MANTLE PLUME GEODYNAMICS

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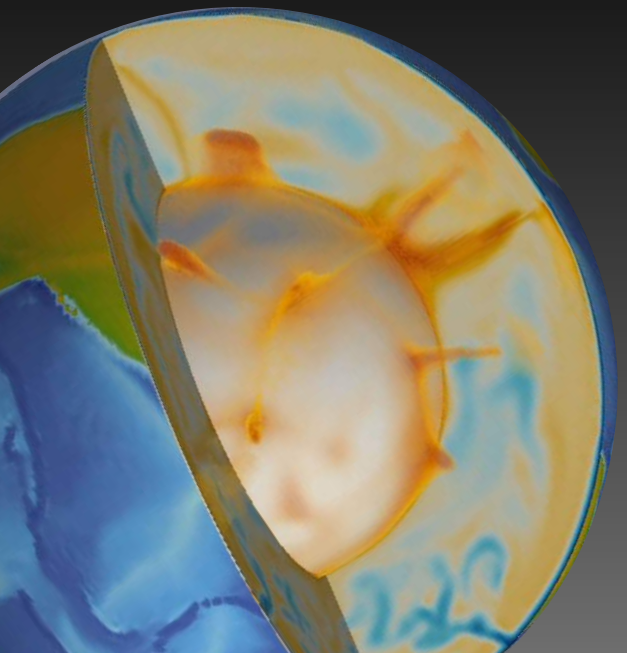
INSIGHTS FROM NUMERICAL EXPERIMENTS



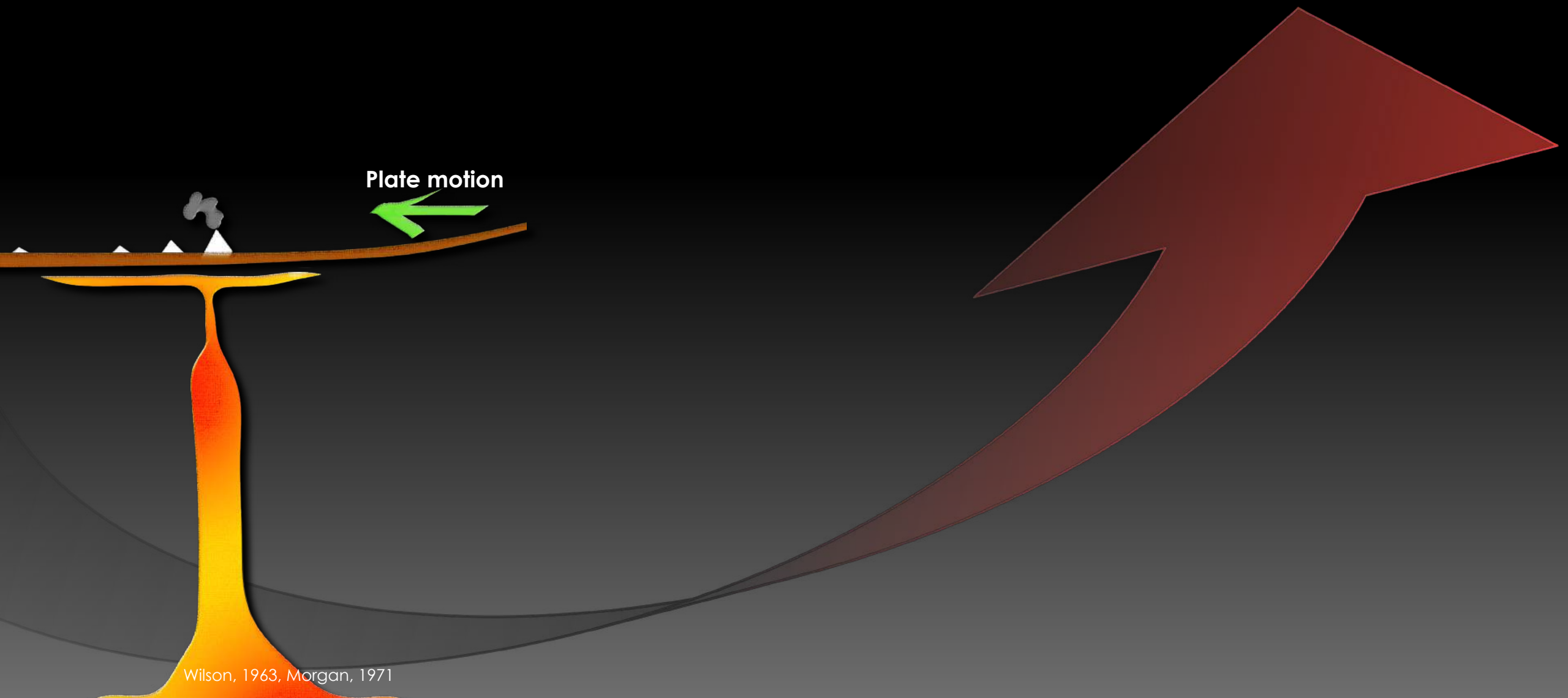
MAËLIS ARNOULD

N. COLTICE, N. FLAMENT, C. MALLARD,

B. MATHER, M. RODRIGUEZ, M. SORET ET AL.

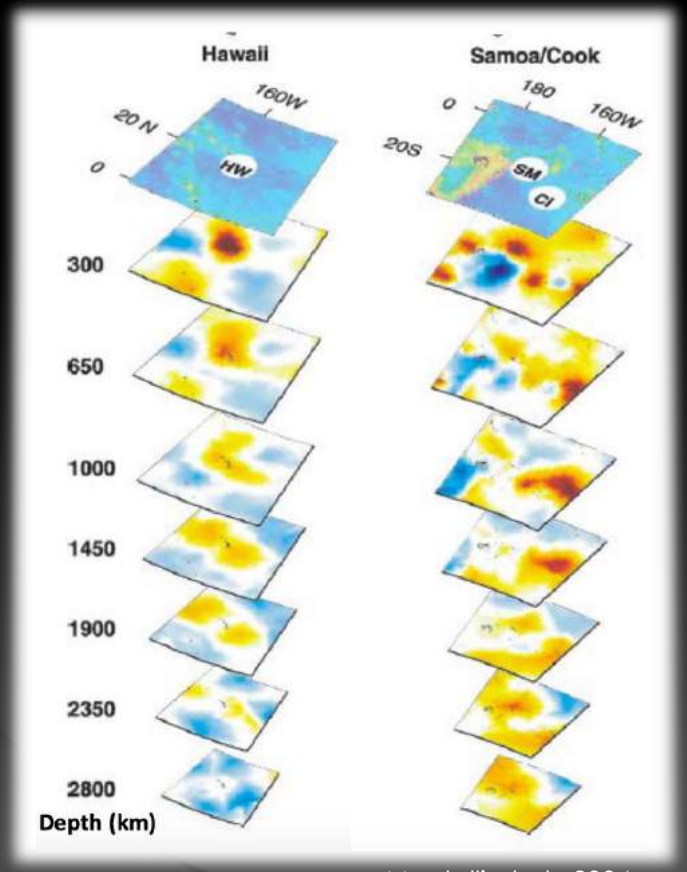
08TH OCTOBER 2021 – COLLÈGE DE FRANCE

OUR VIEW OF MANTLE PLUMES…



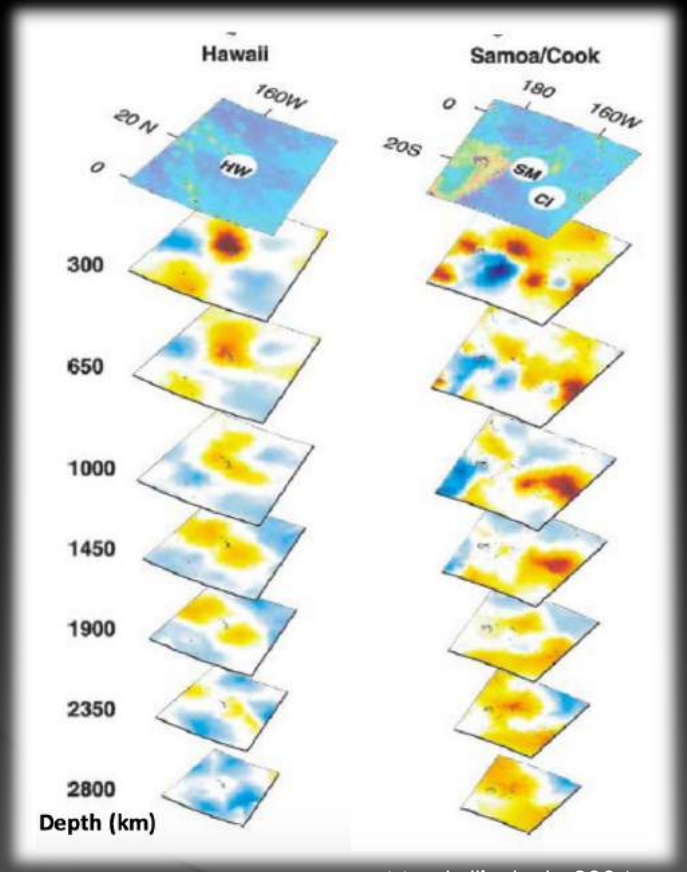
Wilson, 1963, Morgan, 1971

OUR VIEW OF MANTLE PLUMES…

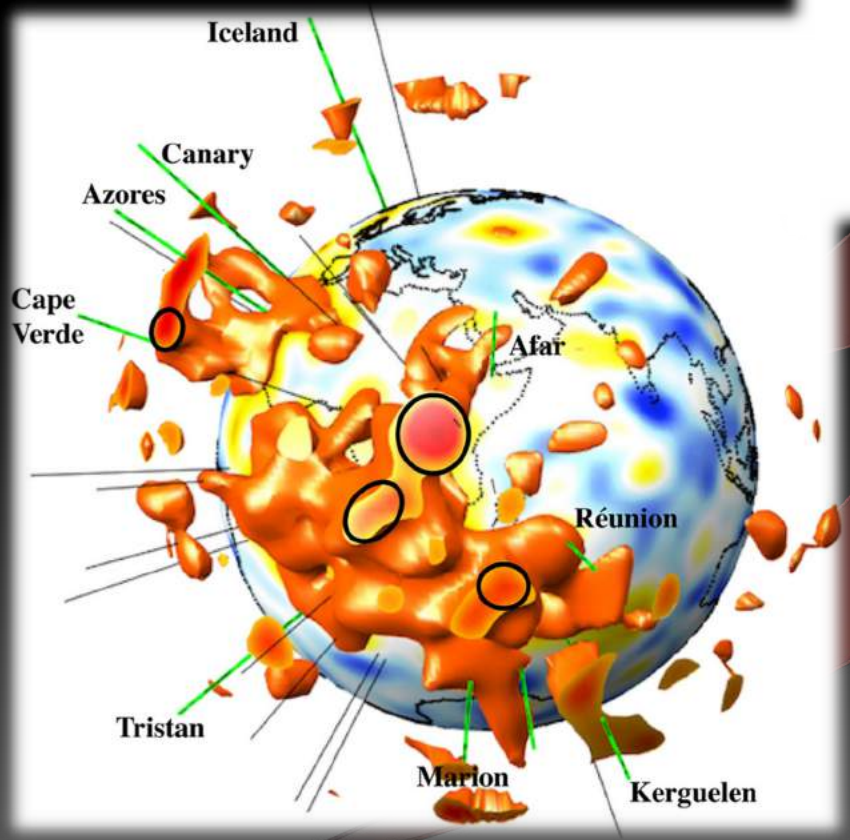


Montelli et al., 2004

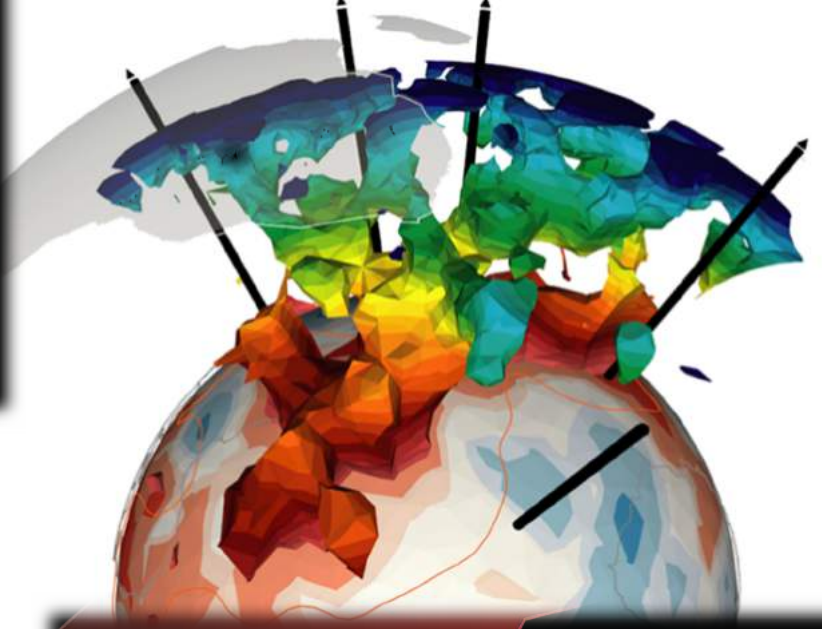
OUR VIEW OF MANTLE PLUMES…



Montelli et al., 2004

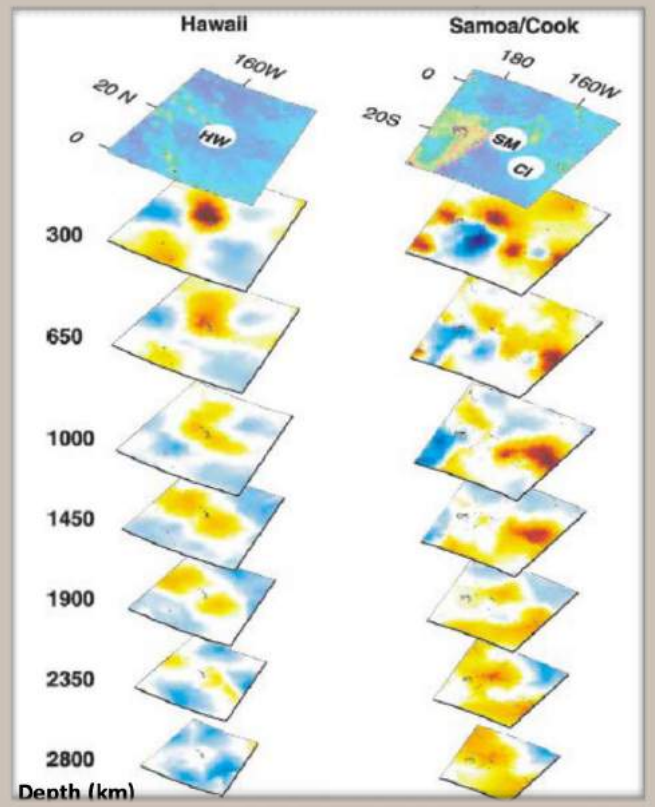


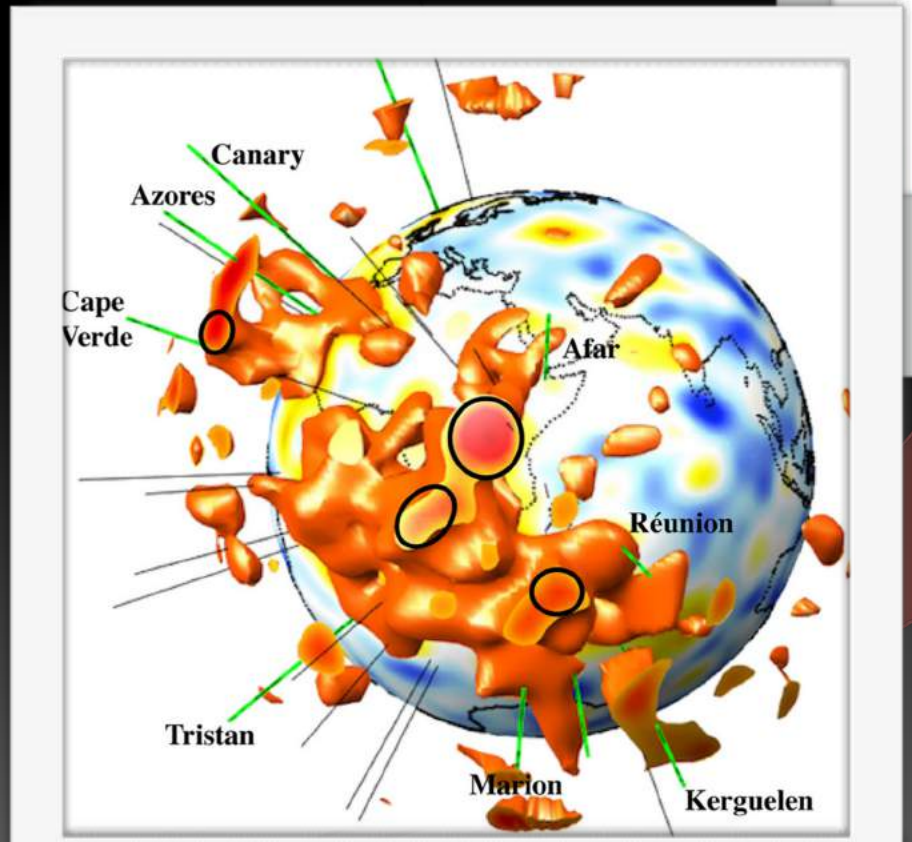
Davaille and Romanowicz, 2020

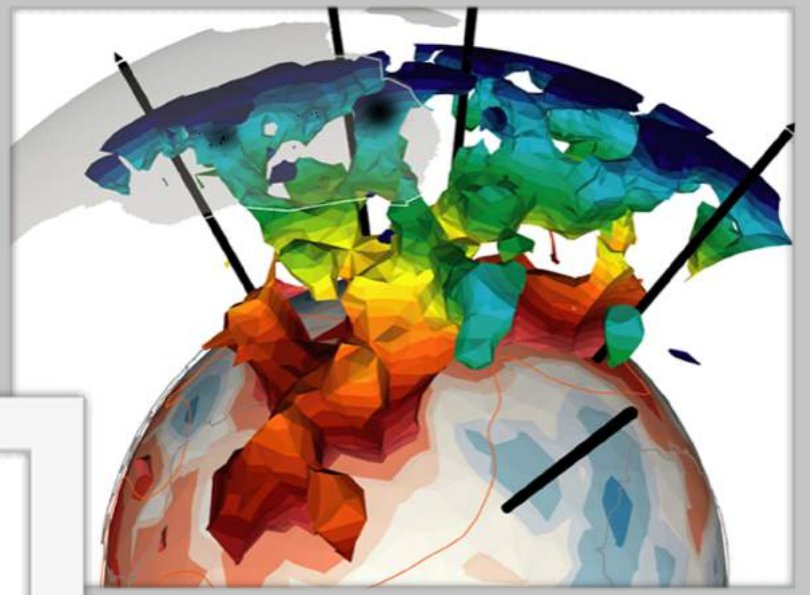


Tsekhmistrenko et al., 2021

OUR VIEW OF MANTLE PLUMES…







MODELING MANTLE PLUME DYNAMICS

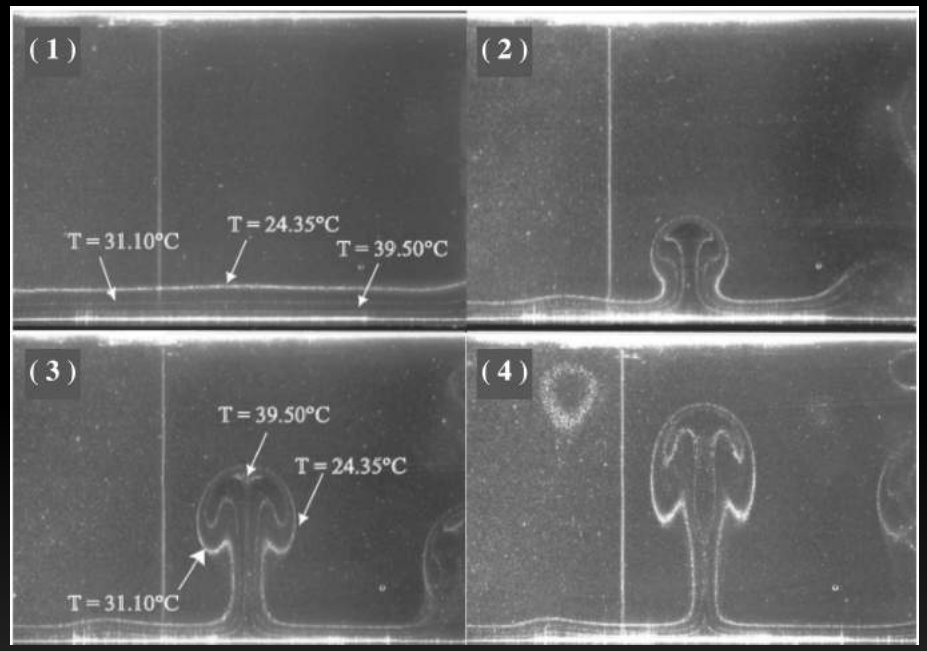
Tsekhmistrenko et al., 2021

MODELING MANTLE PLUME DYNAMICS

Tsekhmistrenko et al., 2021

From a collection of drawings gathered by researchers working on a famous hotspot (University of Hawaii)

