Hotspot motion inferred from mantle flow models: implications for global plate reconstructions

(fitting the track of the Hawaiian–Emperor seamount chain, including the bend)

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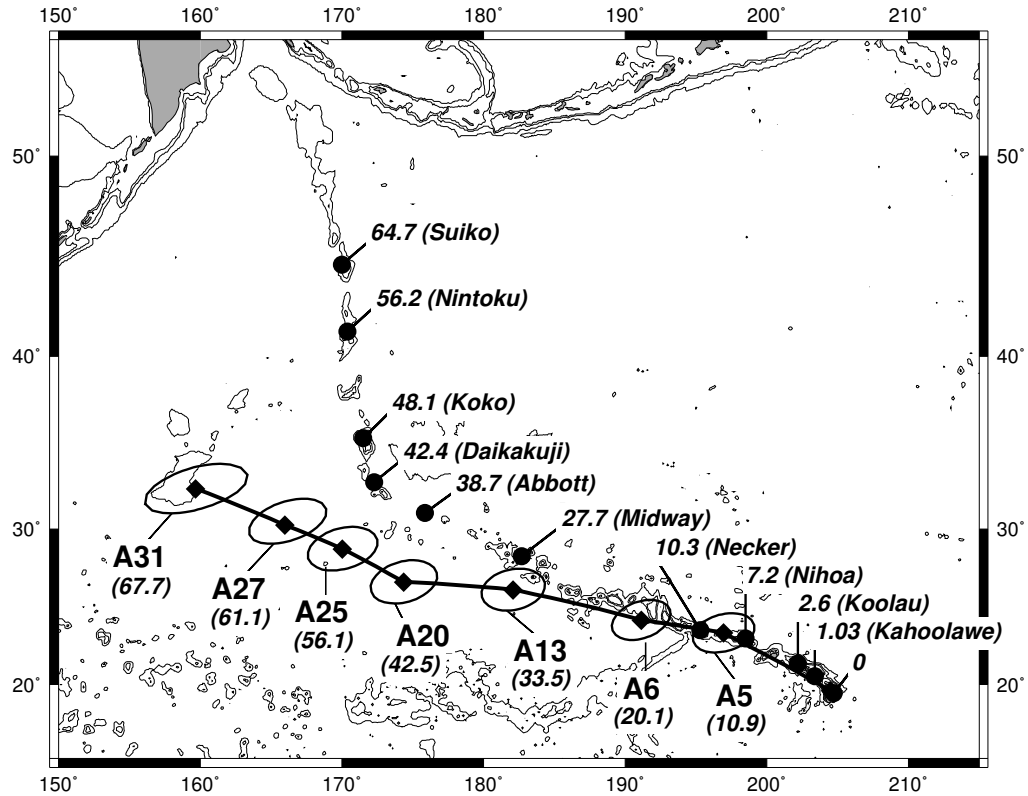
Introduction:

Long–known discrepancy between Hawaiian hotspot track and predicted track from plate circuits assuming hotspot fixity (e.g. Molnar and Stock, 1987)

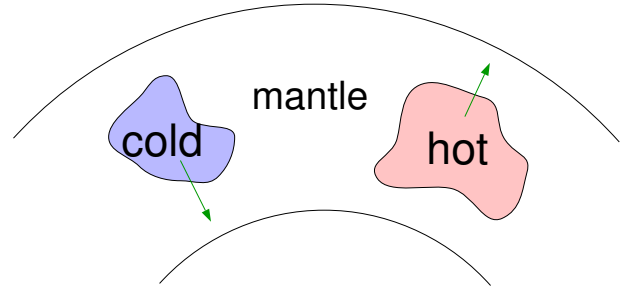


(figure from Cande et al., 1995)

Here we show how this discrepancy can be resolved by a combination of **hotspot motion**, obtained from geodynamic modeling, and **intraplate deformation** in accord with geologic observations.

Corollary: Success of this model – based on assuming a deep plume origin – supports this assumption, for at least some major plumes.

Essentials of numerical model

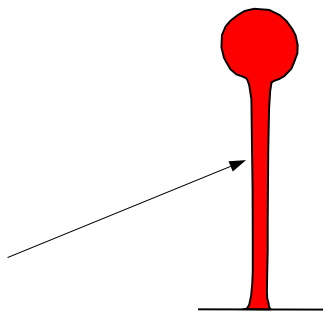


Mantle flow model

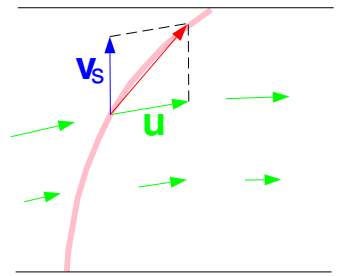
Large–scale flow inferred from surface plate velocities and internal density anomalies (from seismic tomography).

