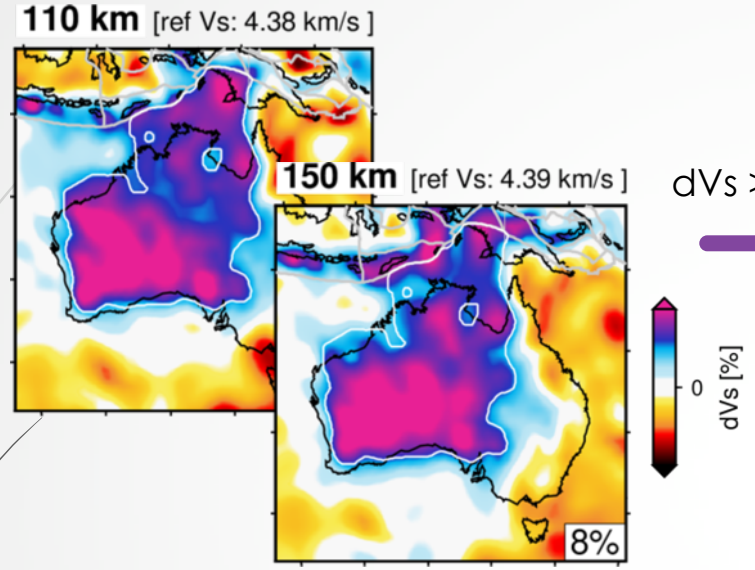
The Australian Lithosphere



- Cratonic lithosphere **terminates** at N boundary Australian Plate.
- Almost all **Archean** and **Proterozoic outcrops** underlain by cratonic lithosphere.
- All **volcanics** underlain by **warm, thin** lithosphere
- **Gap** in **Cosgrove Track** coincides with **thicker, colder** lithosphere.
- **Peak** in low velocity below **East Australian** hotspot at 110 km, vanished at 150 km.
- **No** peak in low velocity below current position **Lord Howe** and **Tasmanid** hotspot. – Waned plume?

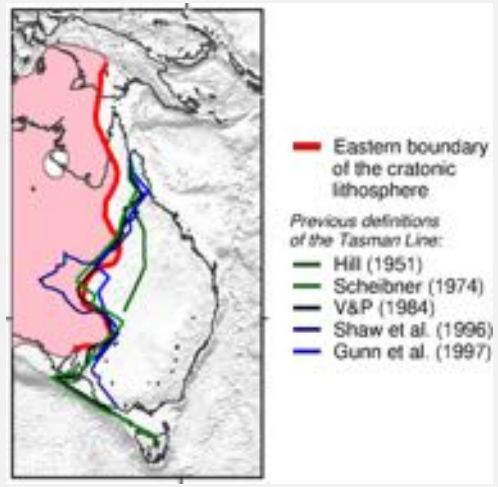
The Australian Cratonic Lithosphere (ACL)

= Part of the Australian Plate where **dVs > 4.5%** at 110-150 km depth.



dVs > 4.5%

East ACL & Tasman Lines

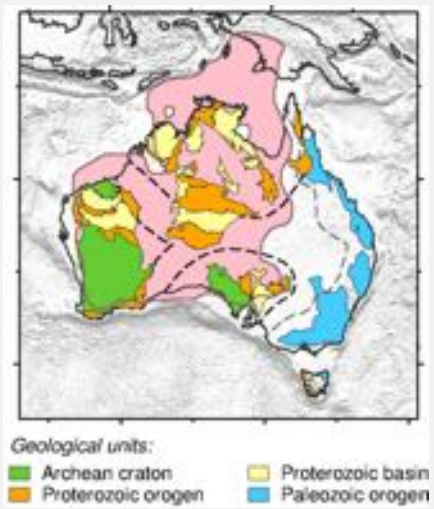


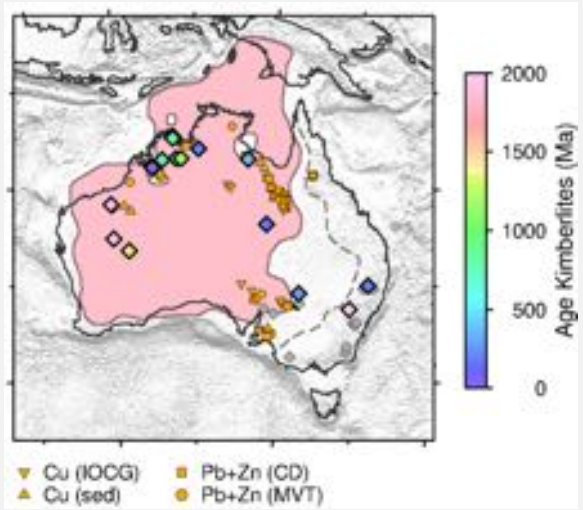
Geological units

No distinction between the Australian Cratonic Provinces (dashed lines).

Georgetown inlier not underlain by cratonic lithosphere.

Southern **Gawler** and **Yilgarn** craton not underlain by ACL.





Diamonds & sed. hosted metals

Diamondiferous kimberlites mostly within cratonic lithosphere, except:

- The easternmost outcrops
- The **recent diamonds** south of the **Kimberley** Craton, located above an **indent** in the ACL.

No correlation sediment hosted metals and the **boundary** of the ACL.

Conclusions

- **Aus21**: a new regional upper mantle S-wave tomography model of the entire Australian Plate generated using almost **1 million waveforms**.

- The various active **subducting slabs** are observed that make up the convergent margins in the north and east of the plate as well as the the hot uprising material below the SEIR in the south.
- **A single plume source** is observed in the transition zone, sourcing the (waned) Tasmanid and Lord Howe hotspots and possibly also the East Australian hotspot.
- **Samoa** hotspots shows no deep source, but a possible source is observed further south below the **Kermadec slab**.
- Other hotspots either show a **shallow source** (Cocos-Keeling, Balleny), or are **not visible** in the upper mantle (Indian-Ocean, C1 & C2, Chatam).
- The lithospheric structure of the Australian continent is visualized, including the **deep craton root** covering the vast majority of the continent and the **thin, warm** lithosphere below it's **volcanically active** eastern margin.
- A new outline is created of the **Australian Cratonic Lithosphere** (ACL).
- Various (possibly continental) **slab remnants** are visible in the transition zone below the convergent margins in the north and below the Australian continent.

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Thank you!

Feel free to contact me for any questions/discussions!

You can contact me through the vEGU booth or by emailing me at:

delaat@cp.dias.ie

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