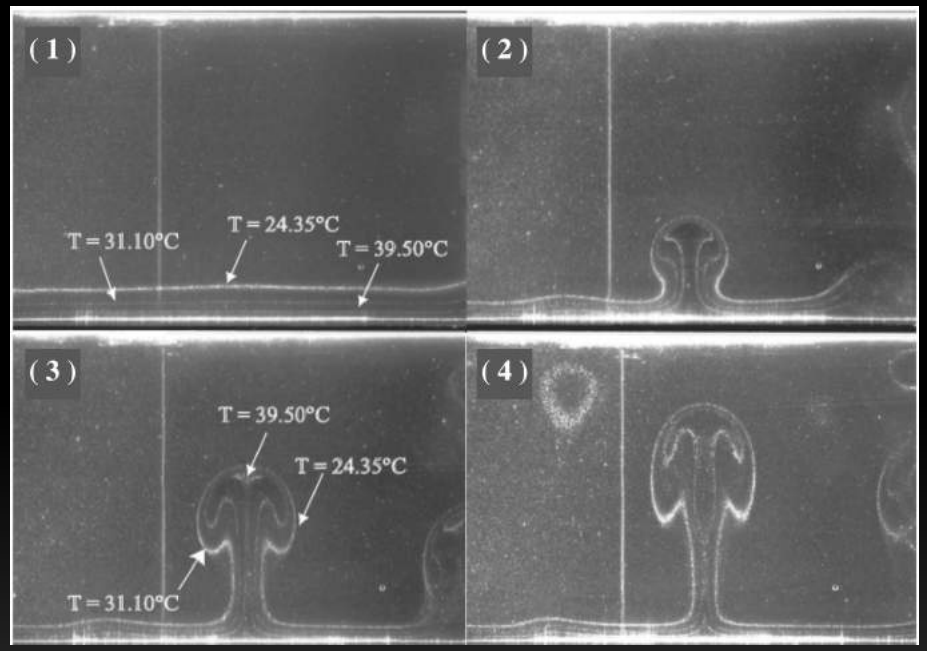
MODELING MANTLE PLUME DYNAMICS



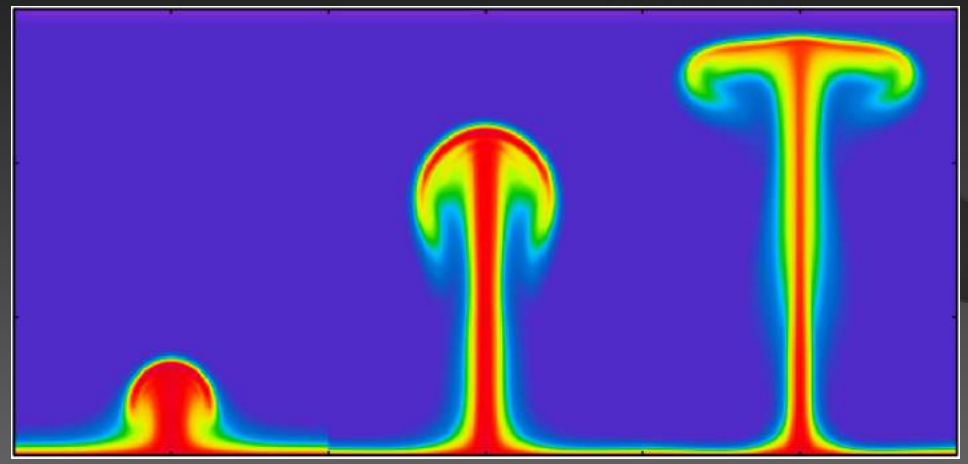
Davaille and Romanowicz, 2020

Tsekhmistrenko et al., 2021

MODELING MANTLE PLUME DYNAMICS



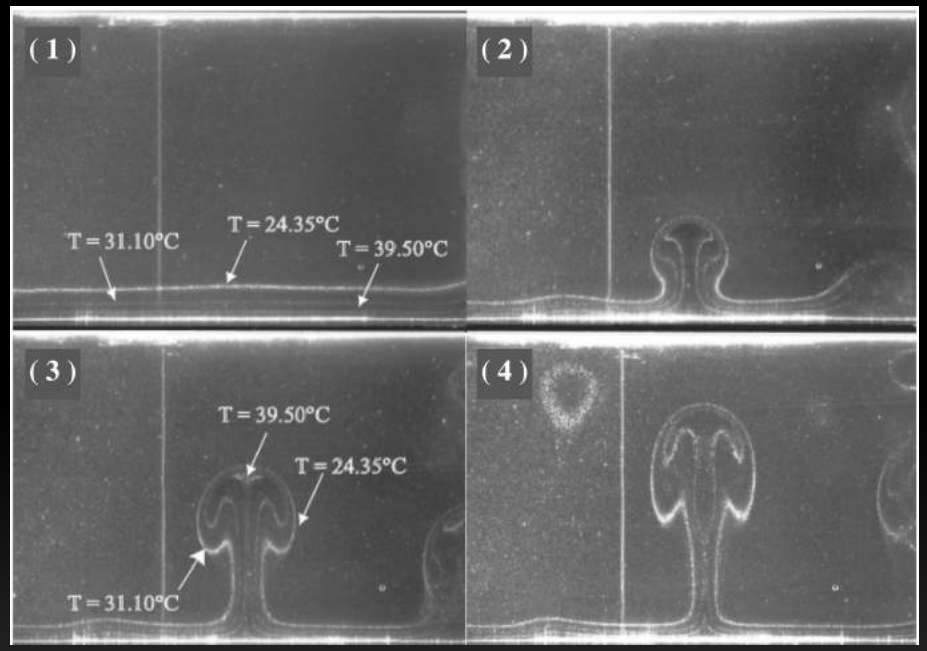
Davaille and Romanowicz, 2020



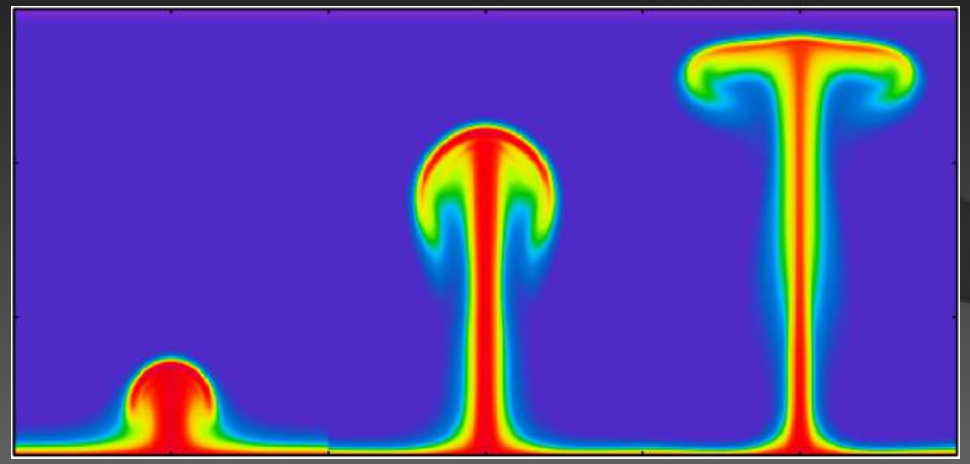
Farnetani and Hofmann, 2011

Tsekhmistrenko et al., 2021

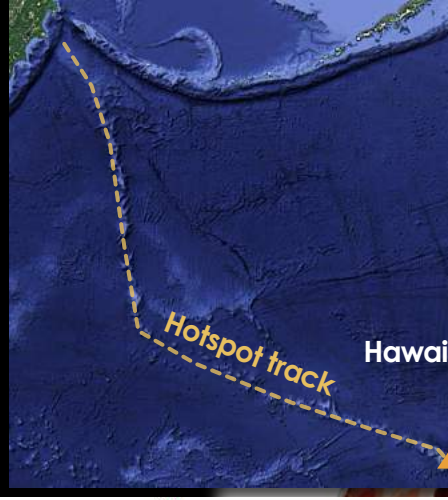
MODELING MANTLE PLUME DYNAMICS

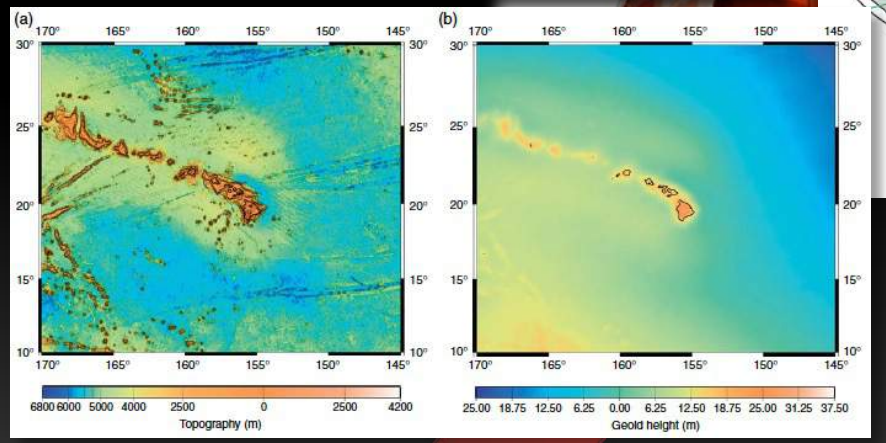


Davaille and Romanowicz, 2020

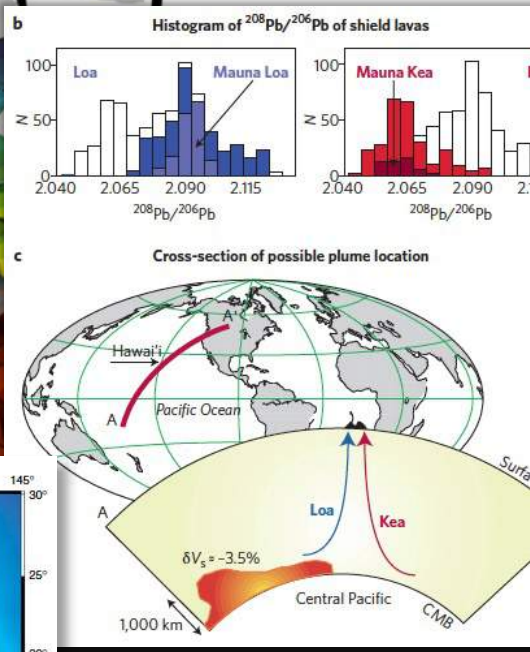


Farnetani and Hofmann, 2011



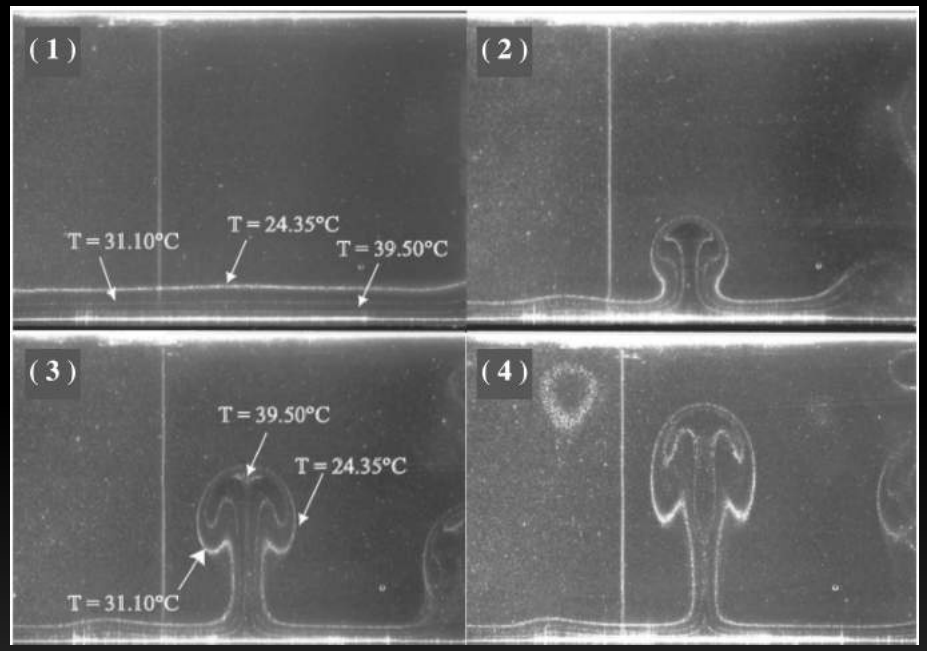


McNutt and Shure, 1986

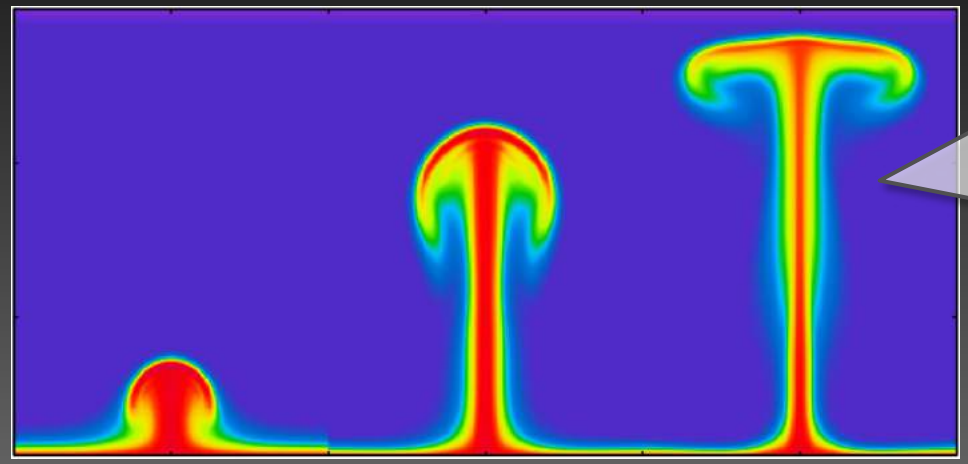


Weis et al., 2011

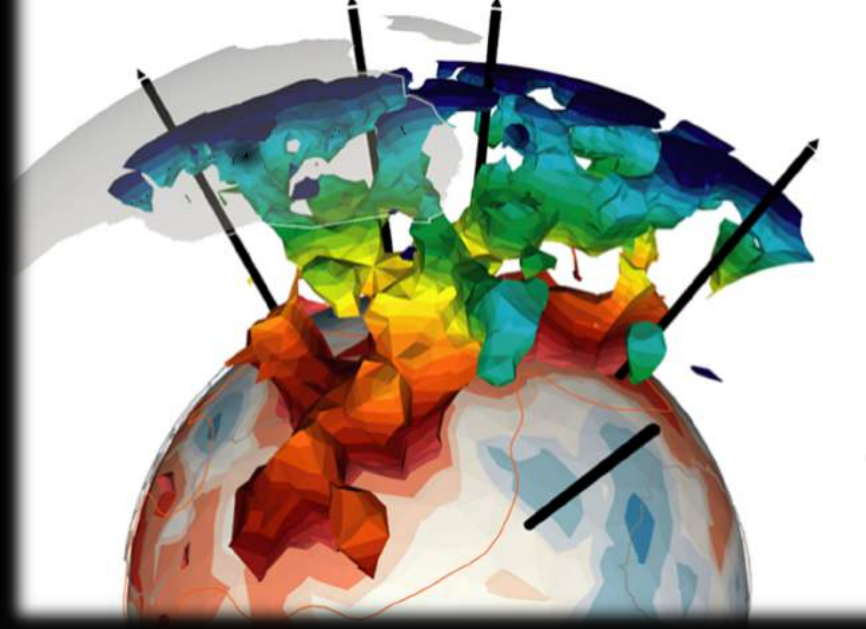
MODELING MANTLE PLUME DYNAMICS



Davaille and Romanowicz, 2020



Farnetani and Hofmann, 2011



Tsekhmistrenko et al., 2021

Is there anyone else out there ? ?

MODELING MANTLE PLUME DYNAMICS

Tsekhmistrenko et al., 2021

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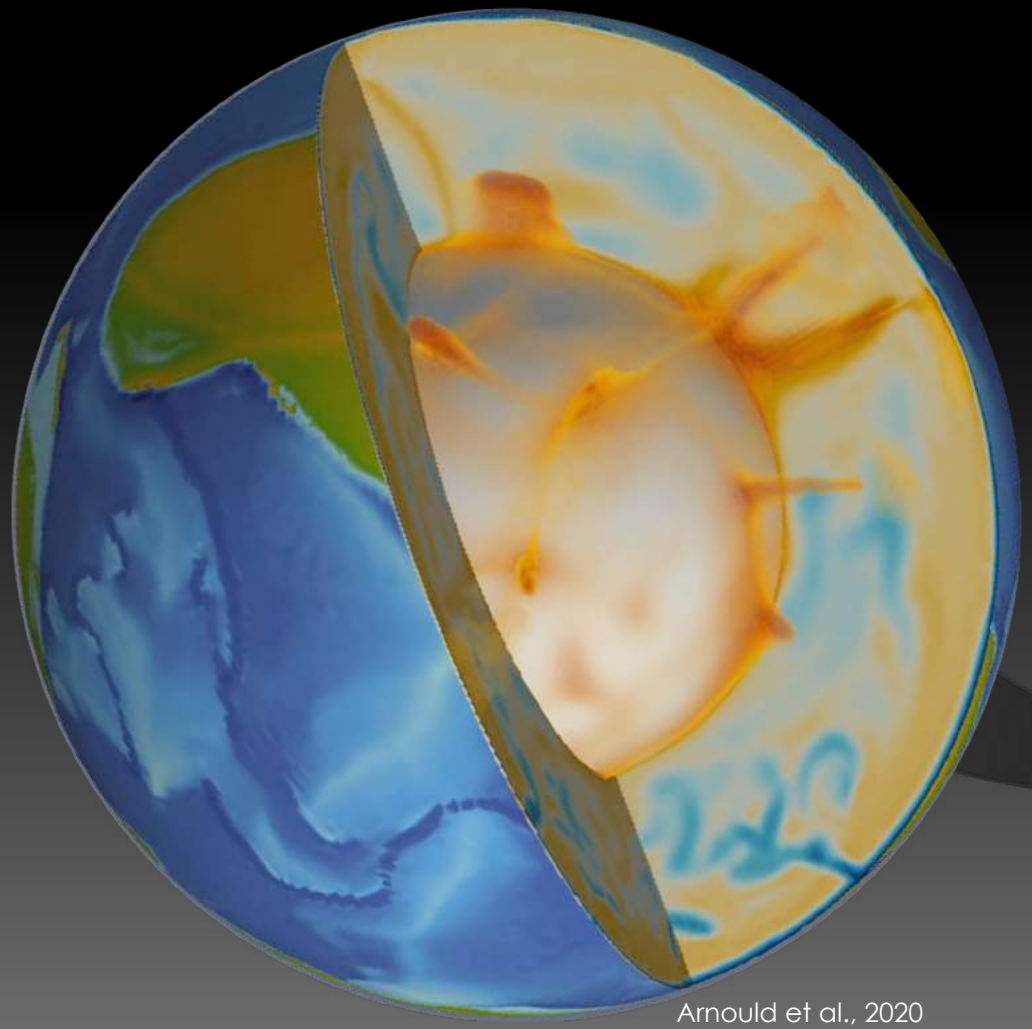
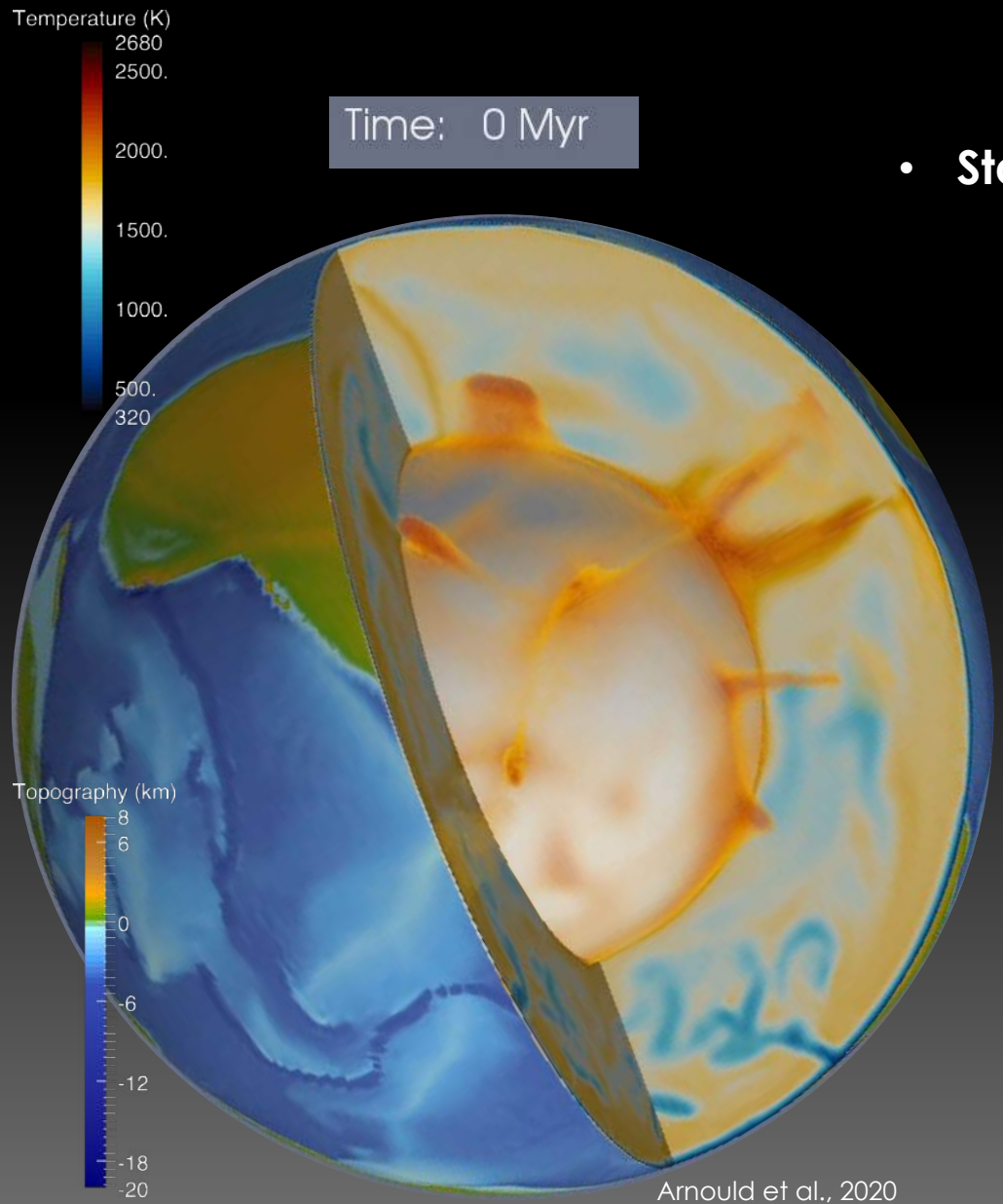