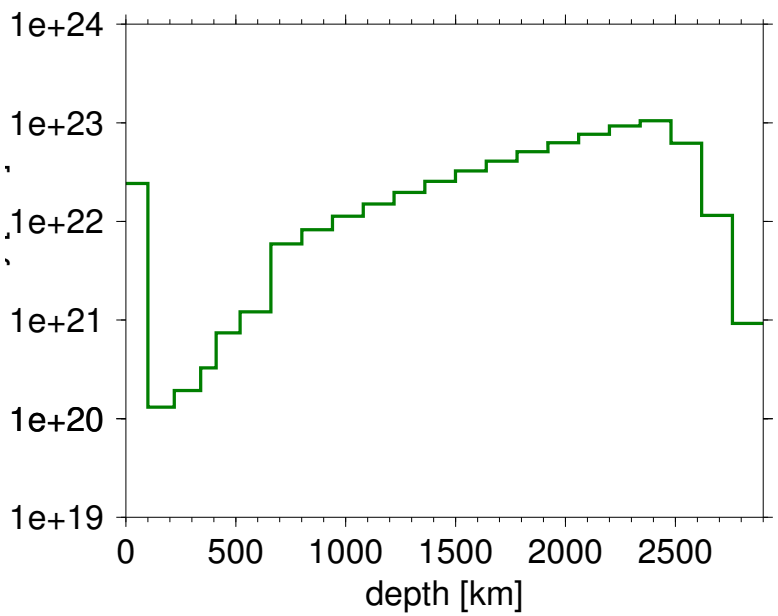
Plume Model

Initial condition: Vertical conduit



Advection of conduit in large– scale flow + buoyant vertical rising

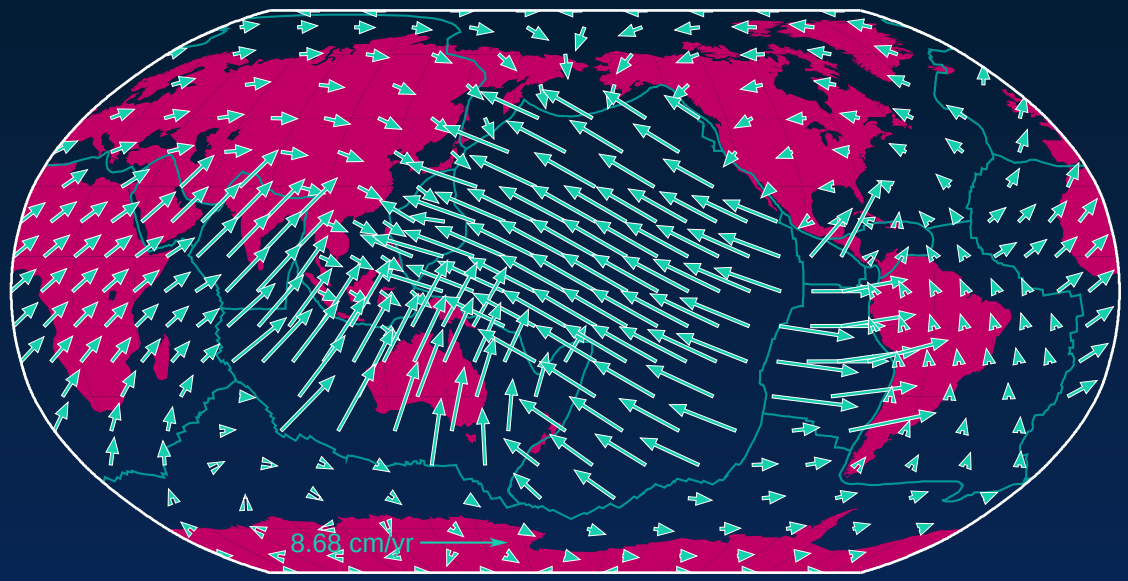


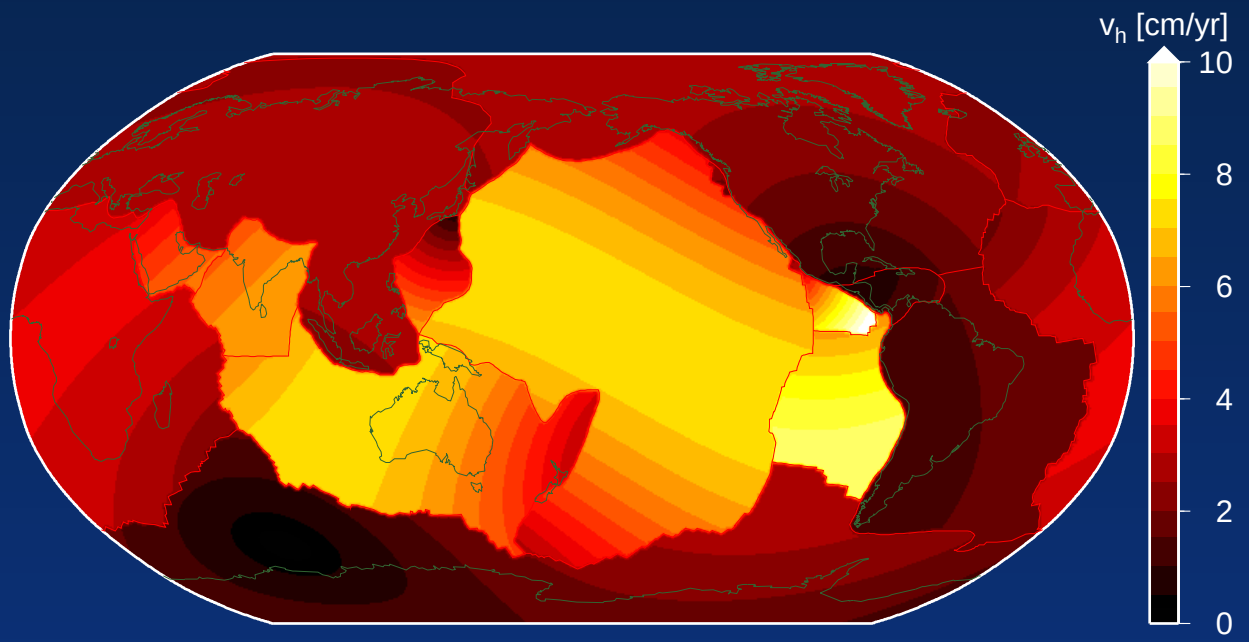


Viscosity structure

Obtained from optimizing fit to geoid, with additional heat flow constraint (Steinberger and Calderwood, 2001)