Arnould et al., 2020

MODELING MANTLE PLUMES IN THEIR ENVIRONMENT



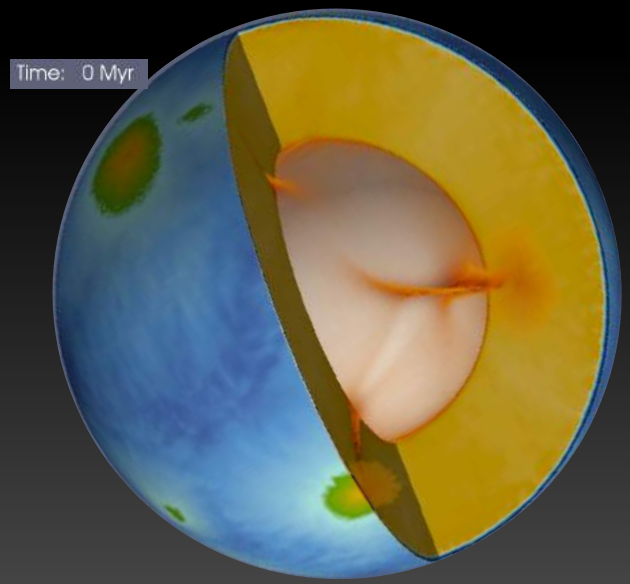
Arnould et al., 2020

- StagYY code
- Boussinesq approximation
- Earth-like Rayleigh number (10^7)
- 7 orders of lateral and radial viscosity variations
- Pseudo-plastic rheology

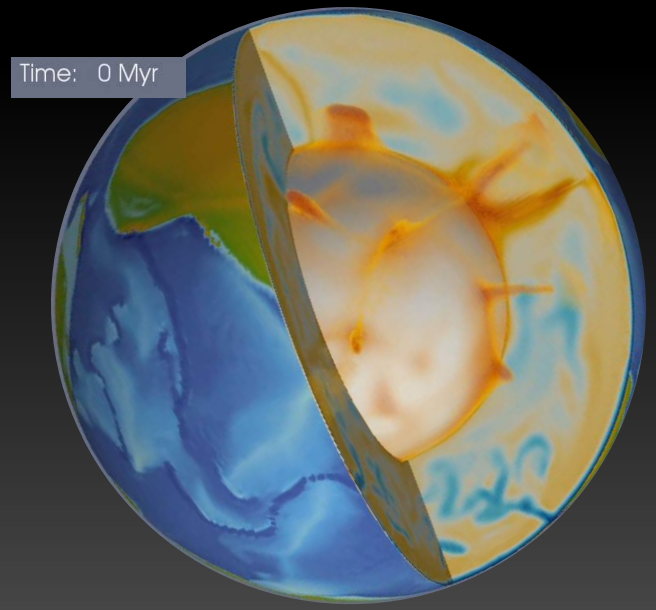
⇒ Plate-like tectonics with Earth-like surface topography, heat flow and velocities

MODELING MANTLE PLUMES IN THEIR ENVIRONMENT

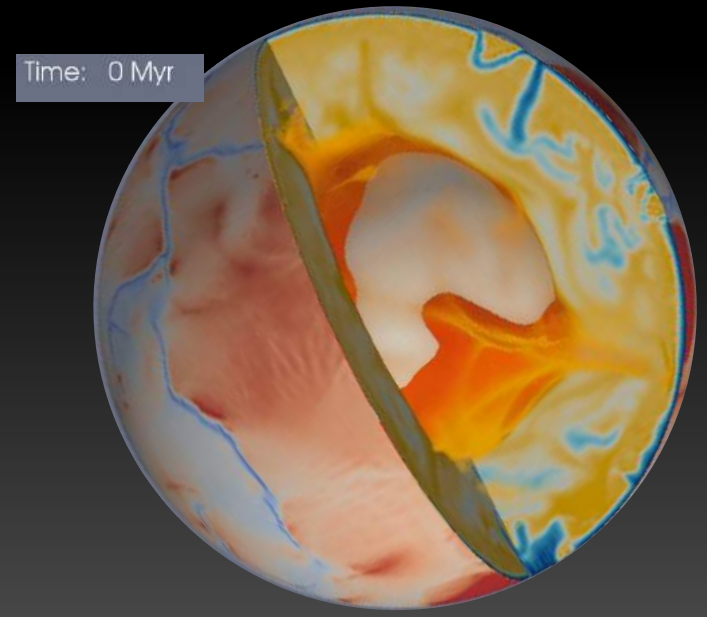
Stagnant lid model



Model with plate tectonics



Model with plate tectonics + thermochemical heterogeneities

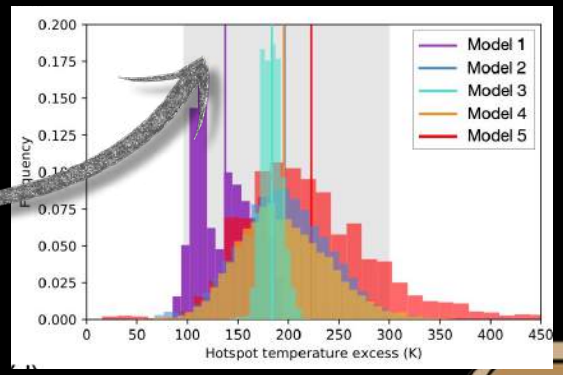


Arnould et al., 2020

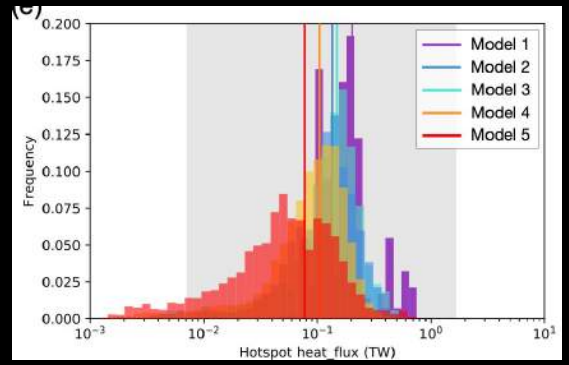
MODELING MANTLE PLUMES IN THEIR ENVIRONMENT

Shaded areas = range of observations

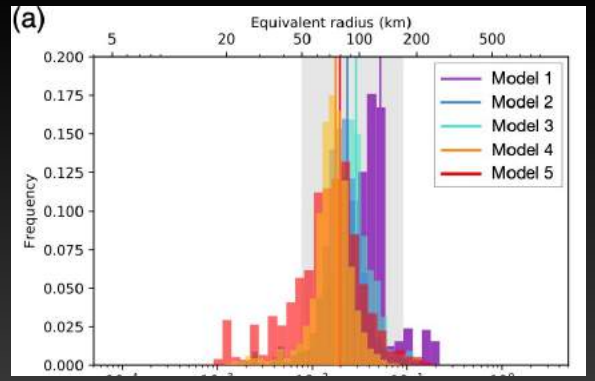
Plume temperature excess

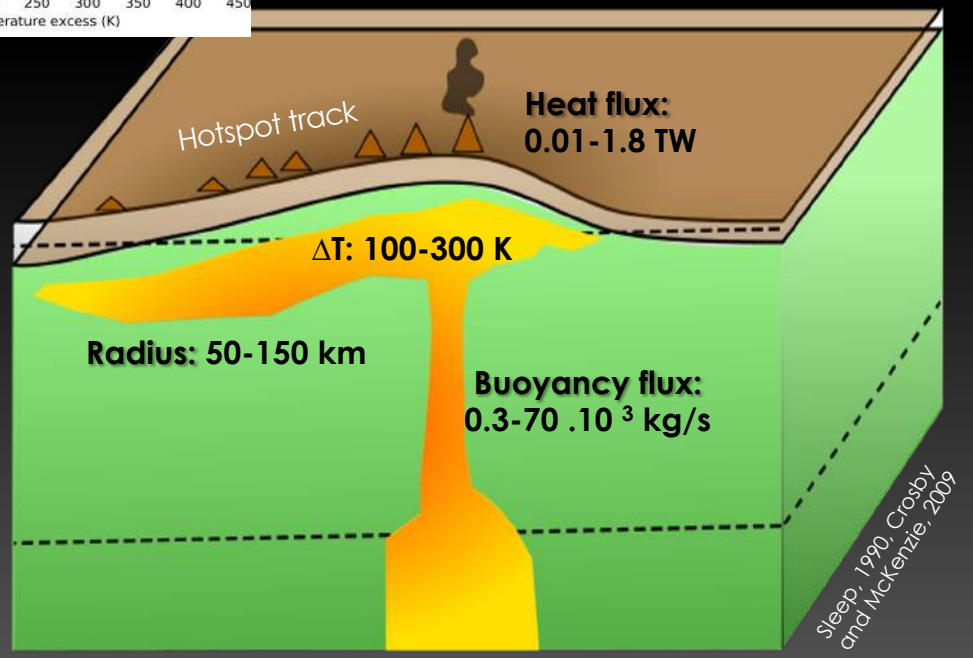


Plume heat flux

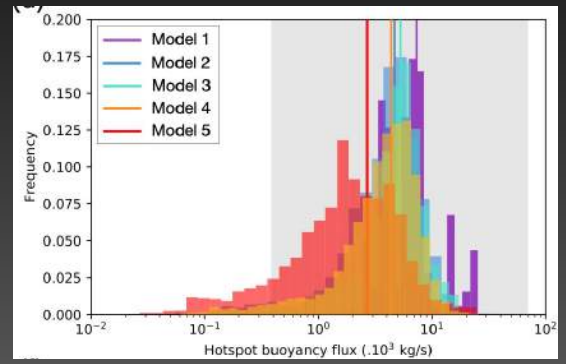


Plume radius



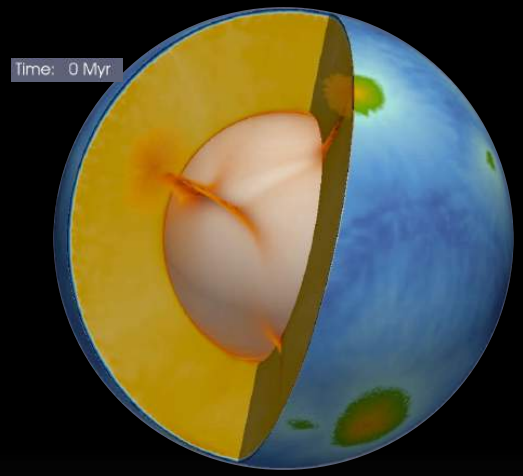
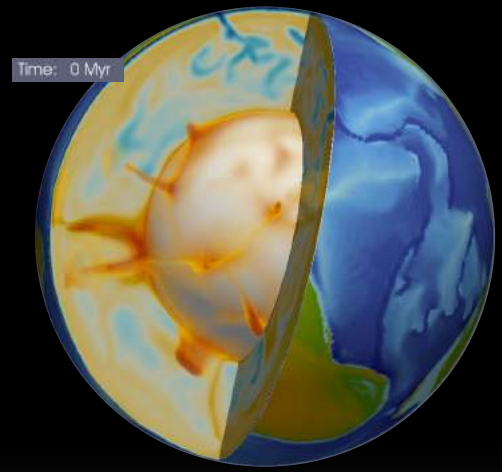
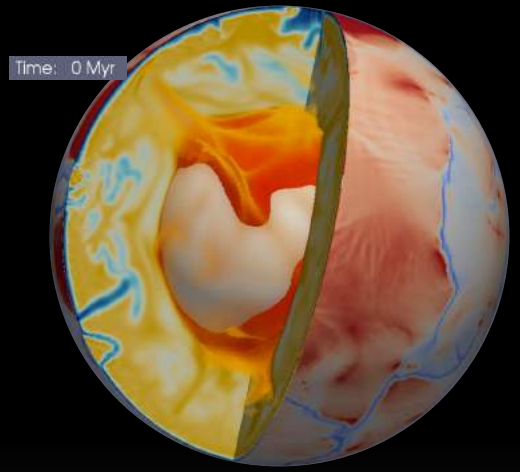


Plume buoyancy flux



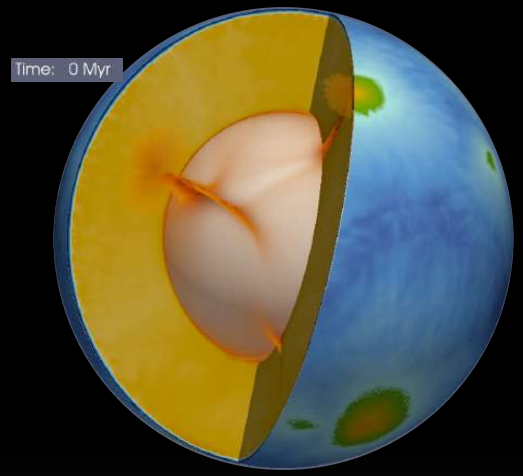
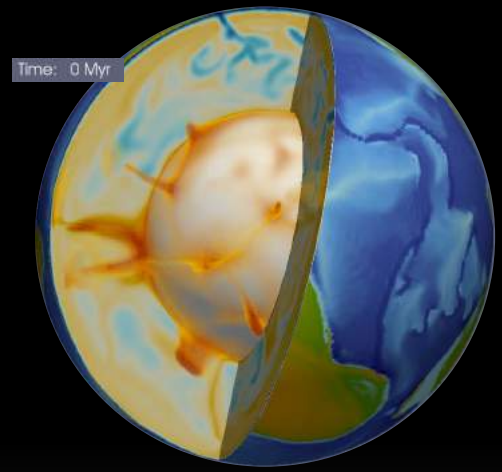
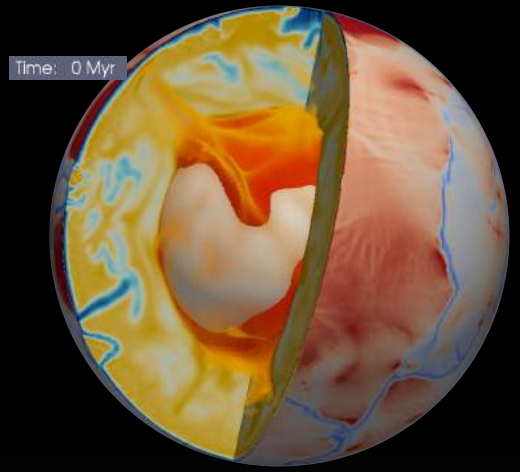
Model 1 = stagnant-lid, thermal plumes
Model 2 = Plate-like behaviour, thermal plumes
Model 5 = Plate-like behaviour, thermochemical plumes

Arnould et al., 2020

Model	Stagnant lid	With plate tectonics	With plate tectonics + thermochemical heterogeneities
			
Lifetime	**All but 2 which merge last at least 235 Myr**	**50% of model plumes live longer than 100 Myr**	**10% of model plumes live longer than 100 Myr**

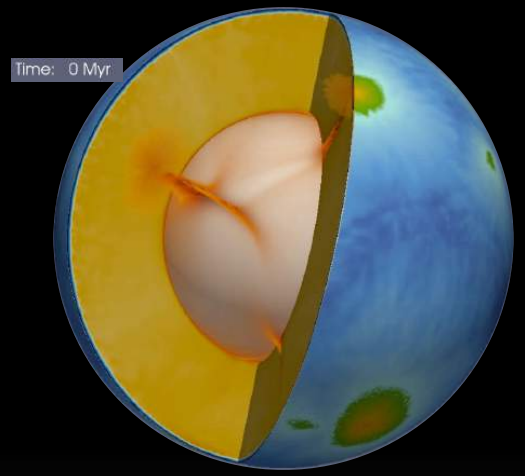
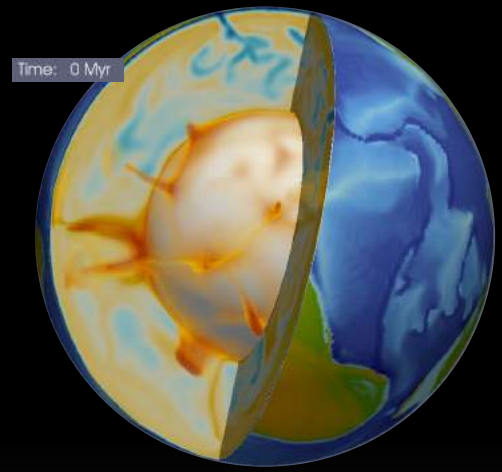
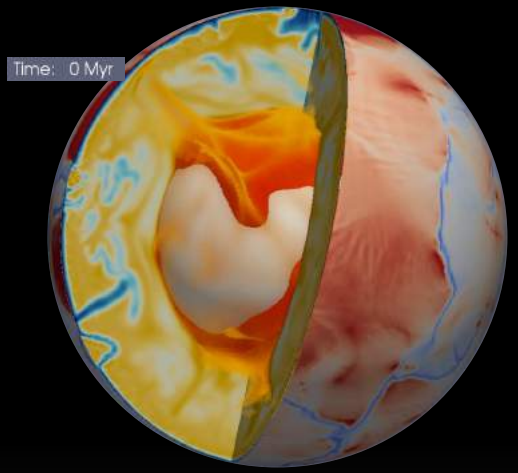
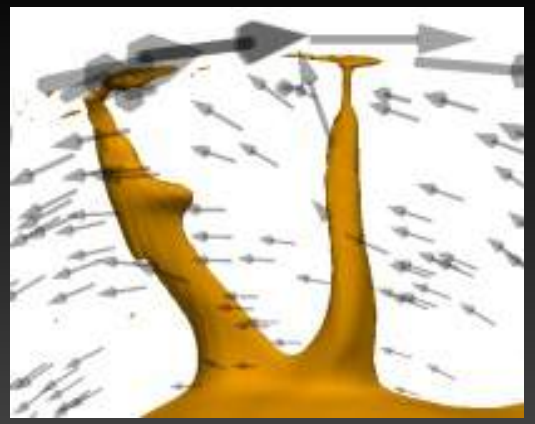
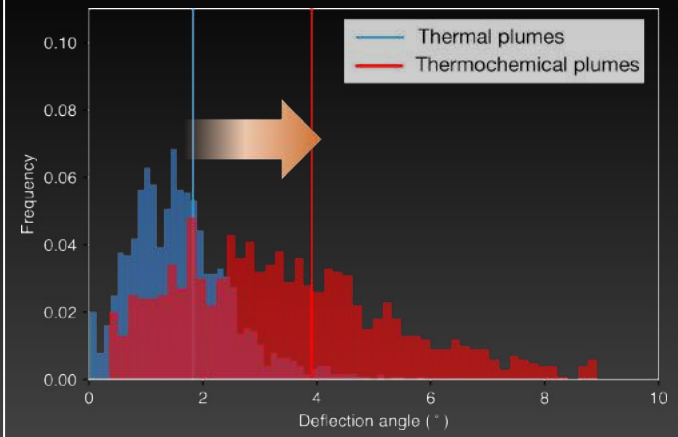
⇒ **Both plate tectonics and basal thermochemical piles restrict mantle plume lifetime**