NUVEL-1 no-net-rotation reference frame



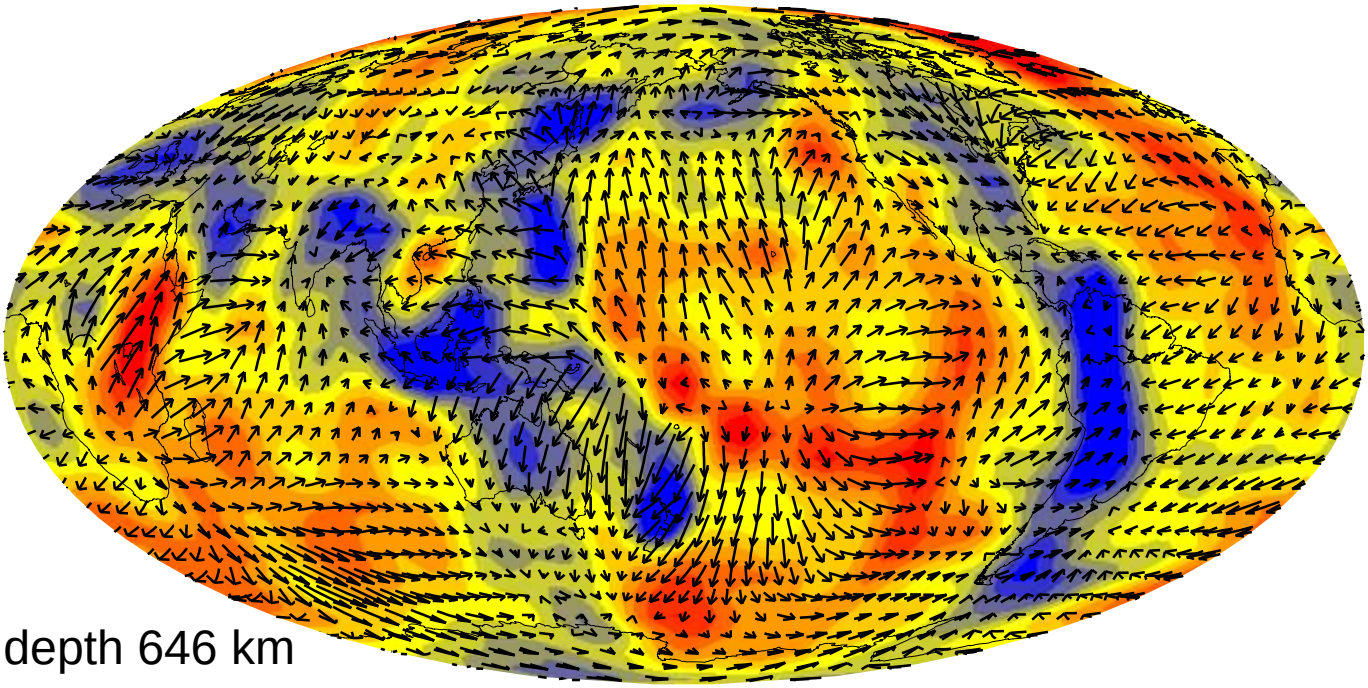


Computed flow field

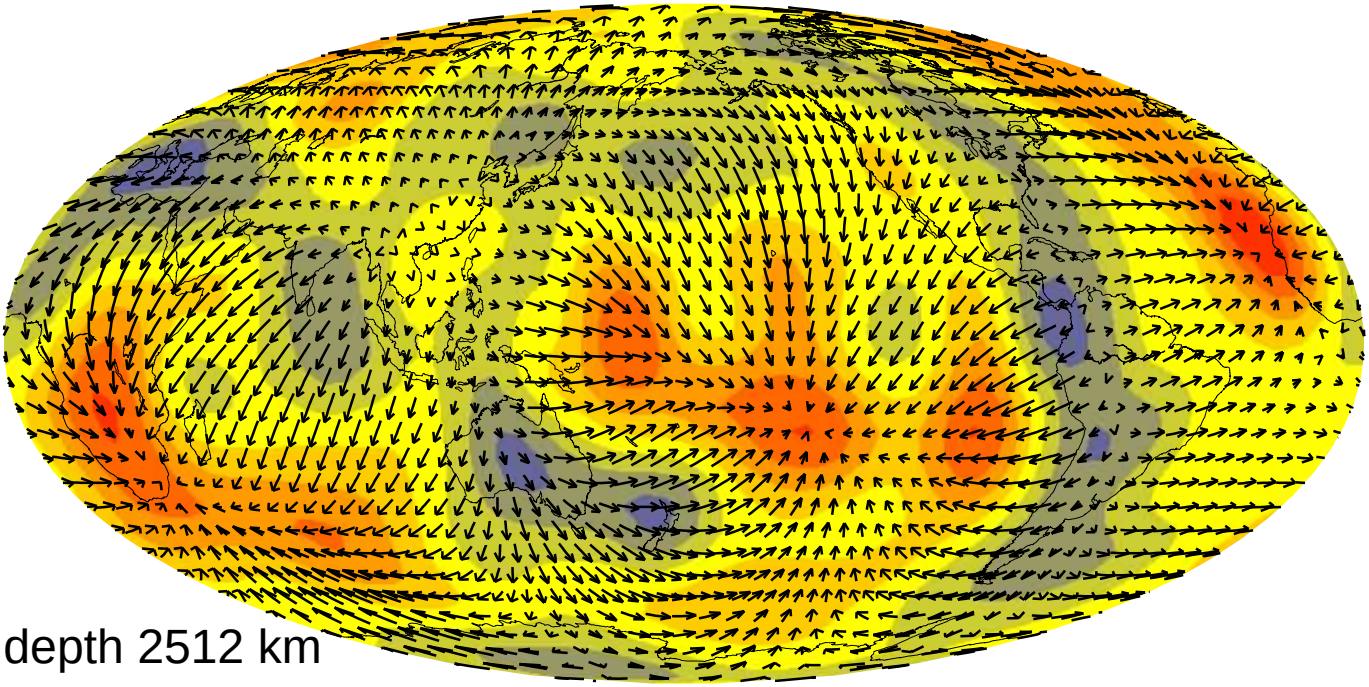
Based on model smean by Becker and Boschi (2002)

$(\delta\rho/\rho)/(\delta v_s/v_s)=0.2$ below 220 km

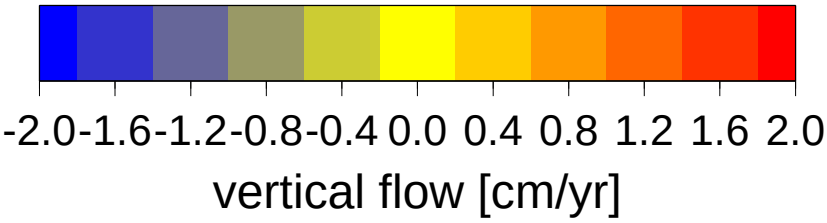
→ 2 cm/yr



depth 646 km

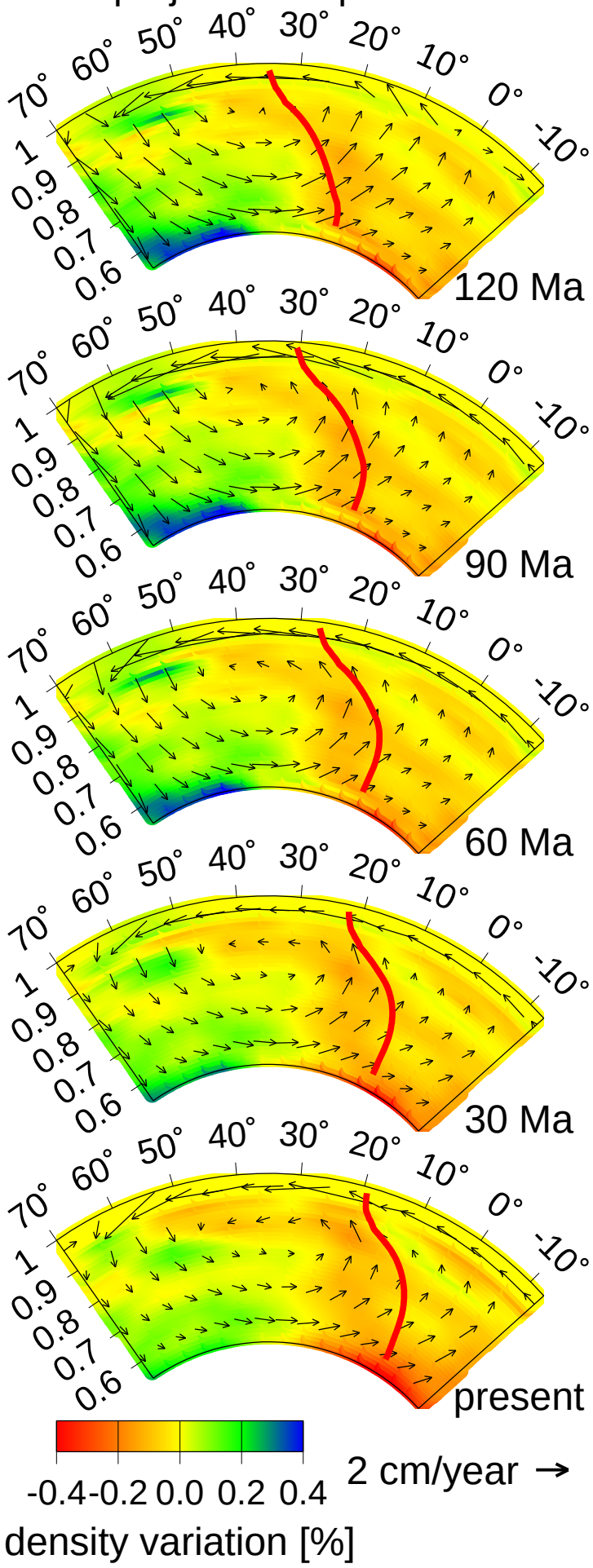


depth 2512 km



N-S mantle cross section at 155° W

and projection of predicted Hawaiian plume conduit (in red)



Step 1:

↑

density field inferred from seismic tomography (here: model *smean* by *Becker and Boschi, 2002*)

↑

compute flow with spectral method (*Hager and O'Connell, 1979, 1981*)

↑

backward advection for t < 68 Ma

also, plate motion b.c. for flow changes with time (for t < 120 Ma)

Step 2:

insert vertical conduit (here: at time 170 Ma)

↓

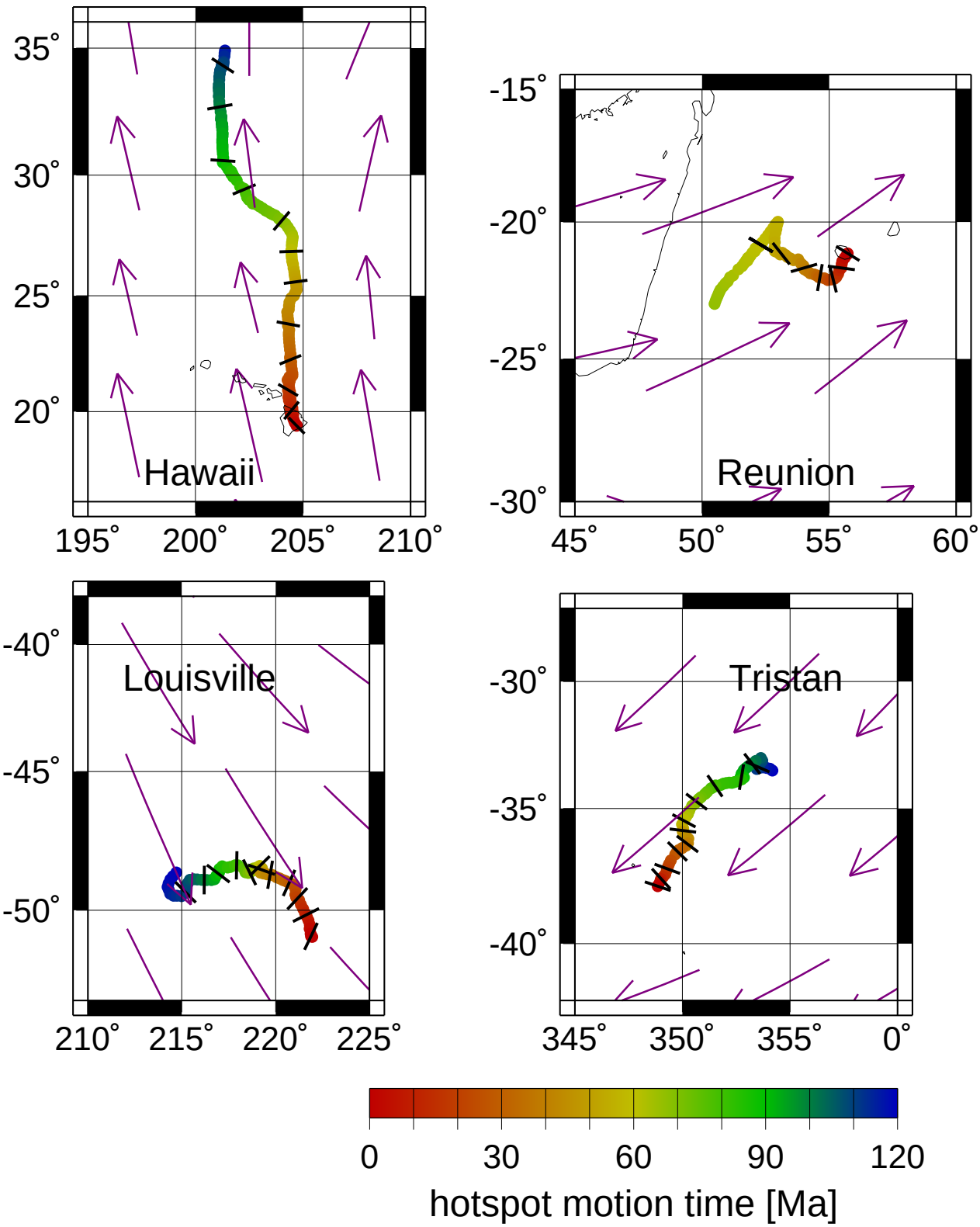