Arnould et al., 2020

Model	Stagnant lid	With plate tectonics	With plate tectonics + thermochemical heterogeneities
			
Mobility	**98%** of plumes move by **< 1 cm/yr** Average relative motion between 2 plumes: **0.4 cm/yr**	**72%** of plumes move by **< 1 cm/yr** Average relative motion between 2 plumes: **1.4 cm/yr**	**50%** of plumes move by **< 1 cm/yr** Average relative motion between 2 plumes: **2.3 cm/yr**

⇒ **Both plate tectonics and basal thermochemical piles enhance mantle plume mobility**

Arnould et al., 2020

Model	Stagnant lid	With plate tectonics	With plate tectonics + thermochemical heterogeneities
			
Shape (Tilt angle)			
	Plumes are vertical (tilt = 0°)	Limited tilt (2°) caused by plate shearing	Enhanced tilt (10°) due to dense basal entrainment

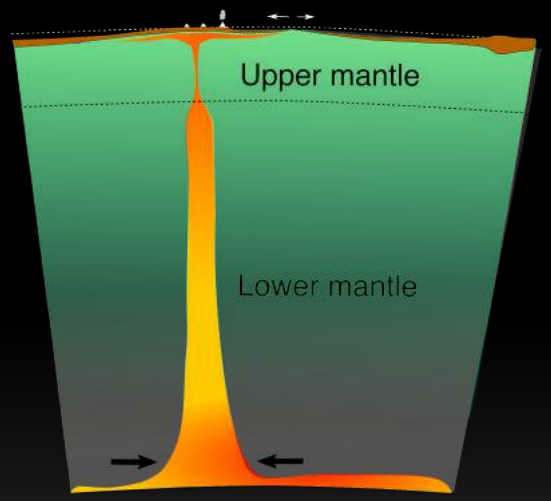
⇒ Both plate tectonics and basal thermochemical piles enhance plume tilting

⇒ Limited effect of mantle wind on plume shape

Arnould et al., 2020

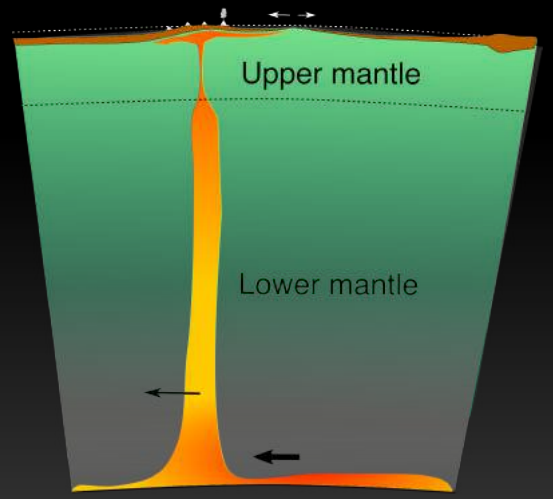
MODELING MANTLE PLUMES IN THEIR ENVIRONMENT

Lateral drift < 0.5 cm/yr



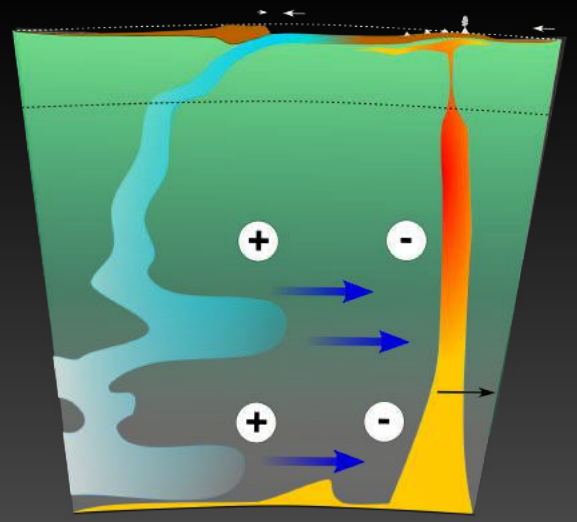
Fixed plumes located
at saddle points

0.5 cm/yr < Lateral drift < 1 cm/yr



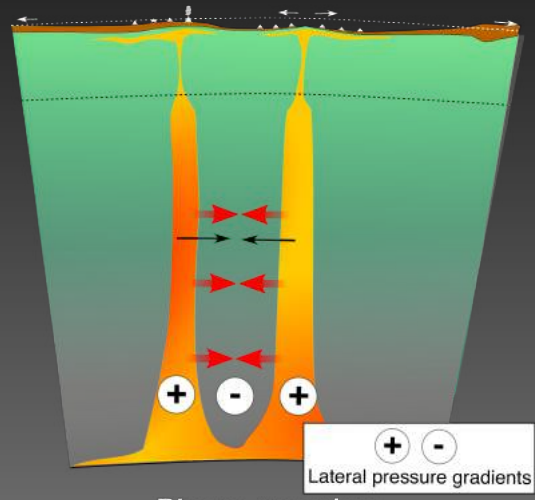
Slow entrainment
by basal mantle flow

1 cm/yr < Lateral drift < 5 cm/yr



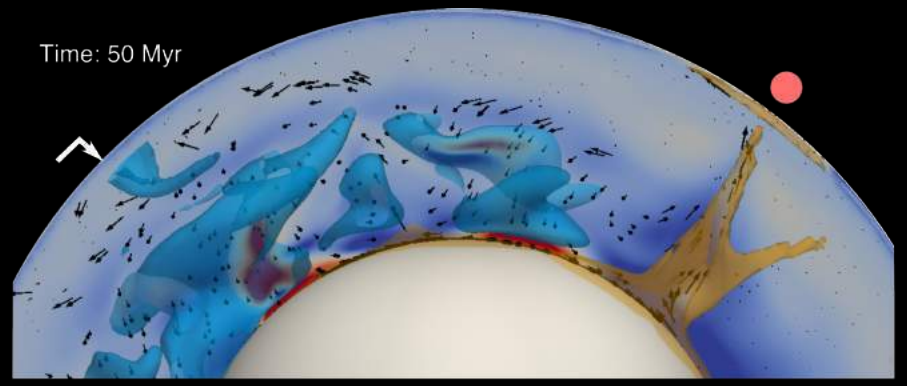
Slab push

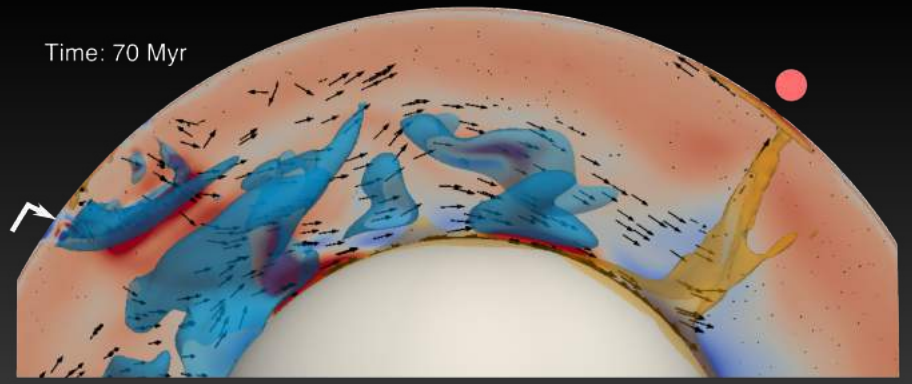
5 cm/yr < Lateral drift < 15 cm/yr

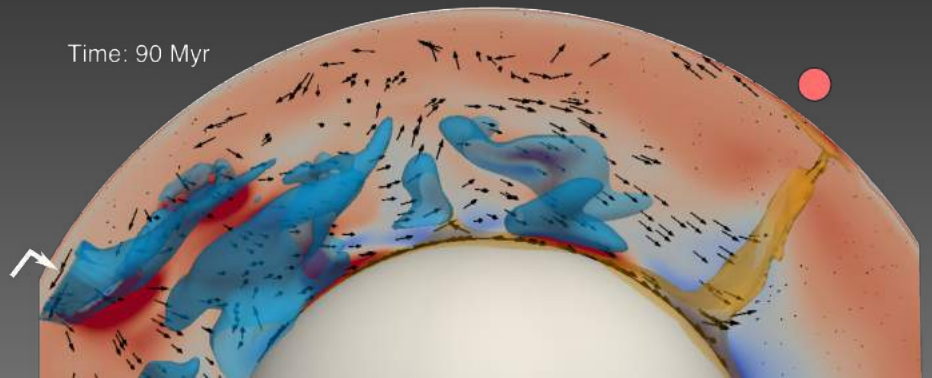


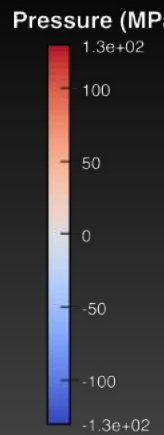
Plume merging

MODELING MANTLE PLUMES IN THEIR ENVIRONMENT

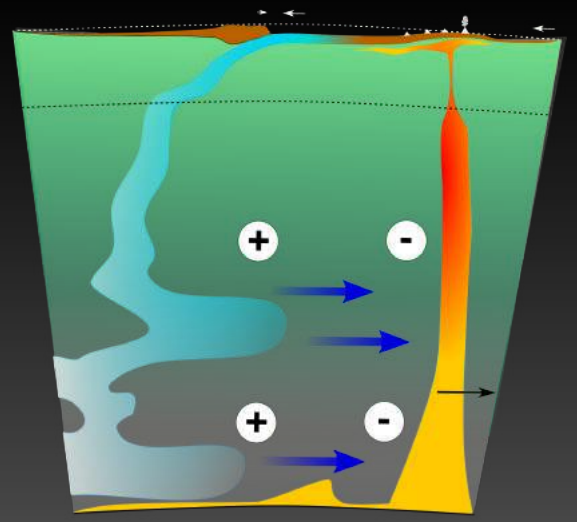






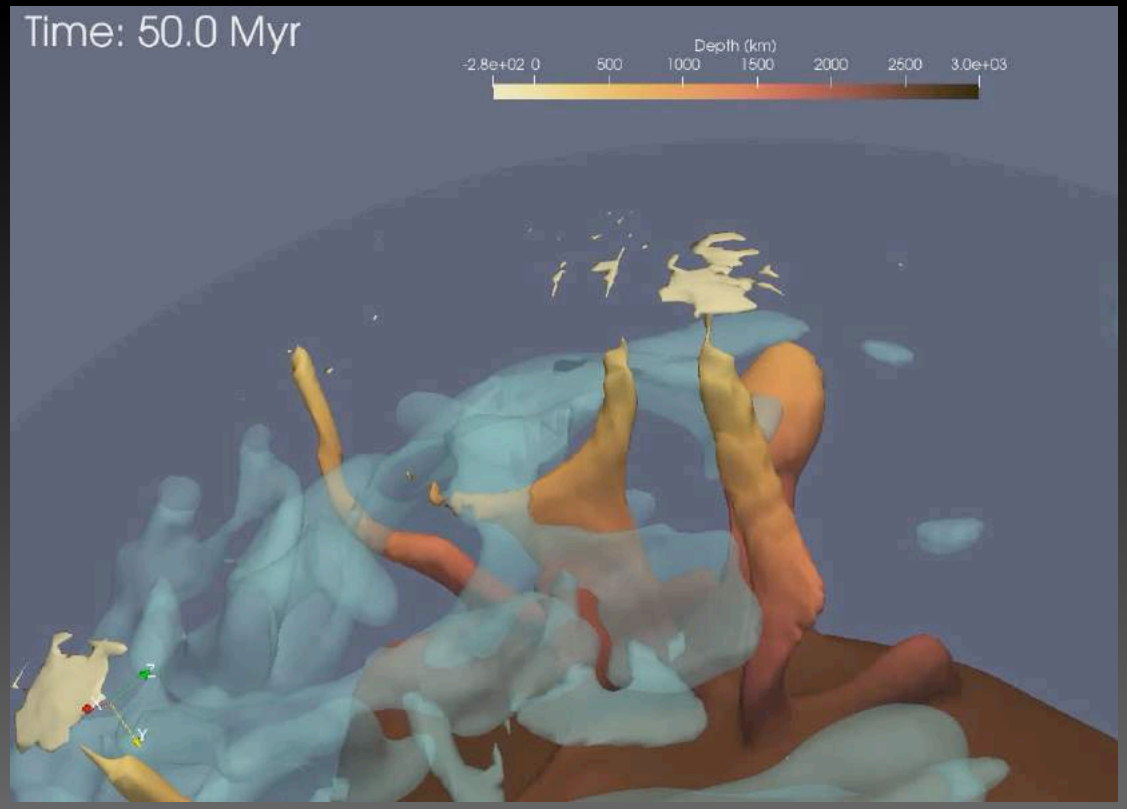


1 cm/yr < Lateral drift < 5 cm/yr

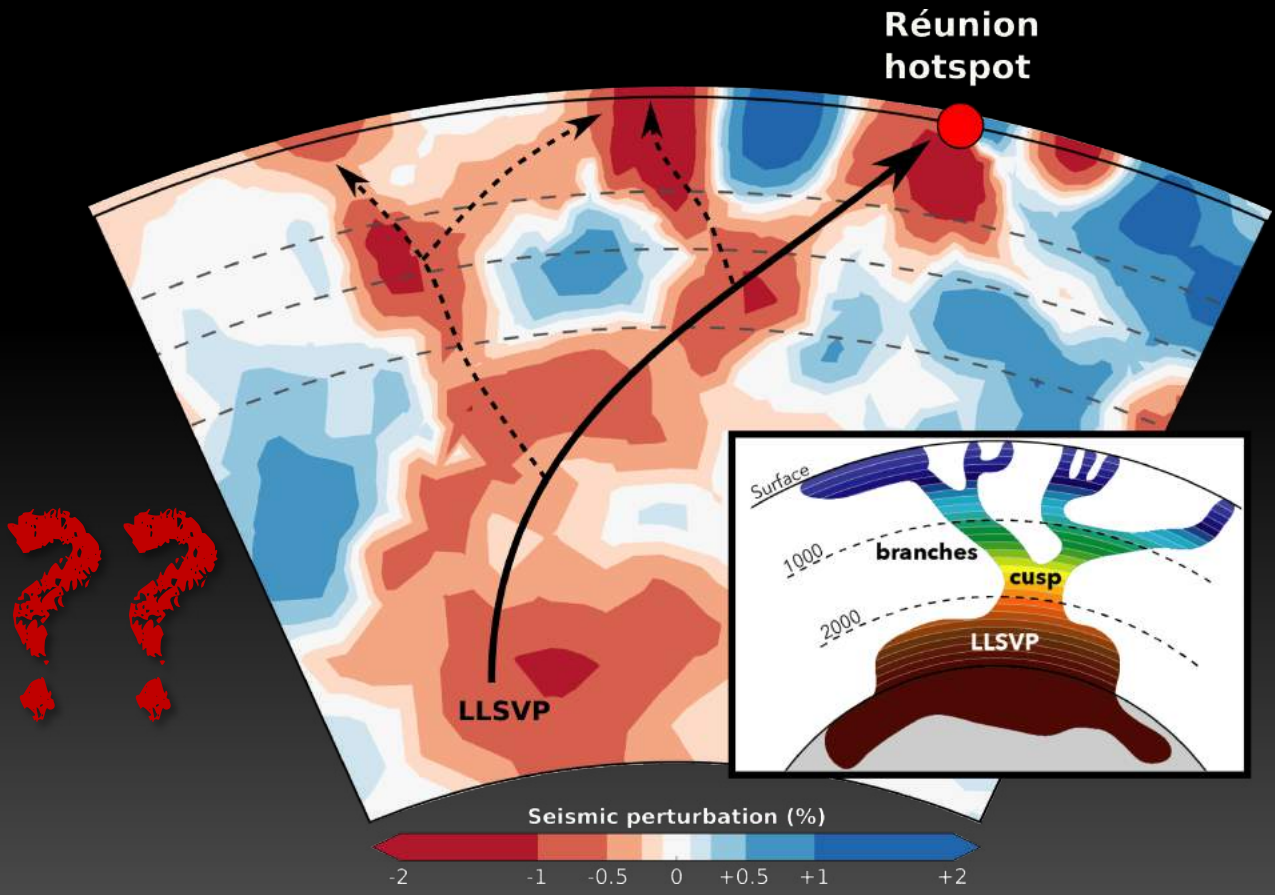


Slab push

MODELING MANTLE PLUMES IN THEIR ENVIRONMENT

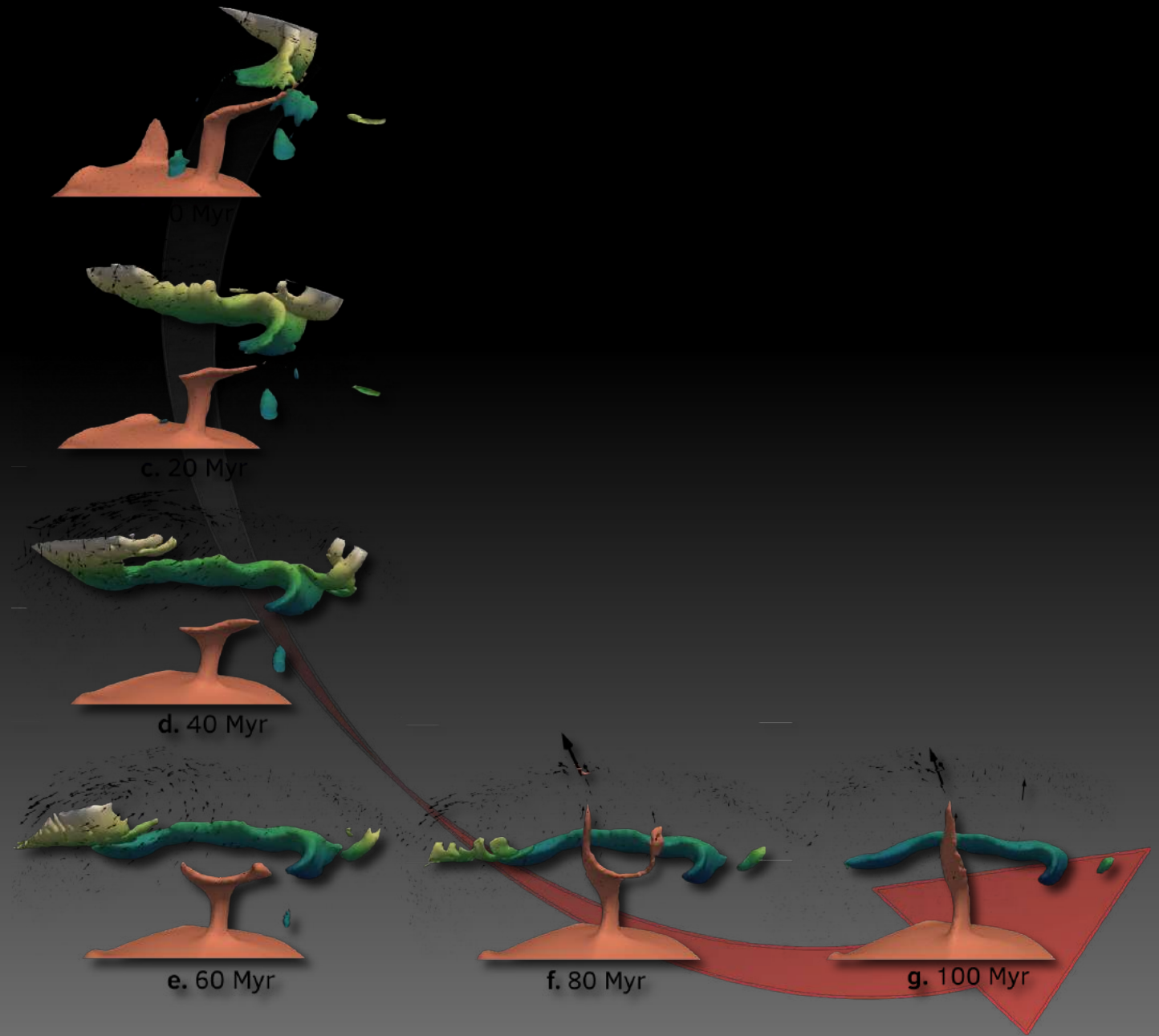


Arnould et al., 2020



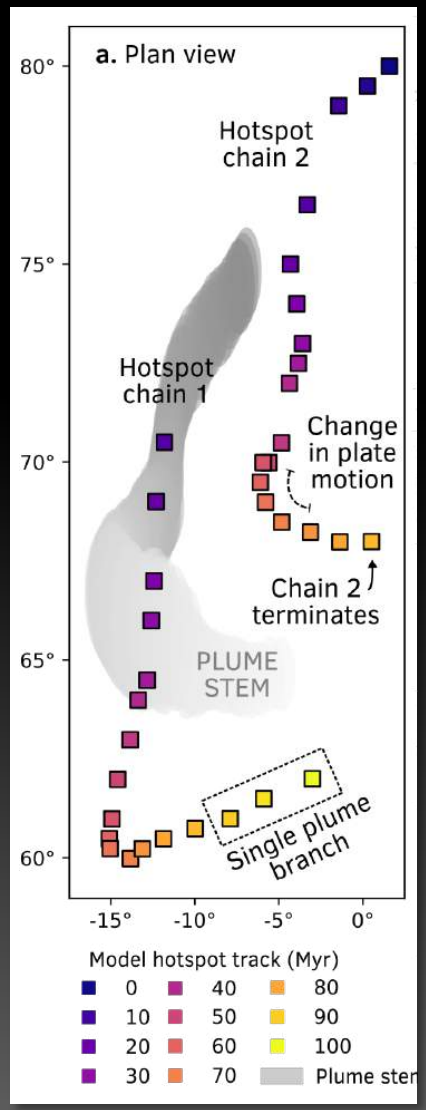
Modified from Tsekhmistrenko et al., 2021.