plume conduit gets distorted

↓

hotspot moves

Computed hotspot motion

and flow at depth 790 km → 1 cm/year



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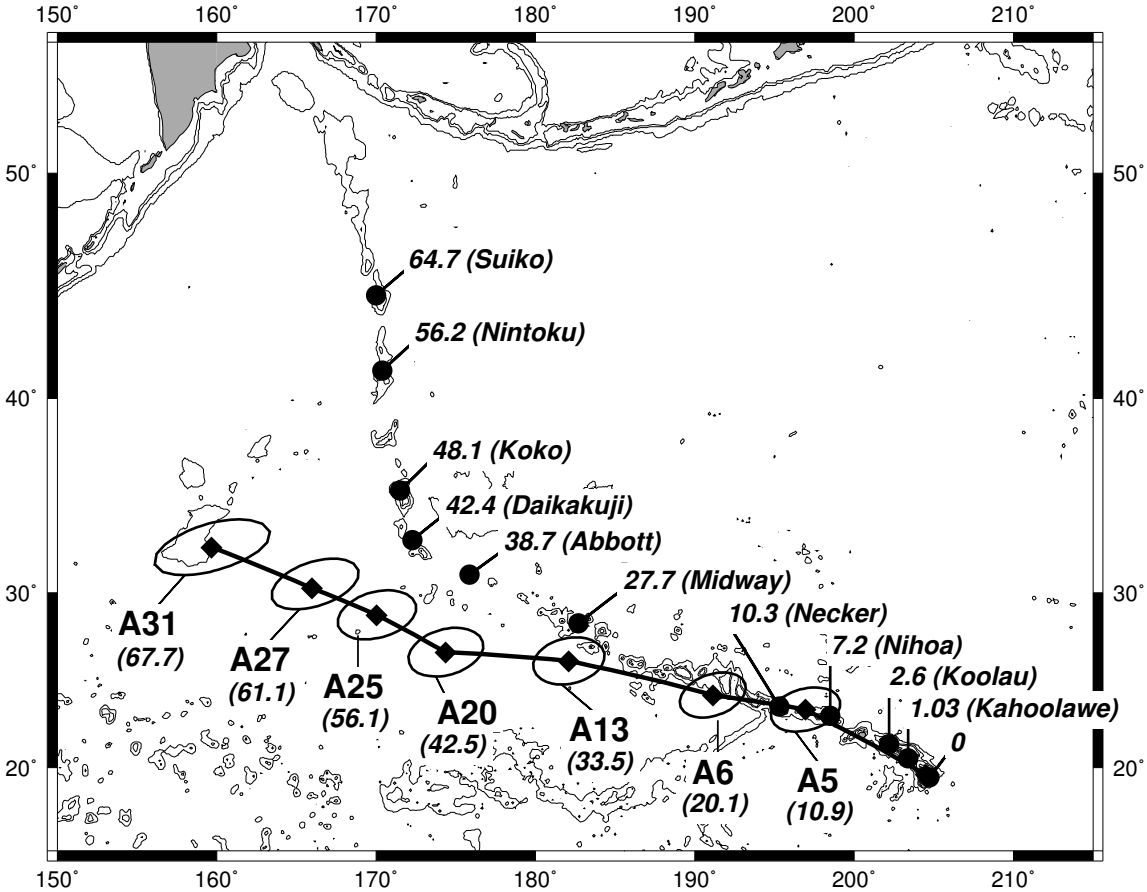

(figure from Cande et al., 1995)

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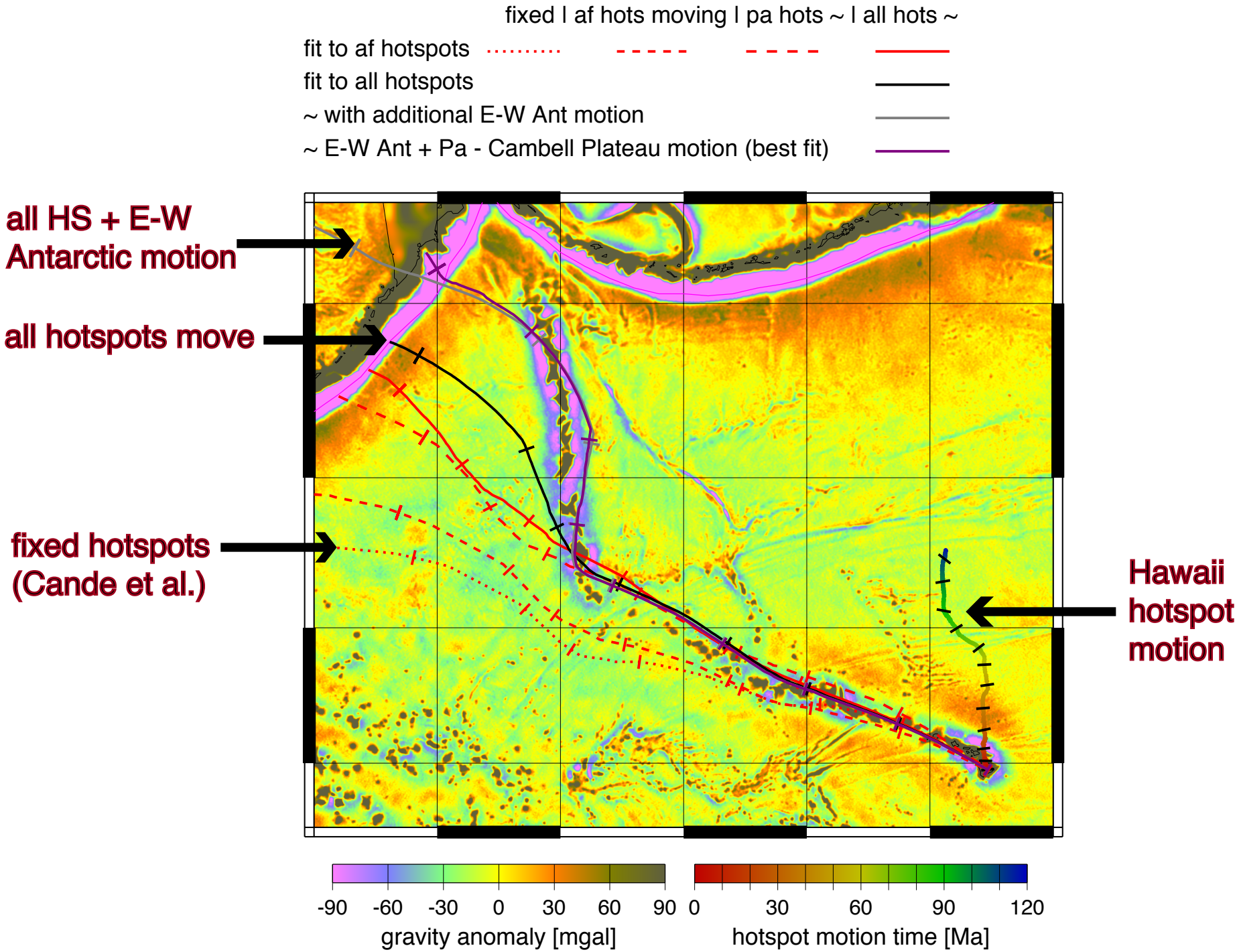
Hawaii hotspot computed motion and track