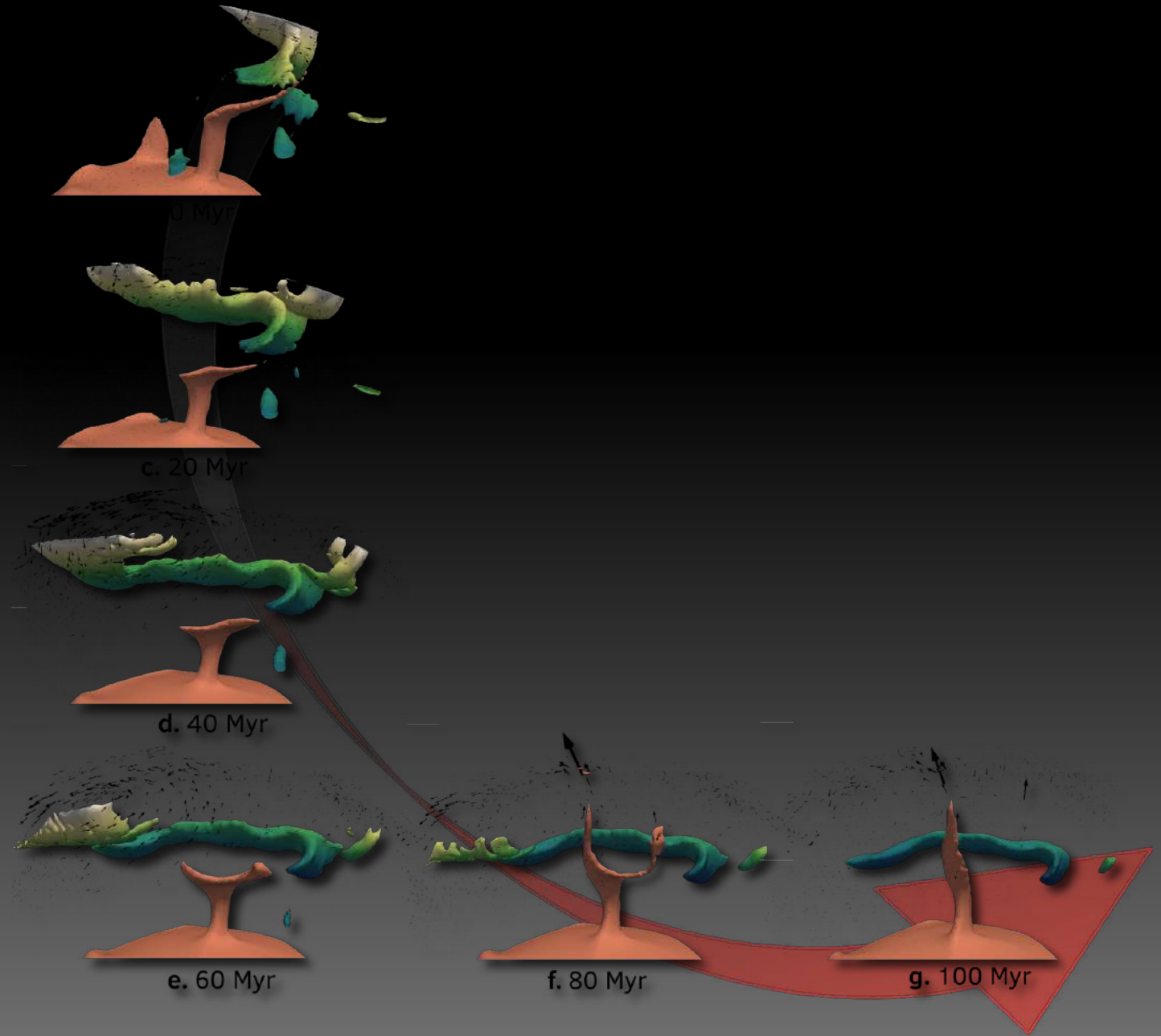
MANTLE PLUMES AND SLAB INTERACTIONS



Mather et al., *in rev.*

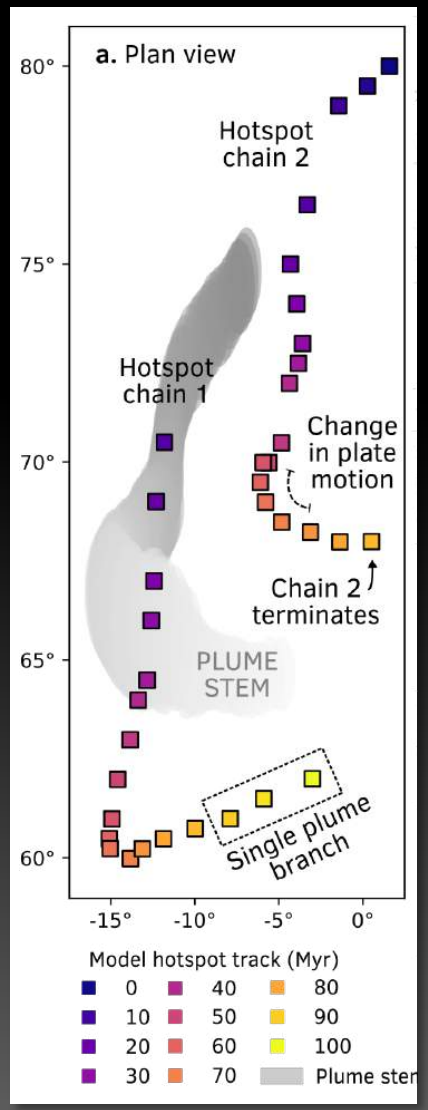
MANTLE PLUMES AND SLAB INTERACTIONS

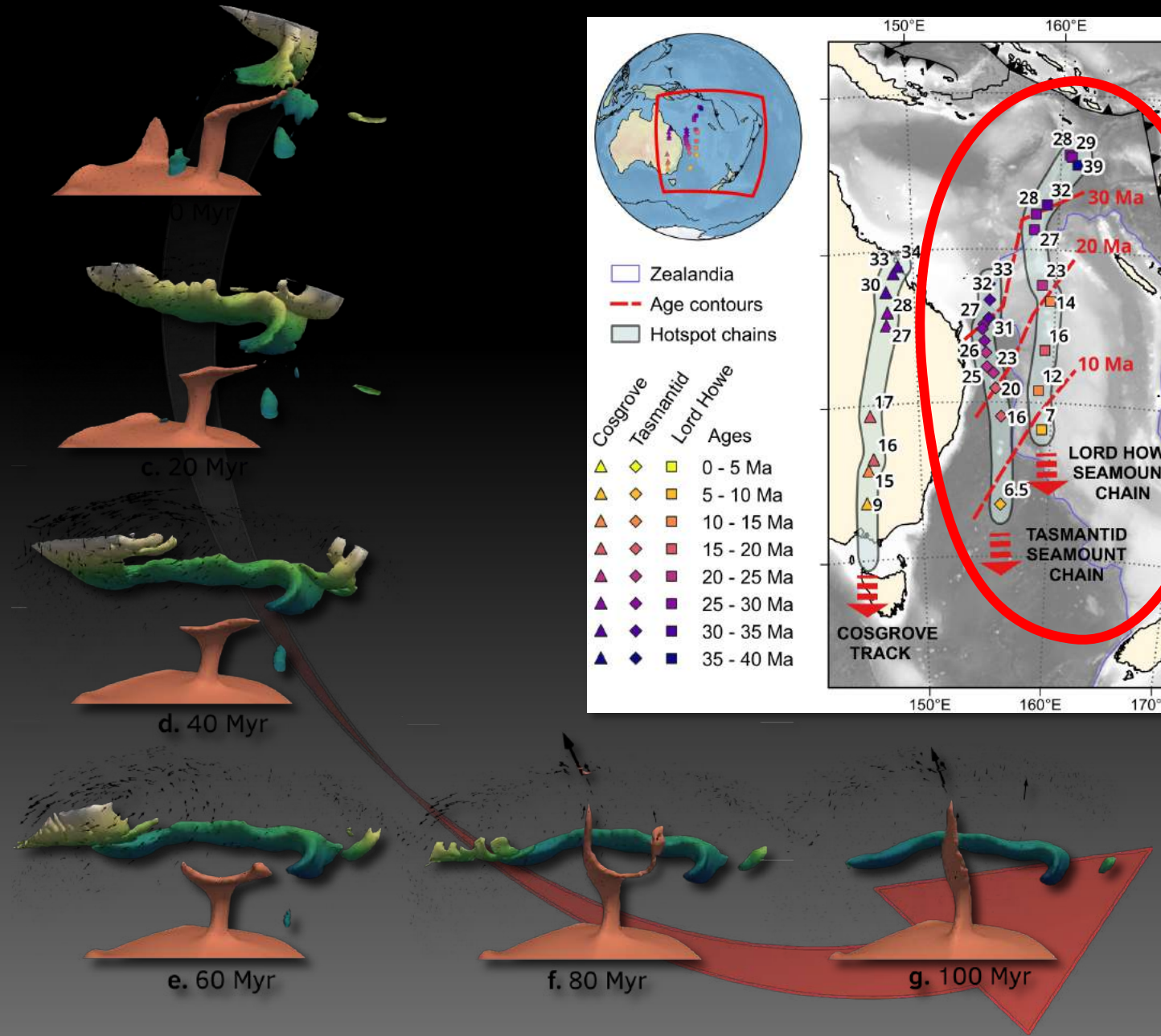




Mather et al., *in rev.*

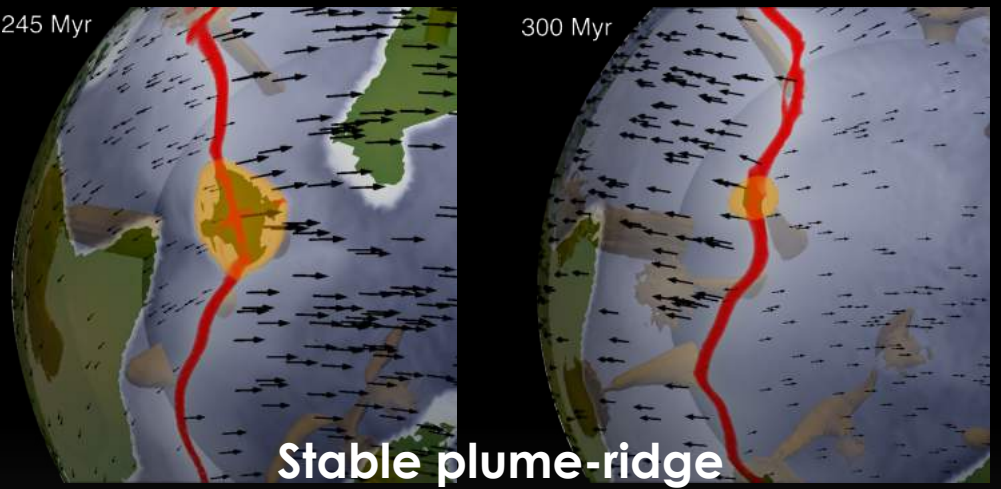
MANTLE PLUMES AND SLAB INTERACTIONS



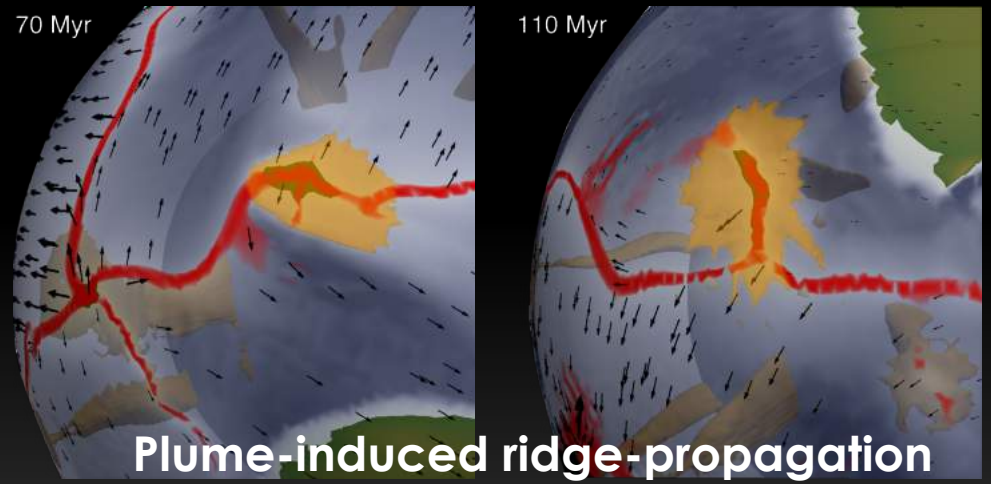


Mather et al., *in rev.*

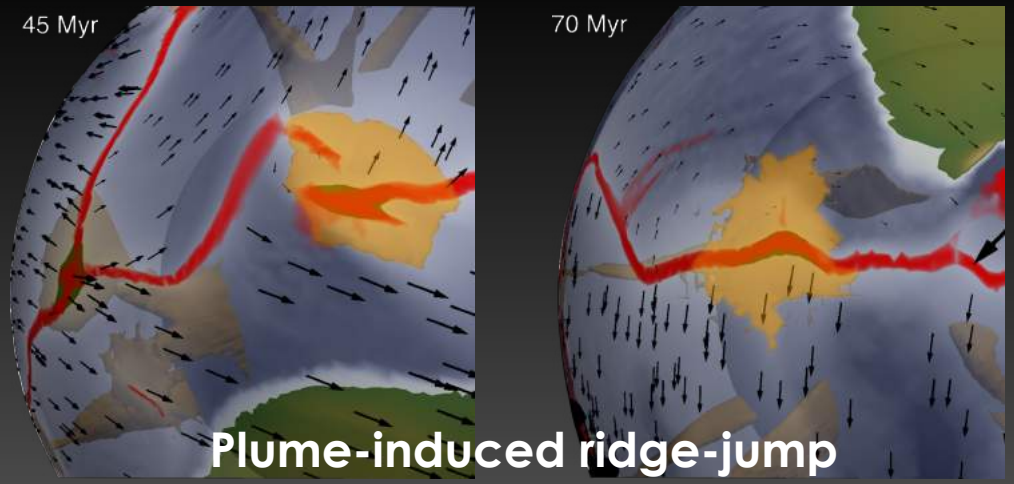
MANTLE PLUMES AND LITHOSPHERE INTERACTIONS



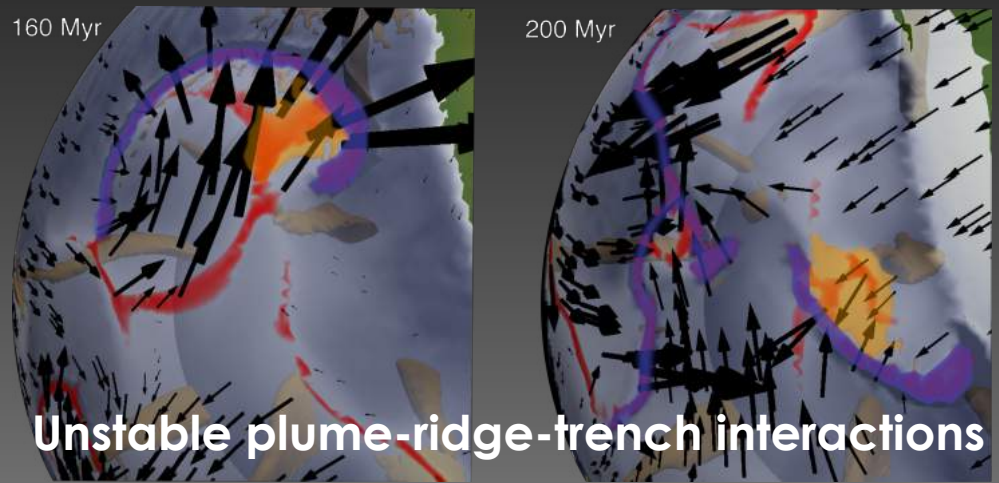
Stable plume-ridge



Plume-induced ridge-propagation



Plume-induced ridge-jump

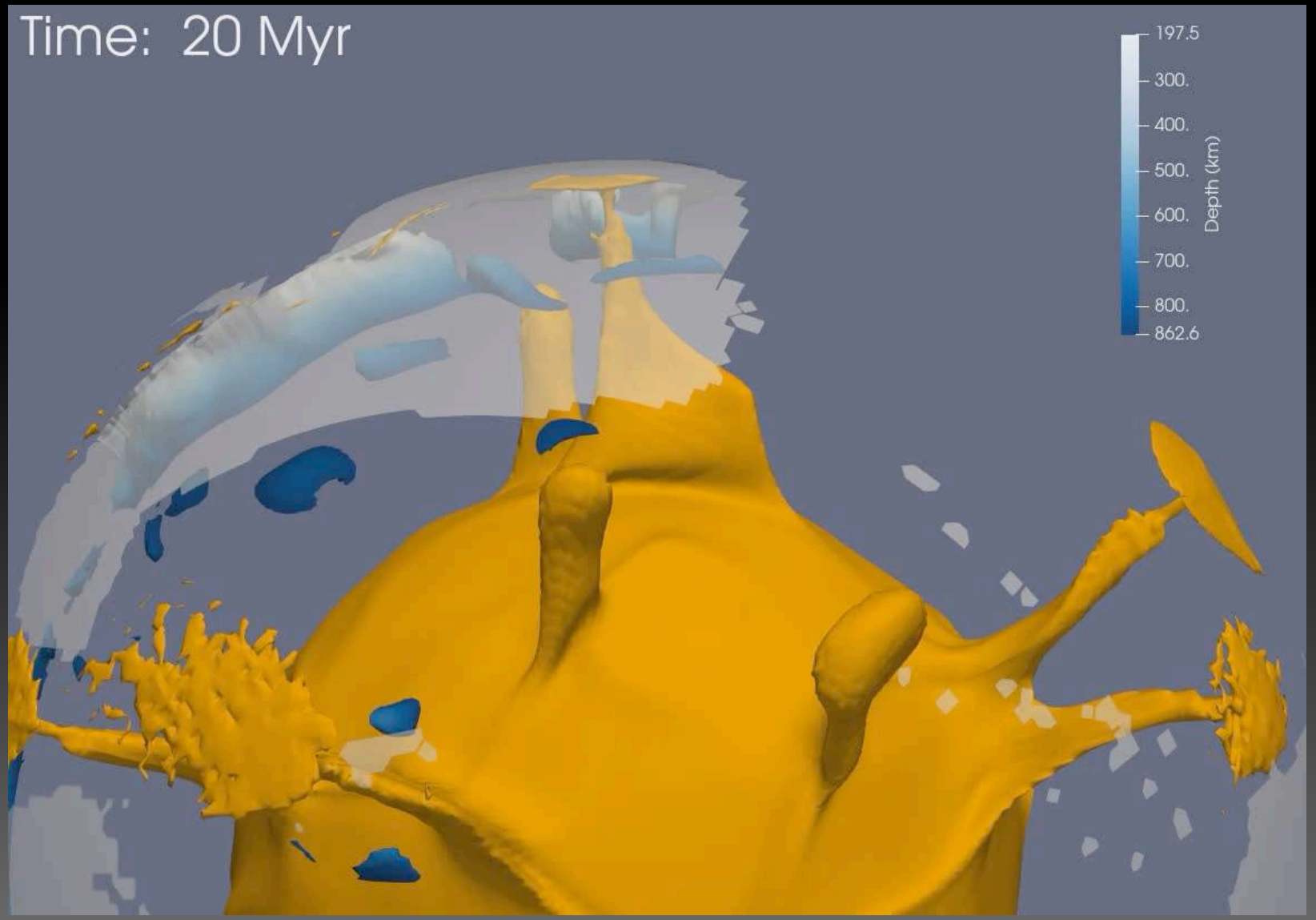


Unstable plume-ridge-trench interactions

A large variety of
plume- lithosppphere interactions

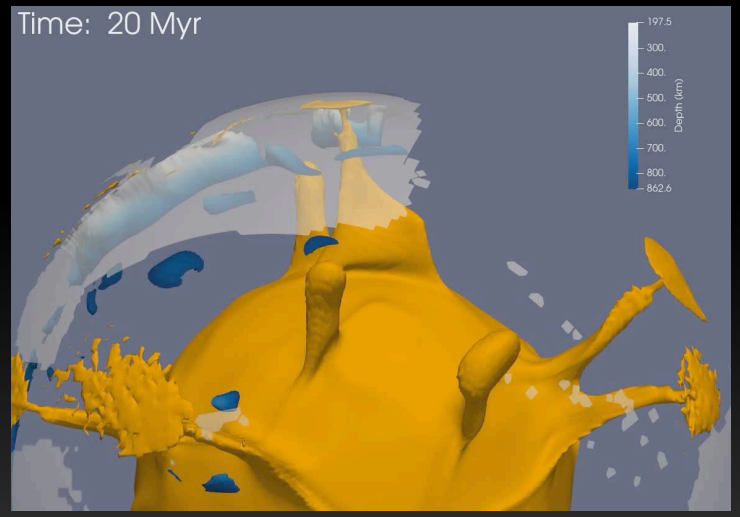
Arnould et al., *2020.*

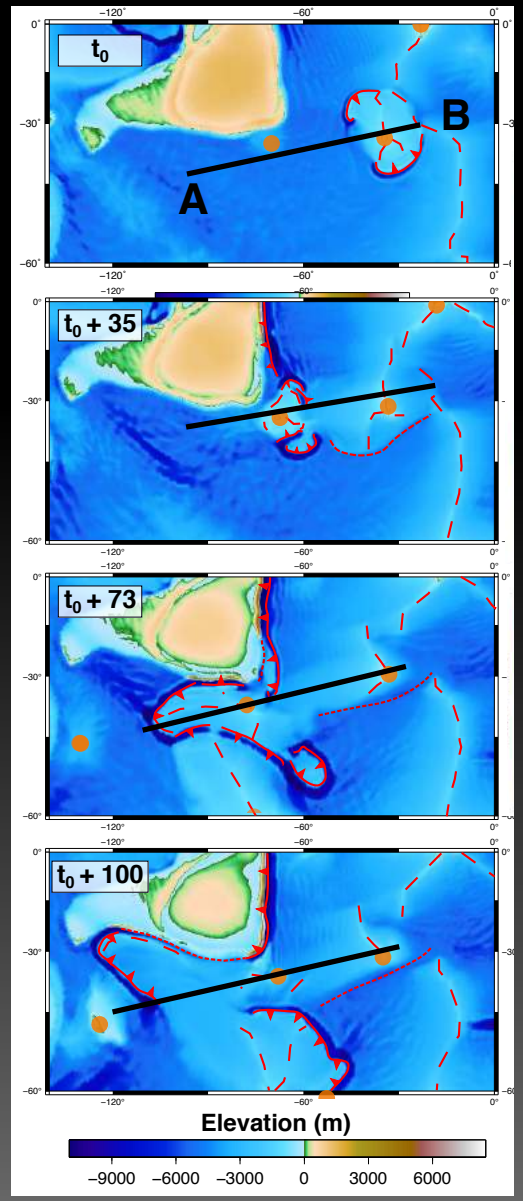