Computed hotspot motion and tracks

fixed | af hots moving | pa hots ~ | all hots ~

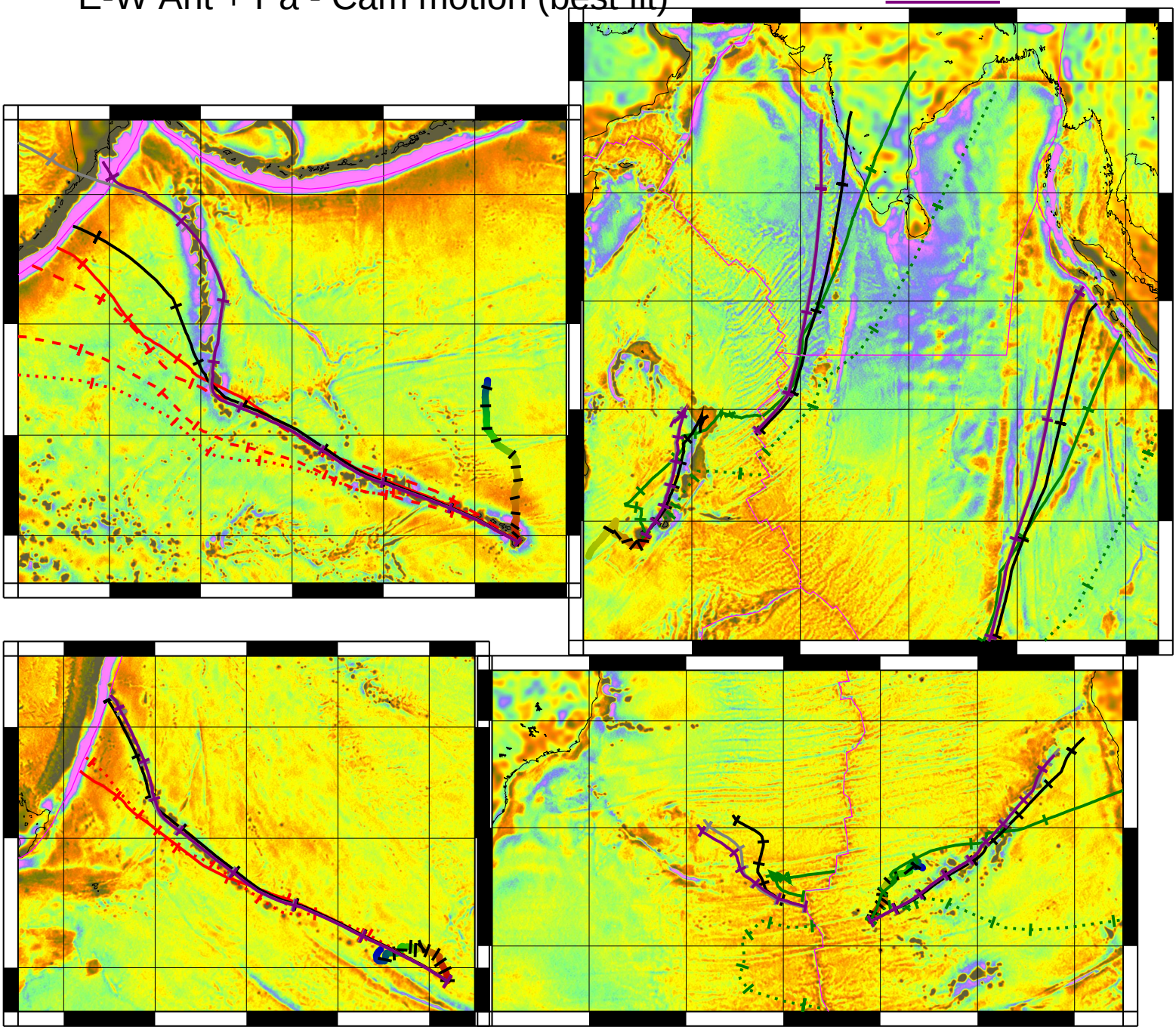
fit to af hots

fit to pa hots

fit to all hots

~ with additional E-W Ant motion

~ E-W Ant + Pa - Cam motion (best fit)



-90 -60 -30 0 30 60 90

gravity anomaly [mgal]

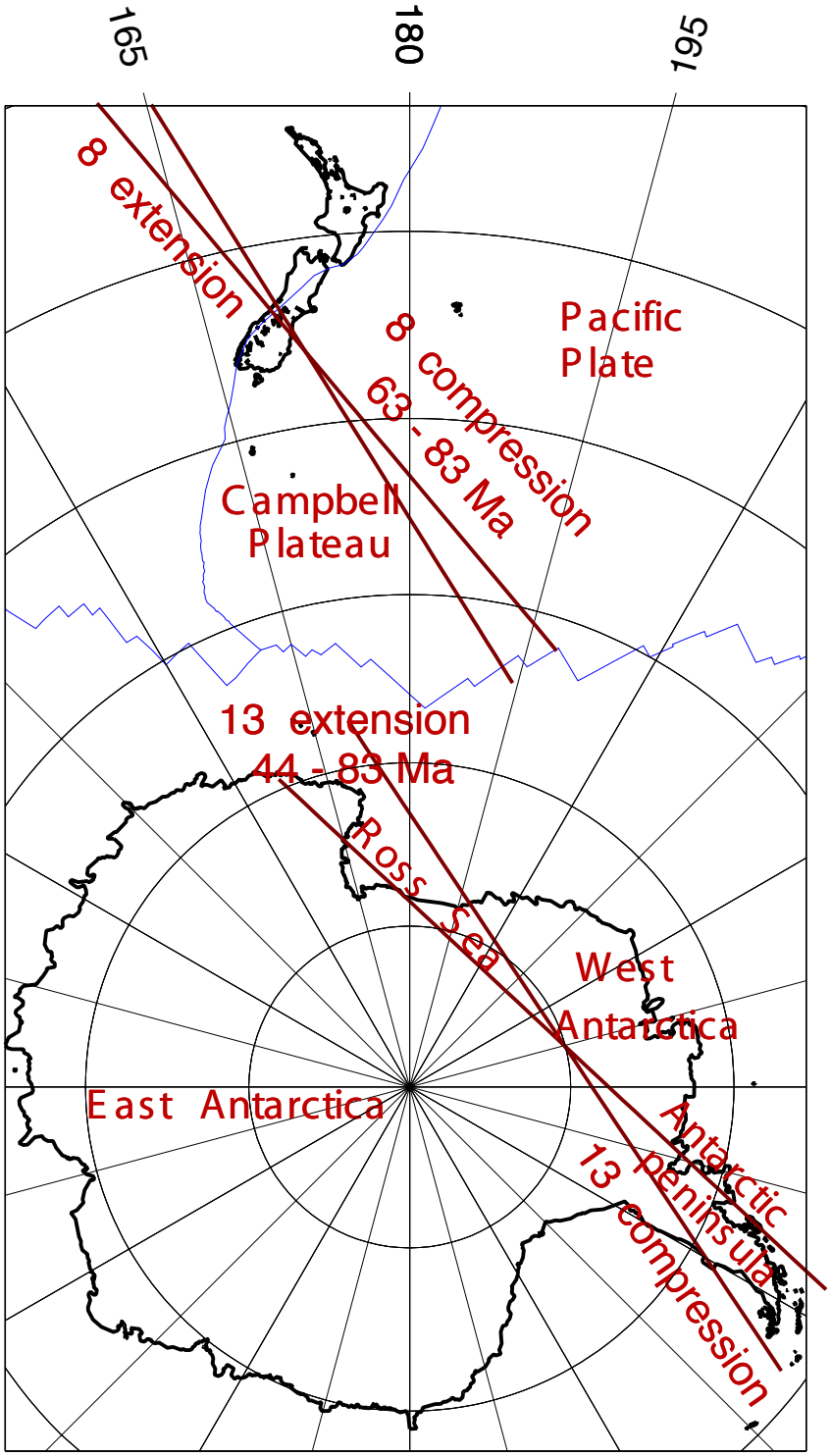
0 30 60 90 120

hotspot motion time [Ma]

Antarctic motion that could account for the northerly trend in the Hawaiian hotspot track prior to 43 My.