MANTLE PLUMES AND SUBDUCTION INITIATION



Rodriguez et al., 2021

MANTLE PLUMES AND SUBDUCTION INITIATION



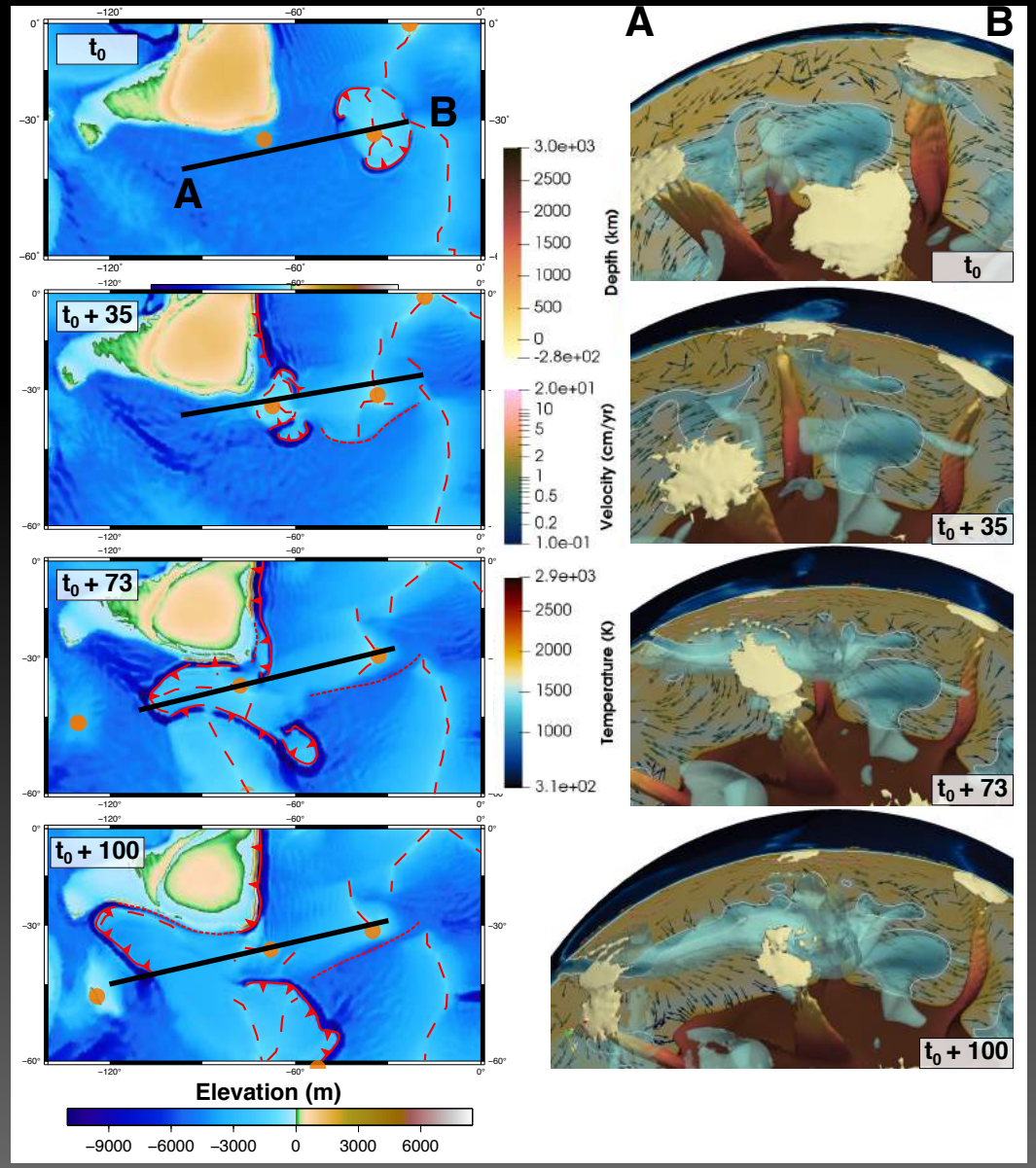


Rodriguez et al., 2021

- Development of multiple ridges and small plates
- Propagation of long segments of subduction
- Age progression of the "deactivation" of the subductions along continental margins

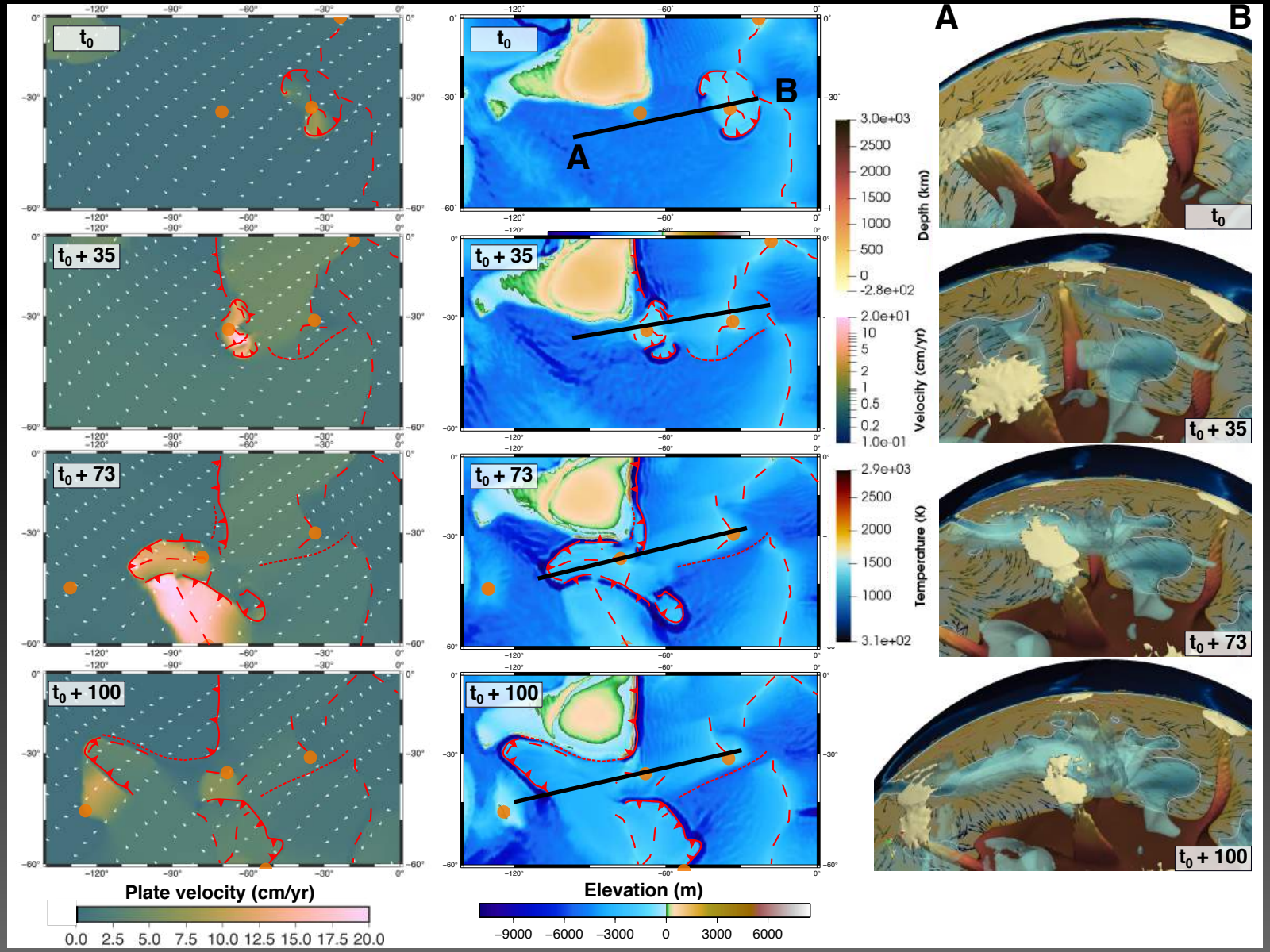
MANTLE PLUMES AND SUBDUCTION INITIATION

- Fast trench retreat (> 5 cm/yr)
- Multiple polarity reversals



Rodriguez et al., 2021

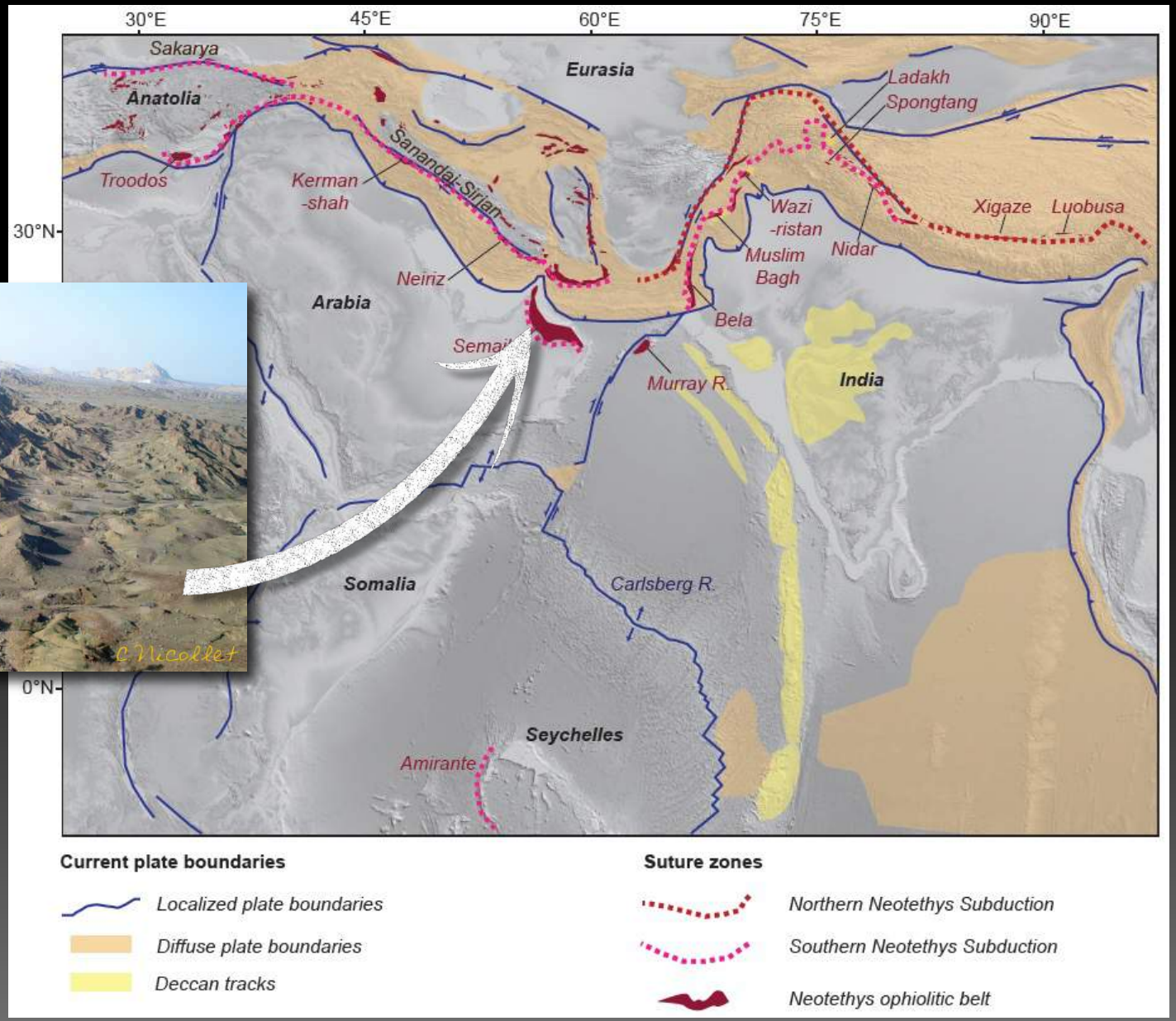
MANTLE PLUMES AND SUBDUCTION INITIATION



- Fast plate velocities
- Fast spreading
- Multiple small-plate rotations
- GPRE

Rodriguez et al., 2021

MANTLE PLUMES AND SUBDUCTION INITIATION



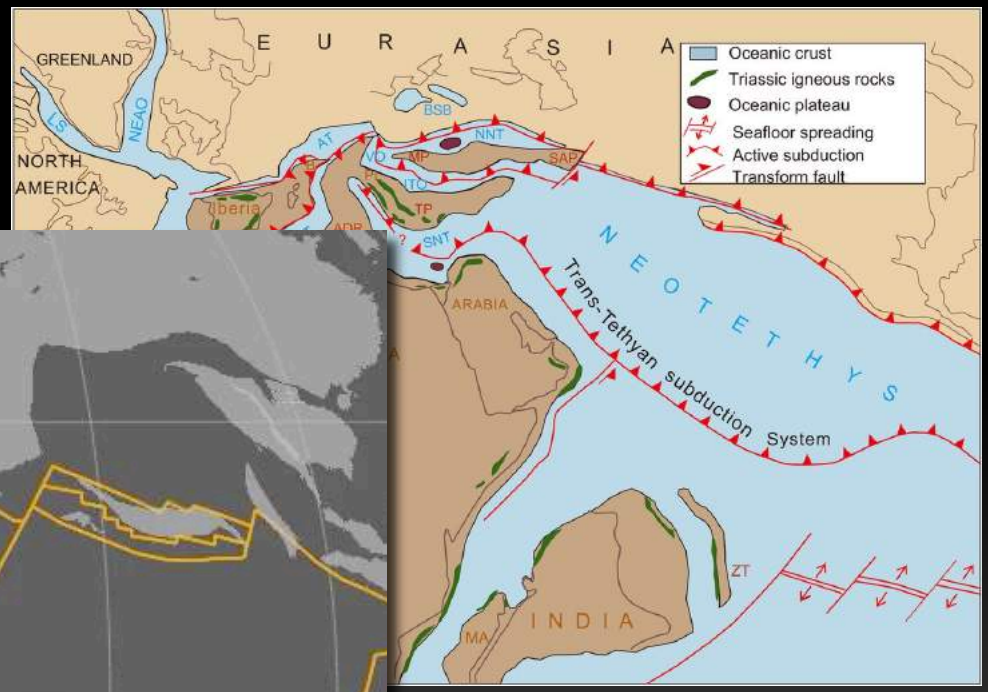
Using ophiolites to reconstruct the closure of the Neotethys