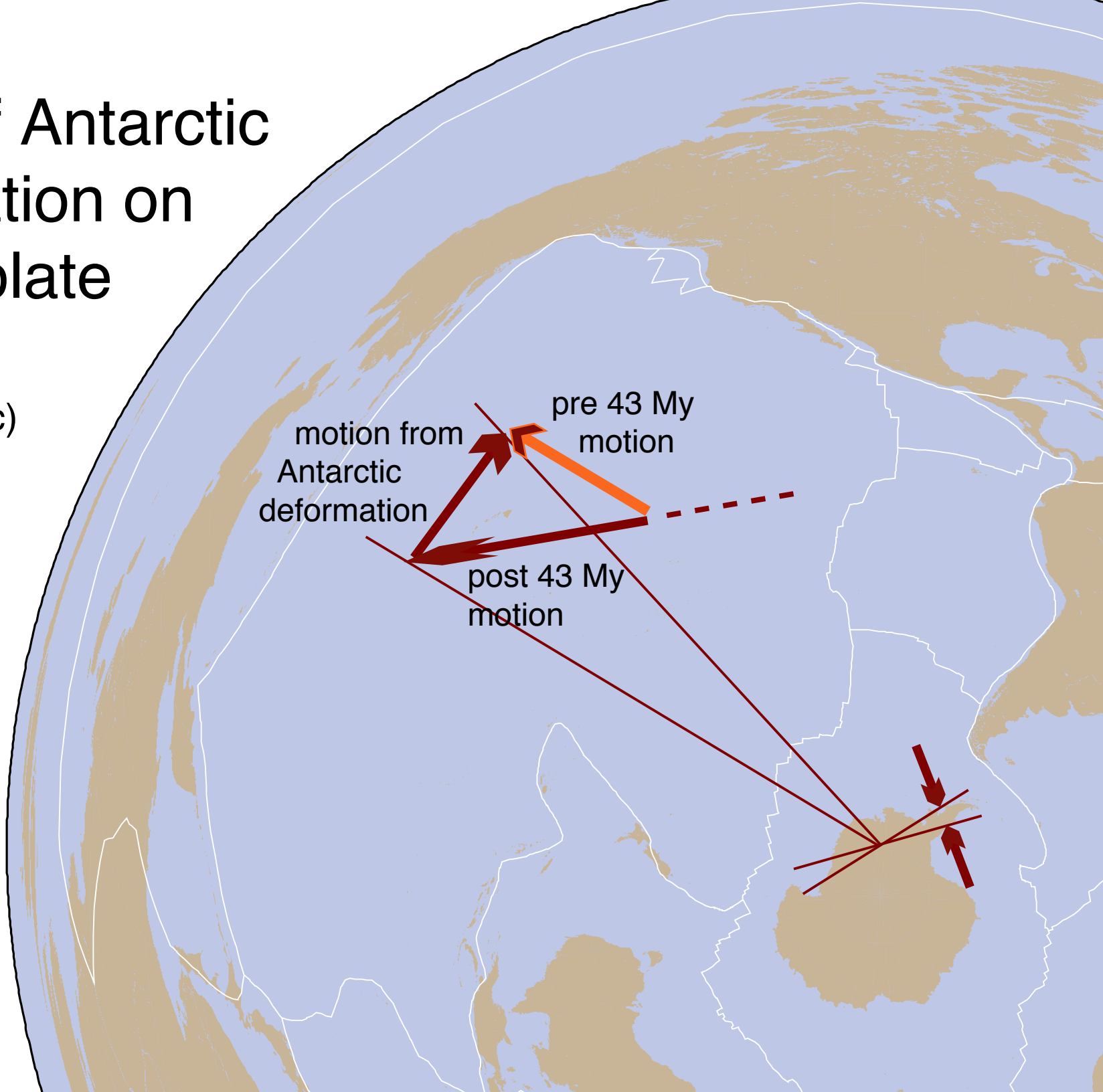
Proposed deformation (Rupert Sutherland, Geological and Nuclear sciences, New Zealand)

Proposed deformation (B. Steinberger)



Effect of Antarctic deformation on Pacific plate motion.

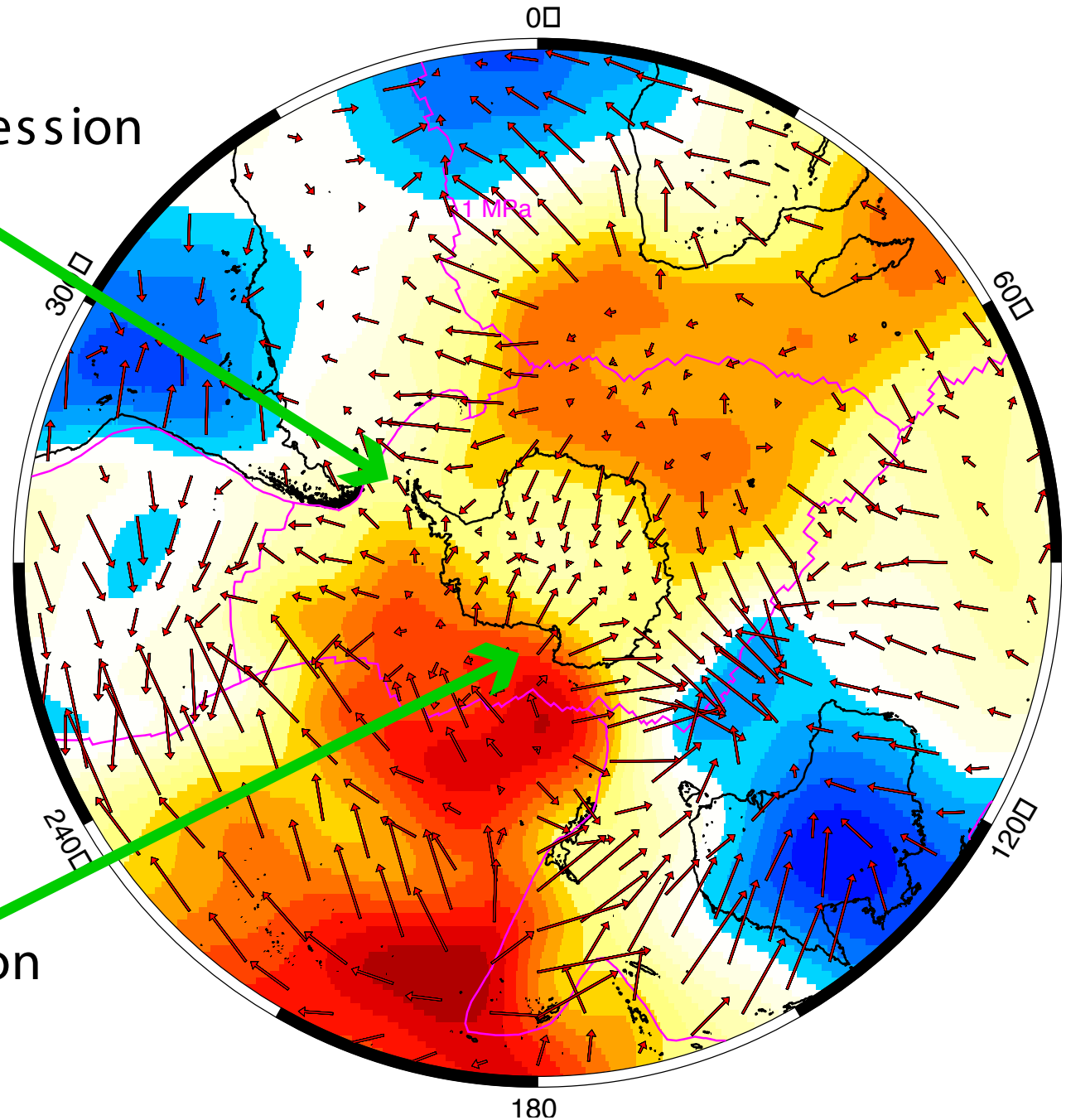
(diagrammatic)



Tractions due to mantle density and plate motion, present day.

converging=compression

Present-day tractions from mantle flow are similar to the proposed deformation for times prior to 43 My ago.

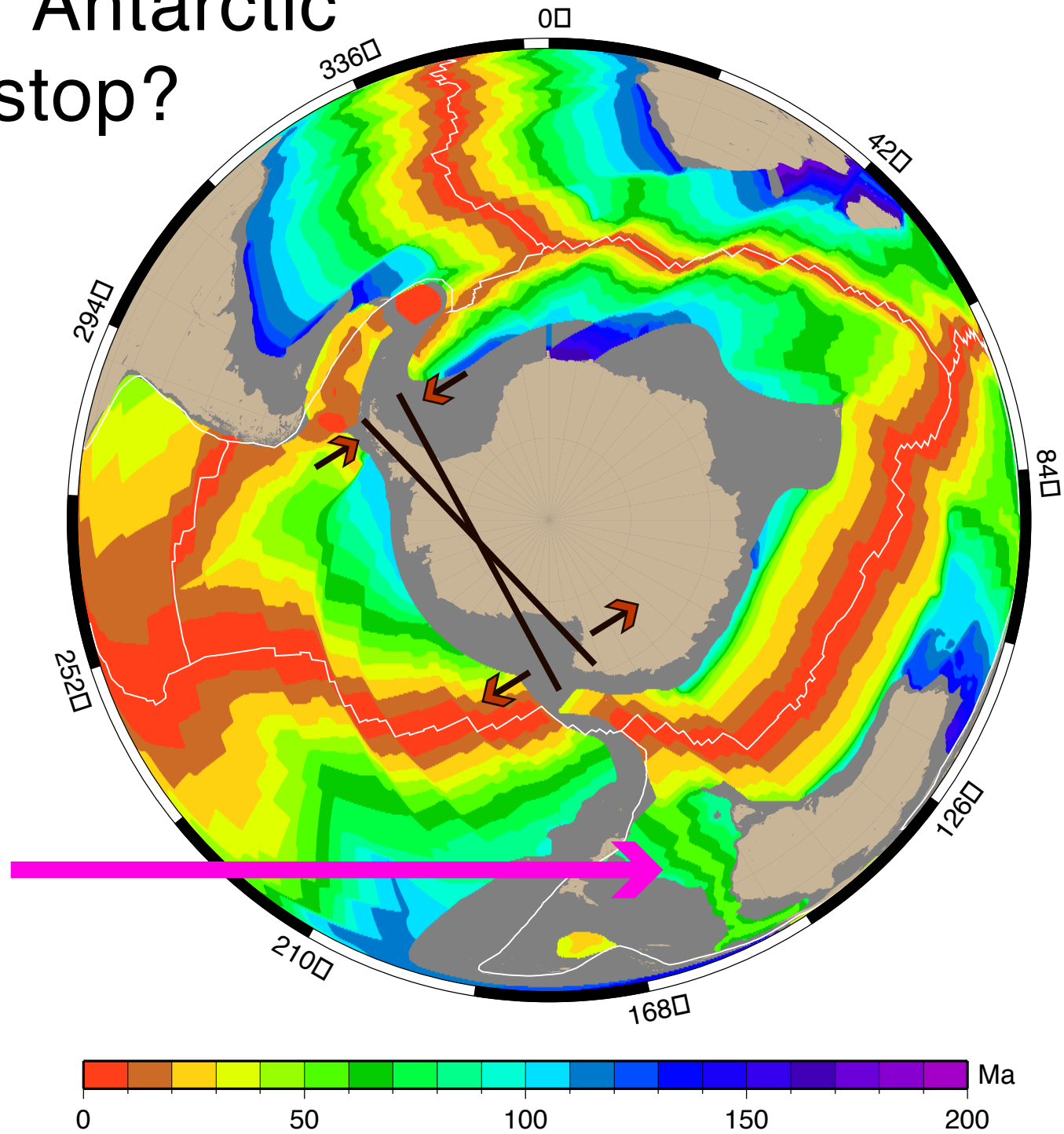


diverging=extension

Why did E-W Antarctic deformation stop?

1. Growth of strong oceanic lithosphere around continent inhibited motion (green areas).

2. Cessation of spreading in the Tasman Sea at ~52My diminished speading extention in Ross Sea.



Summary

- Mantle flow model in accordance with geoid, global heat flux, postglacial rebound – strong increase of viscosity with depth required.
- Southward motion of Hawaiian hotspot predicted. For some models, fast motion during formation of Emperor chain ($\sim$ agrees with paleolatitudes)
- Commonly slow motion ($\lesssim$ 1 cm/yr) predicted: Southward for Kerguelen ($\sim$ agrees with paleolatitudes), south-eastward for Louisville, southward (if any) for Tristan, eastward for Reunion
- Hotspot motion sufficient to fit hotspot tracks on both hemispheres after 43 Ma
- With $\sim$ 13 degrees of rotation between E and W Antarctica between $\sim$ 83 and 43 Ma(+ possibly deformation in New Zealand between $\sim$ 83 and 63 Ma) achieve approximate fit of hotspot tracks on both hemispheres for times before 43 Ma. Proposed deformation consistent with geologic evidence (R. Sutherland, unpublished manuscript).
- Antarctic deformation in accord with stresses from mantle flow — may have stopped after sufficient oceanic lithosphere had formed around Antarctica.
- Combination of hotspot motion and Antarctic deformation sufficient to account for Hawaiian hotspot track with bend at 43 Ma.