Rodriguez et al., 2021

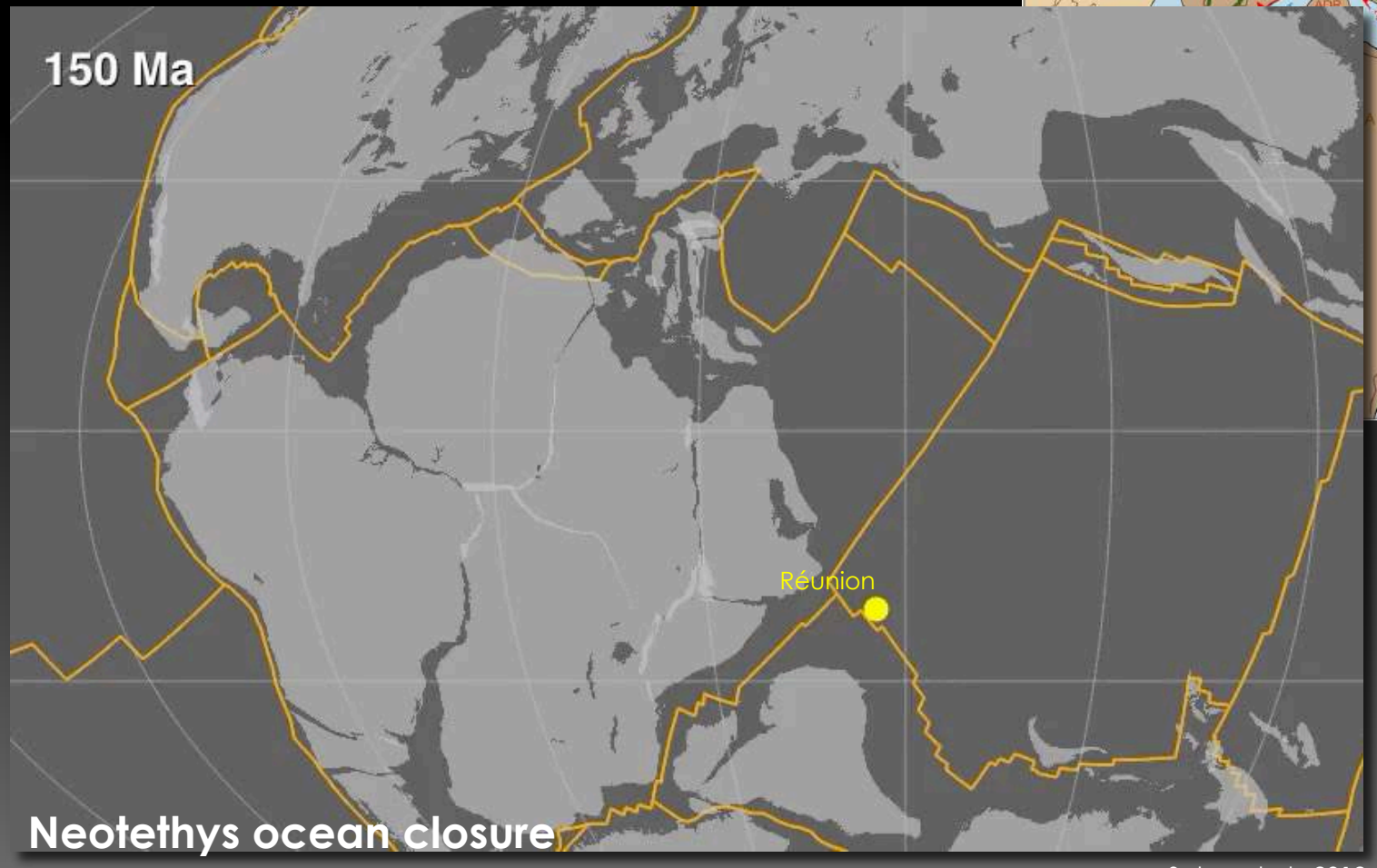
MANTLE PLUMES AND SUBDUCTION INITIATION

A poorly-constrained long and linear subduction zone in the Southern Neotethys…

Late Cretaceous



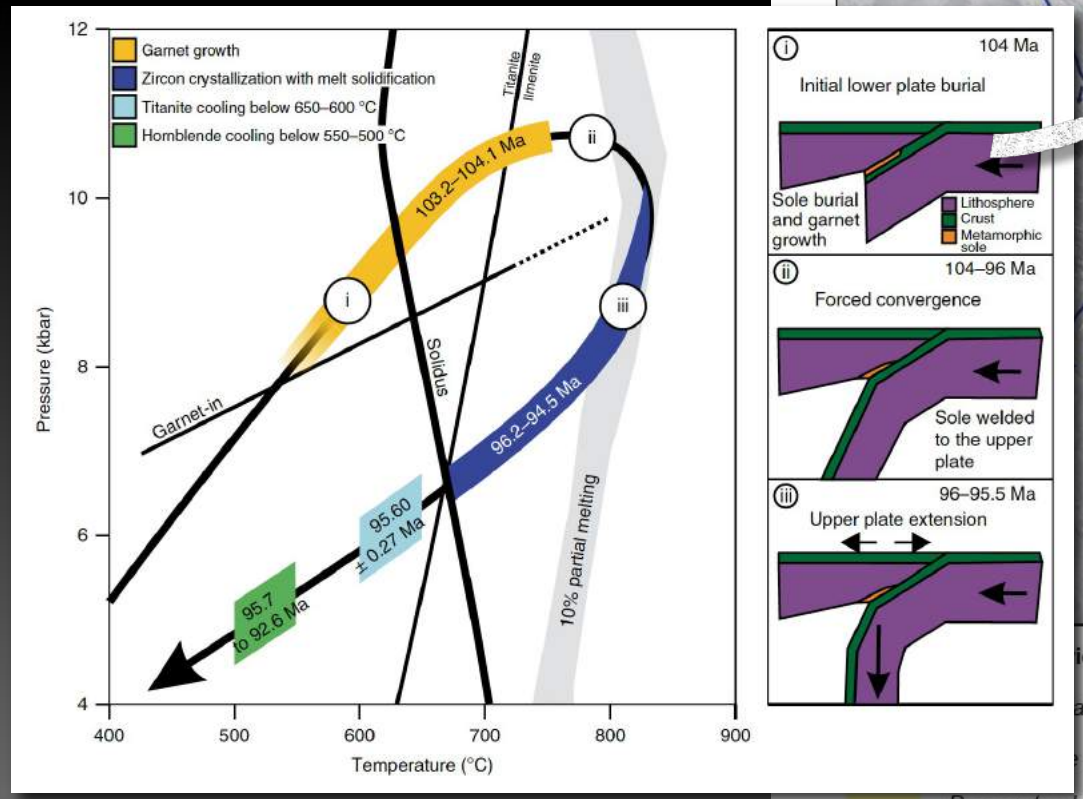
Dilek and Furnes, 2019



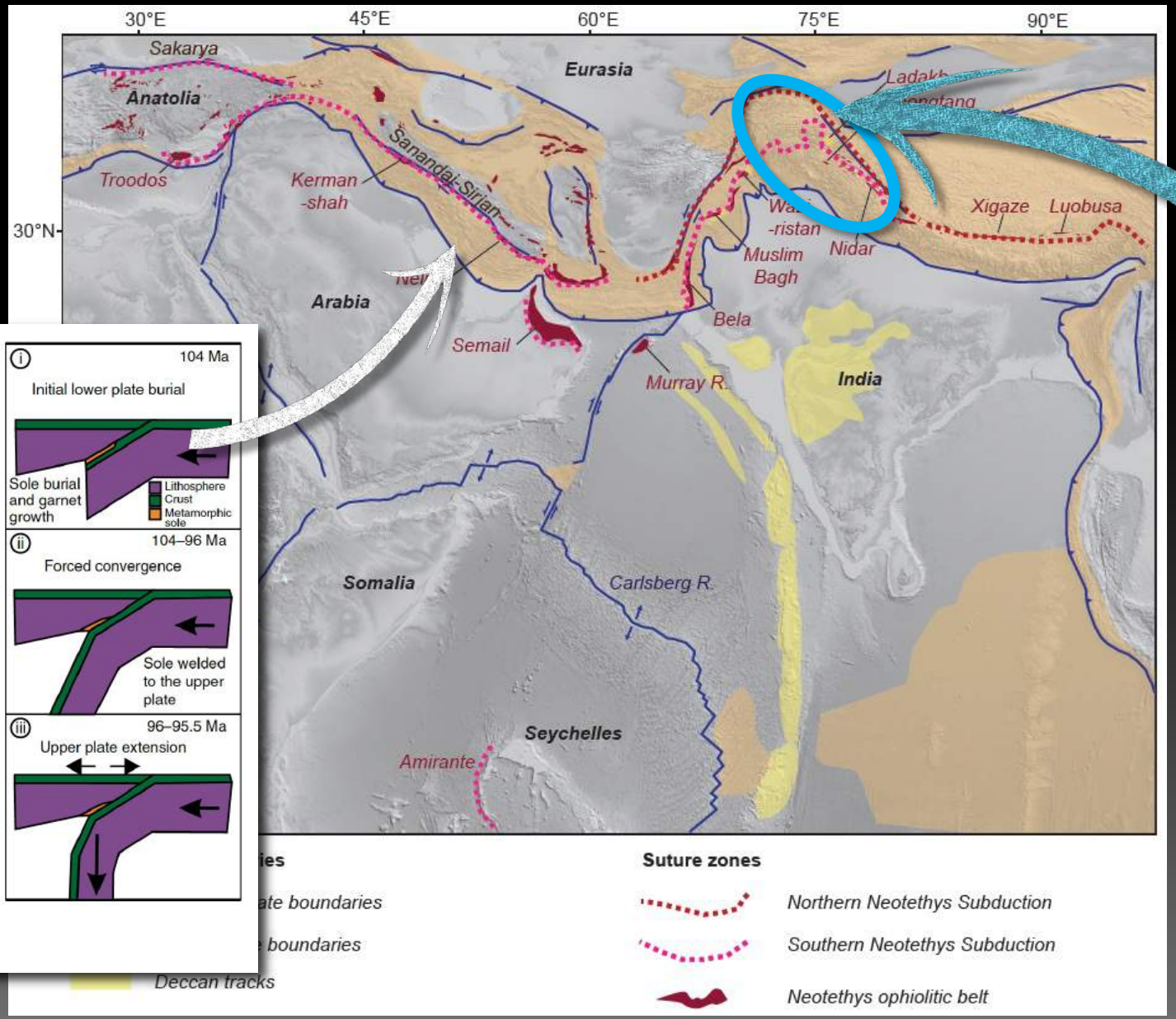
Seton et al., 2012

MANTLE PLUMES AND SUBDUCTION INITIATION

HT in the upper mantle



Soret et al., 2017, Guilmette et al., 2018

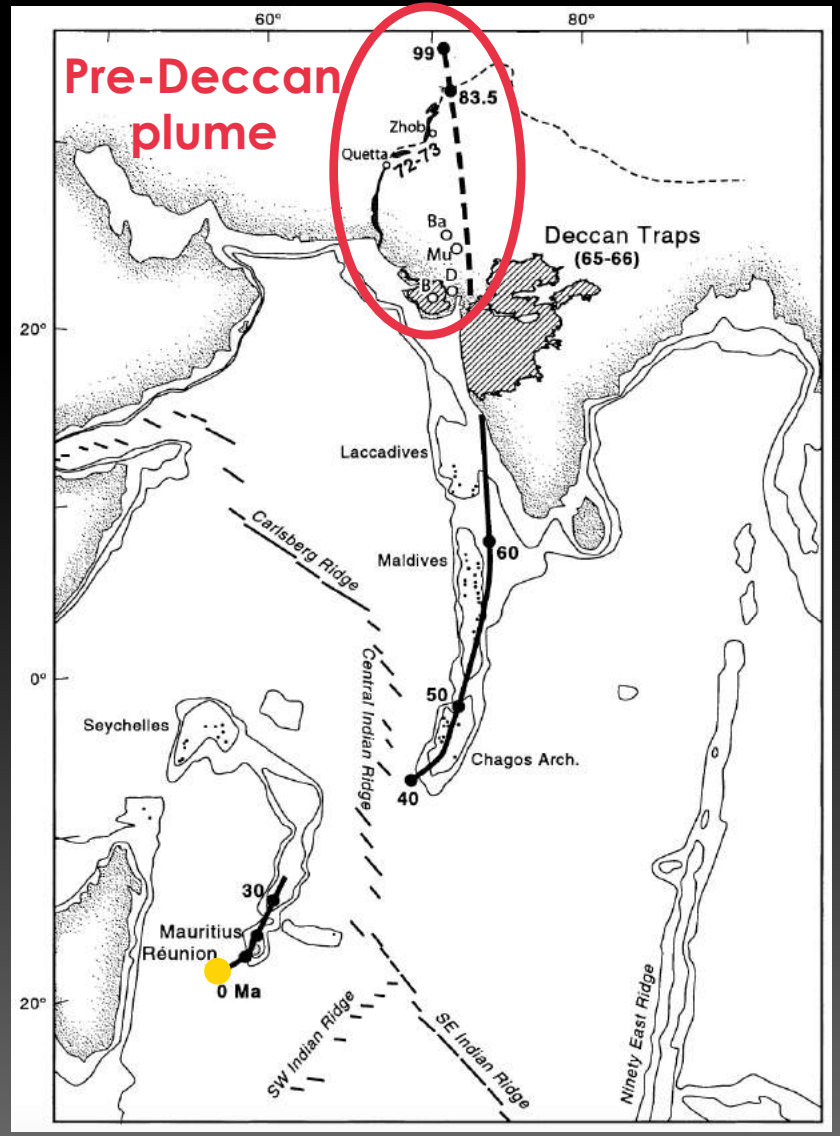


Rodriguez et al., 2021

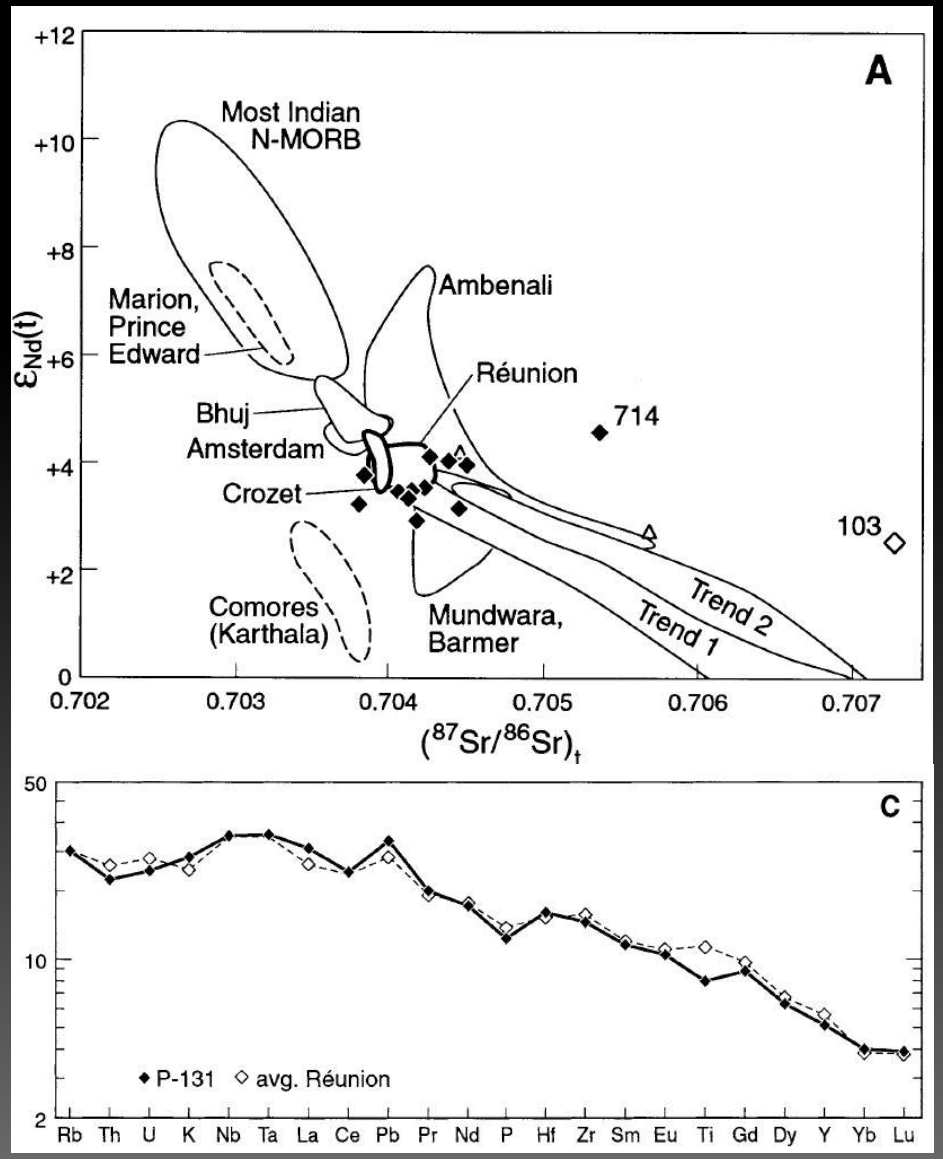
OIB signatures in ophiolites

(Yang and Dilek, 2015)

MANTLE PLUMES AND SUBDUCTION INITIATION



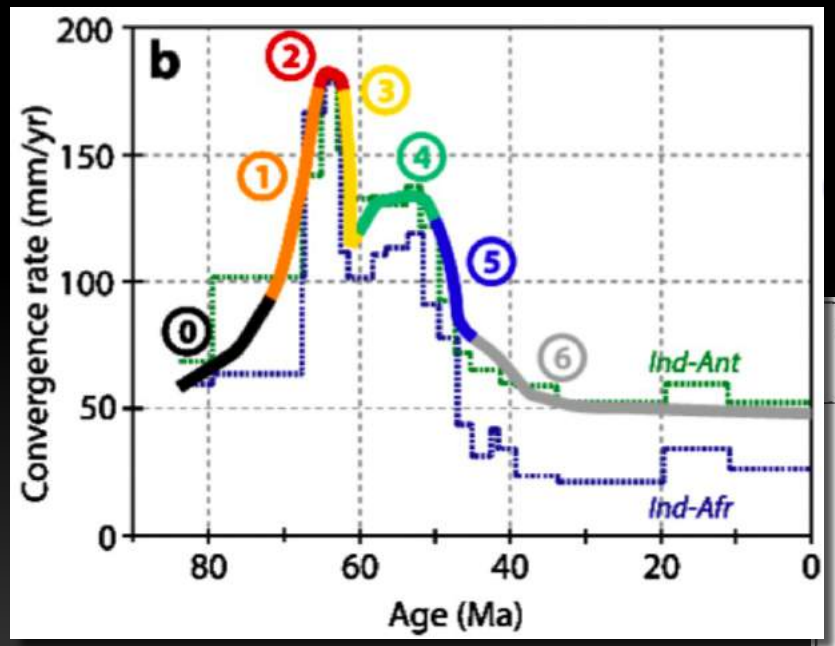
Mahoney et al., 2002



Mahoney et al., 2002

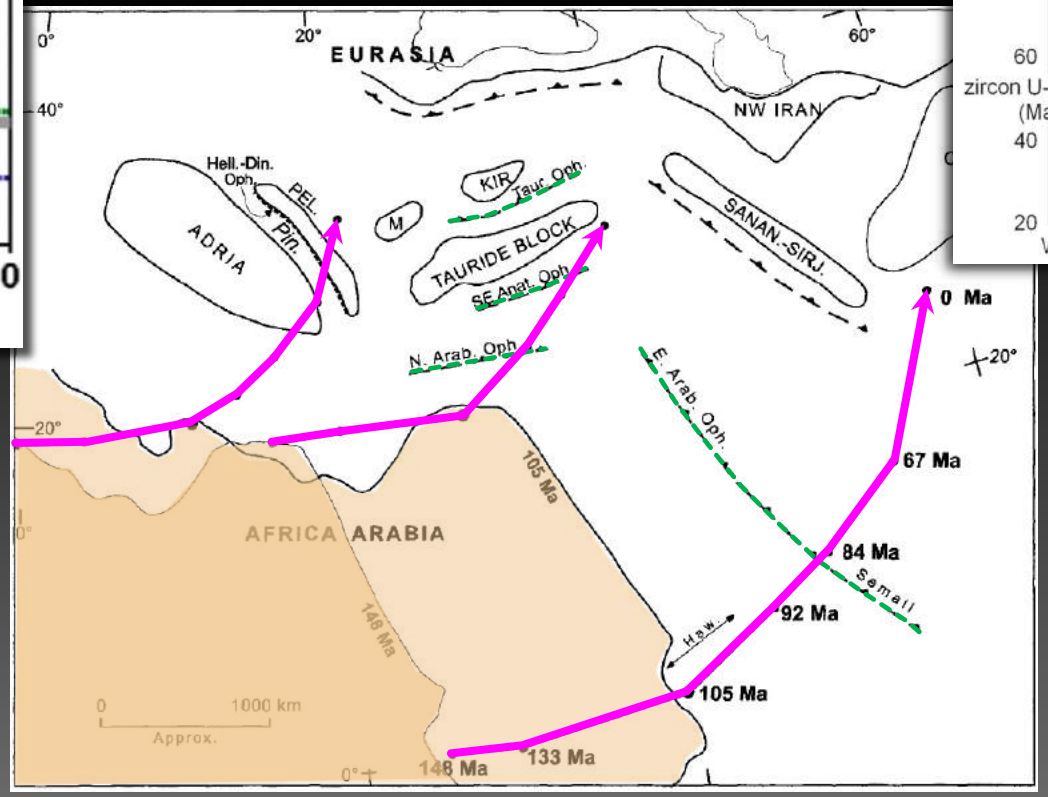
MANTLE PLUMES AND SUBDUCTION INITIATION

Indian plate acceleration (> 15 cm/yr)



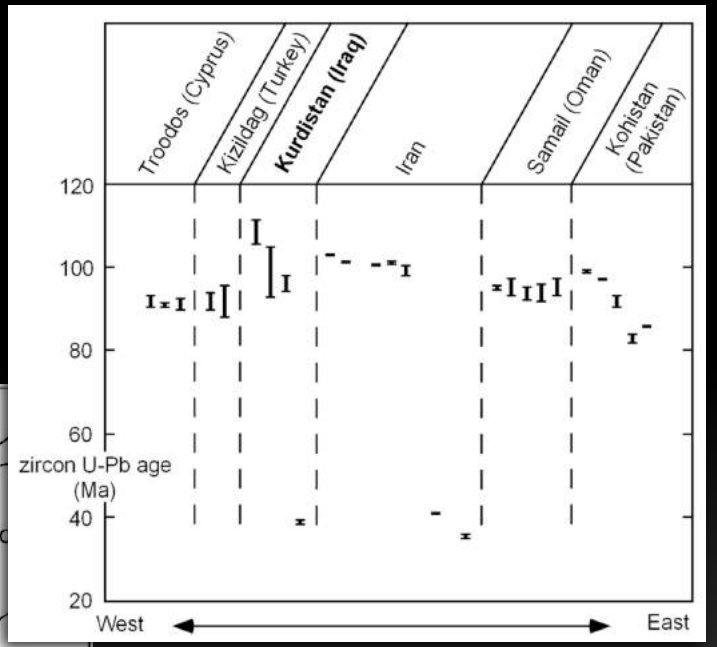
Cande and Stegman, 2011
Van Hinsbergen et al., 2011
Pusok and Stegman, 2020

Large plate reorganisations and fast trench retreat



Garfunkel, 2006

Diachronous obduction



Ali et al., 2019

Evolution of the South-Neotethys subduction

Plate motion

Subductions preluding future obductions

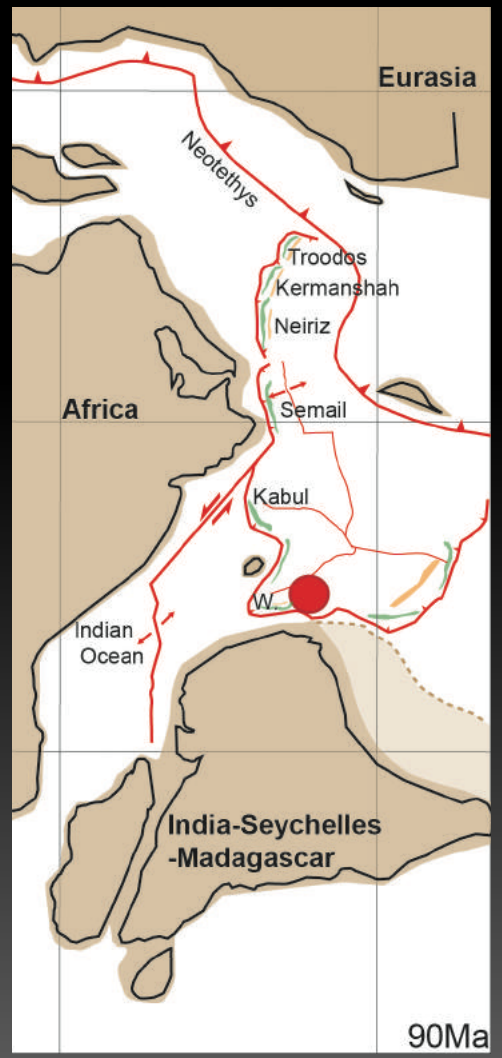
MANTLE PLUMES AND SUBDUCTION INITIATION

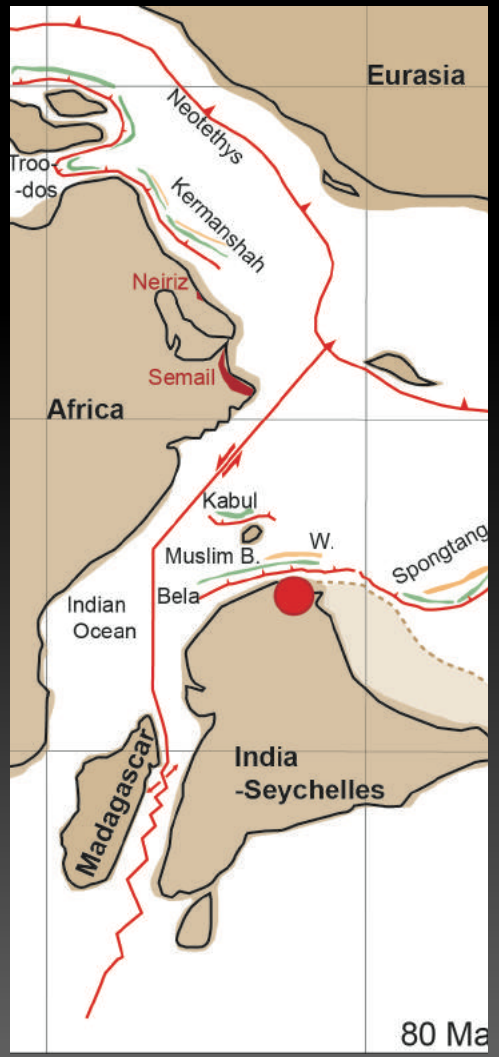
Areas of supra-subduction Zone signature

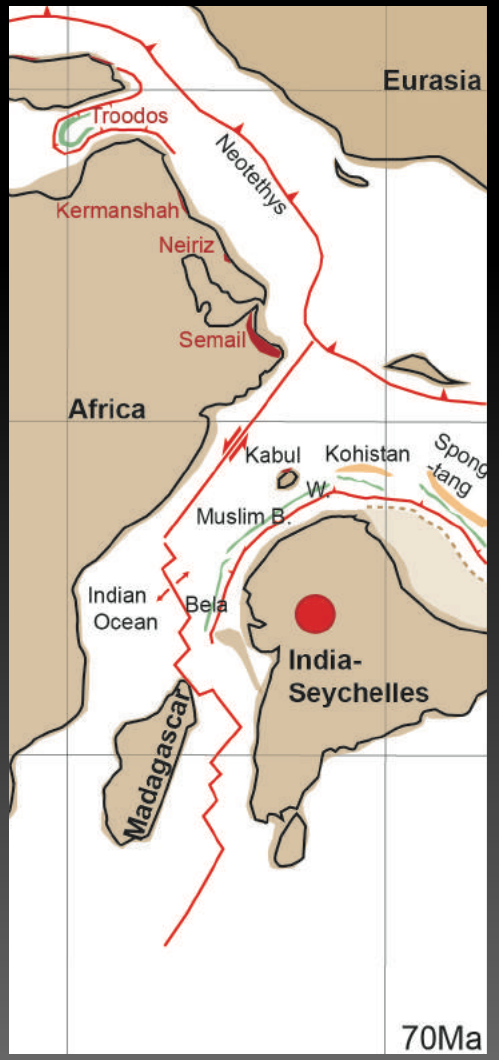
Volcanic arc (Calco-alkaline series)

Réunion plume

W.: Waziristan
Muslim B.: Muslim Bagh







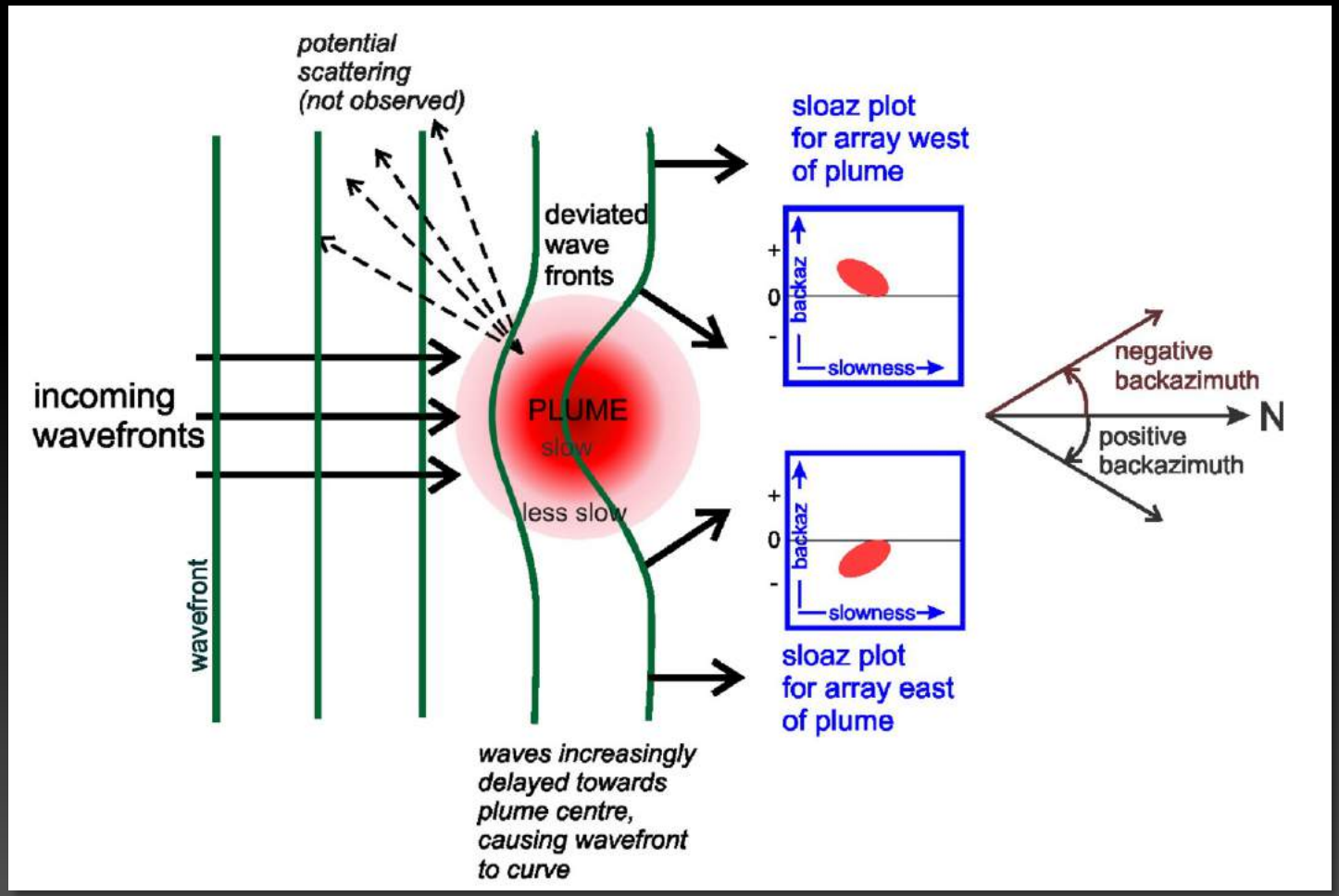
Rodriguez et all., 2021

Our proposed reconstruction:

CONCLUSIONS

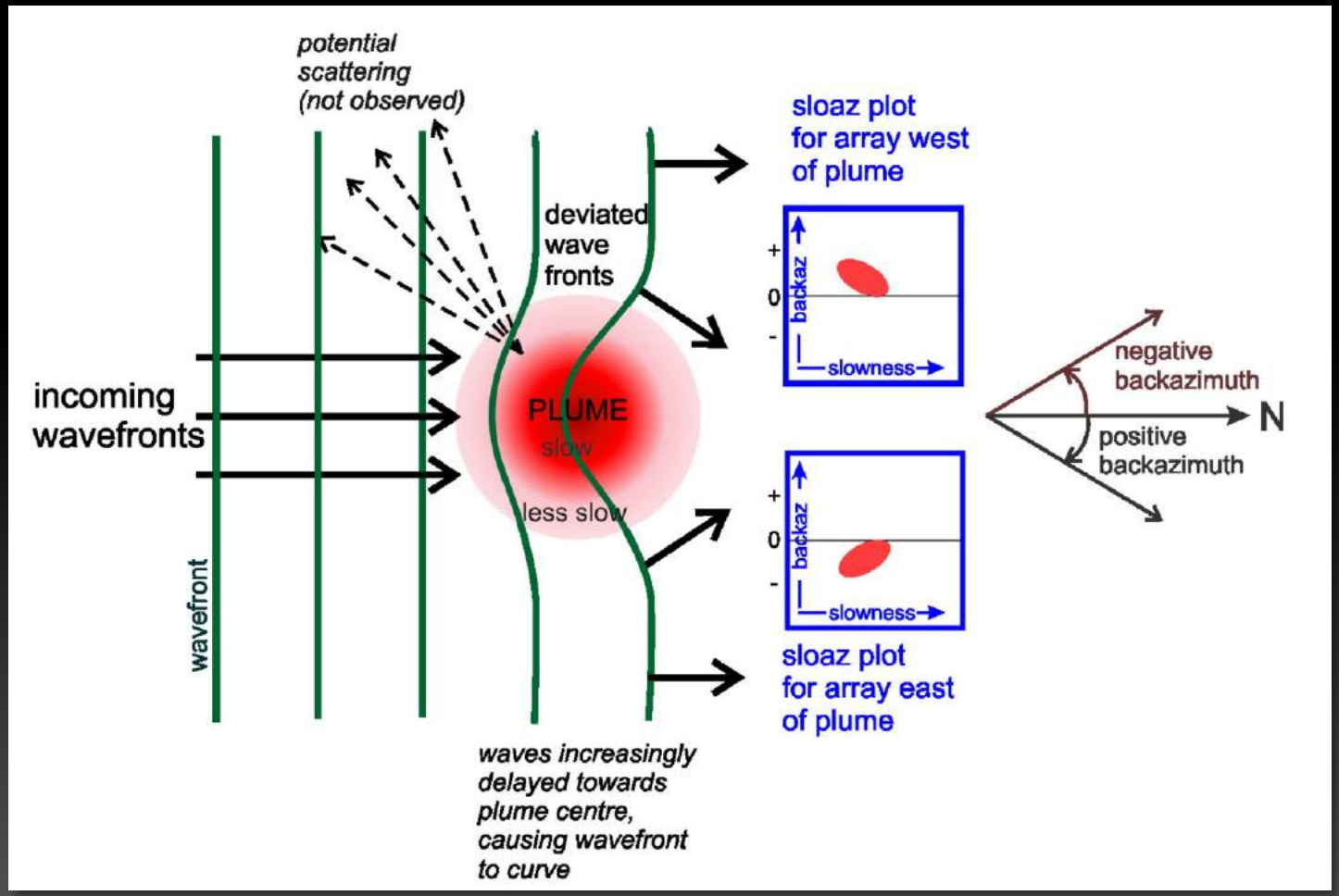
- It may be interesting to model mantle plumes interacting within their environment in order to compare them with / interpret surface geophysical, petrological and seismological observations in terms of dynamics.
- Both model thermal and thermochemical plumes move relatively to each other. Their absolute motions are controlled by tectonic and convective dynamics.
- Plume interactions with slabs may produce complex shapes and dynamics.
- Plumes interaction with the lithosphere can perturb the lithosphere's dynamics over large timescales and lengthscales, by inducing global plate reorganization events.

WHAT'S POSSIBLY NEXT?



Stockmann et al., 2019

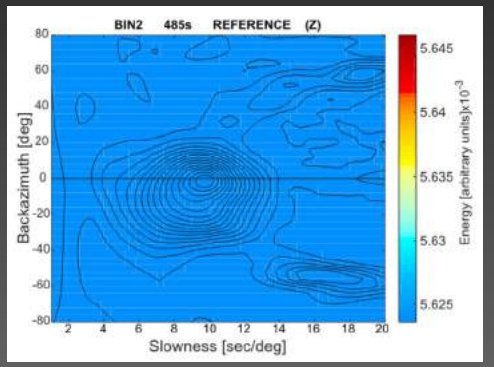
WHAT'S POSSIBLY NEXT?



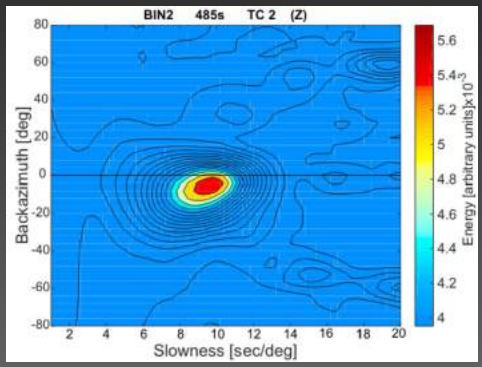
Stockmann et al., 2019

Courtesy of L. Cobden

No plume



Mantle plume



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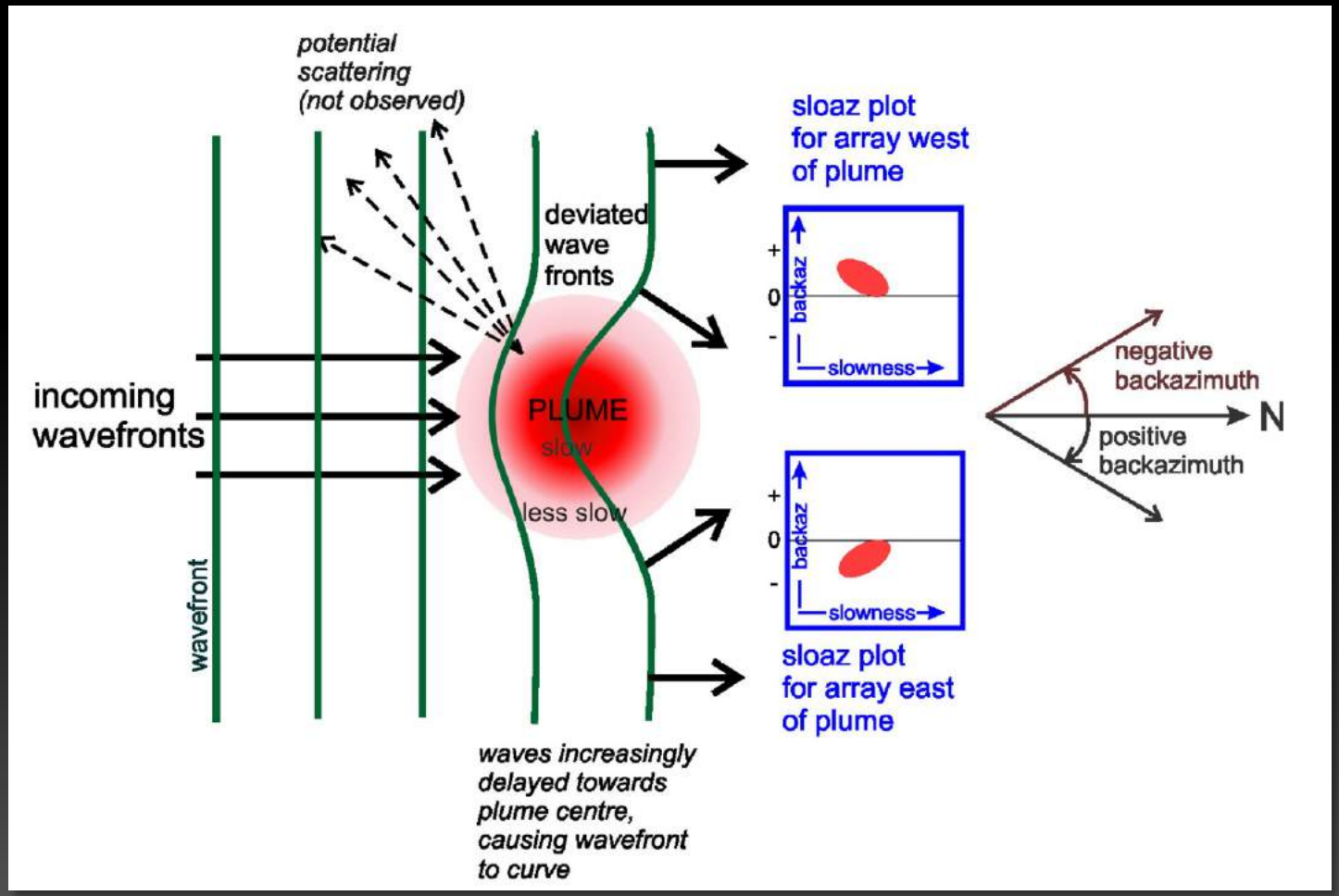
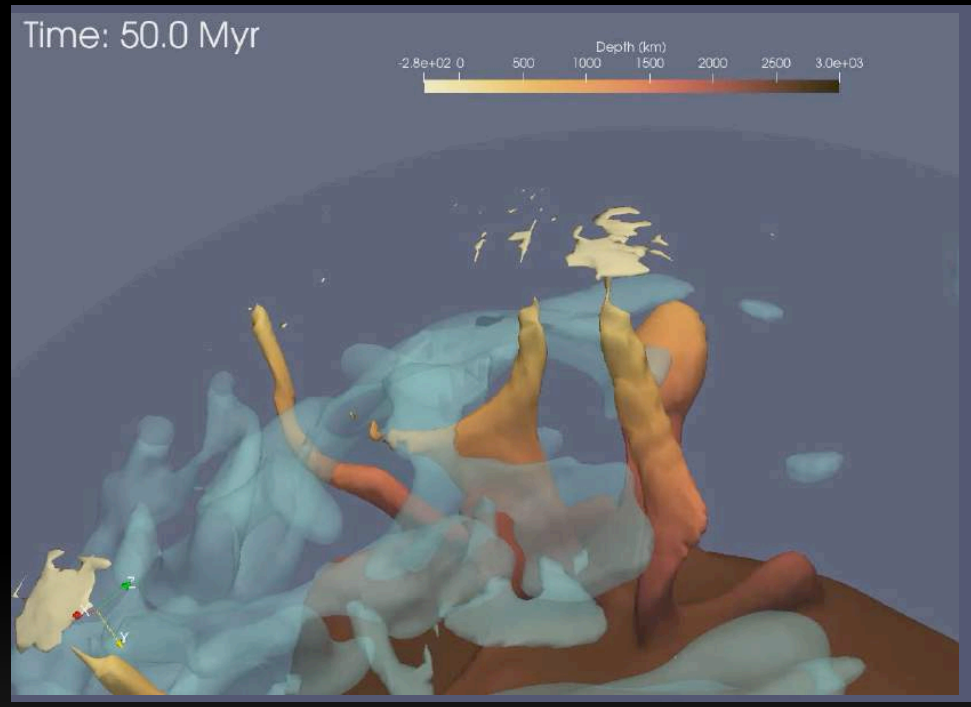
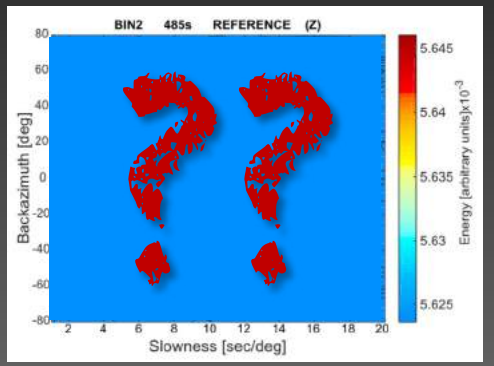


Stockmann et al., 2019



Arnould et al., 2020

Plumes interacting with slabs?




THANK YOU!