Using geochemistry and geochronology to infer long-term convective motions in the deep Earth

Jasper Konter (SOEST/UH)

Collaborators:
Matt Jackson (UCSB)
Anthony Koppers (CEOAS/OSU)
Multiple students: Valerie Finlayson, Kevin Konrad in particular

End-goals

Looking at long-term hotspot history, 2 example goals:

- 1. Absolute plate motion models vs moving plumes
- 2. Where are the conduits anchored (aka find the reservoirs for the geochemical extremes)?

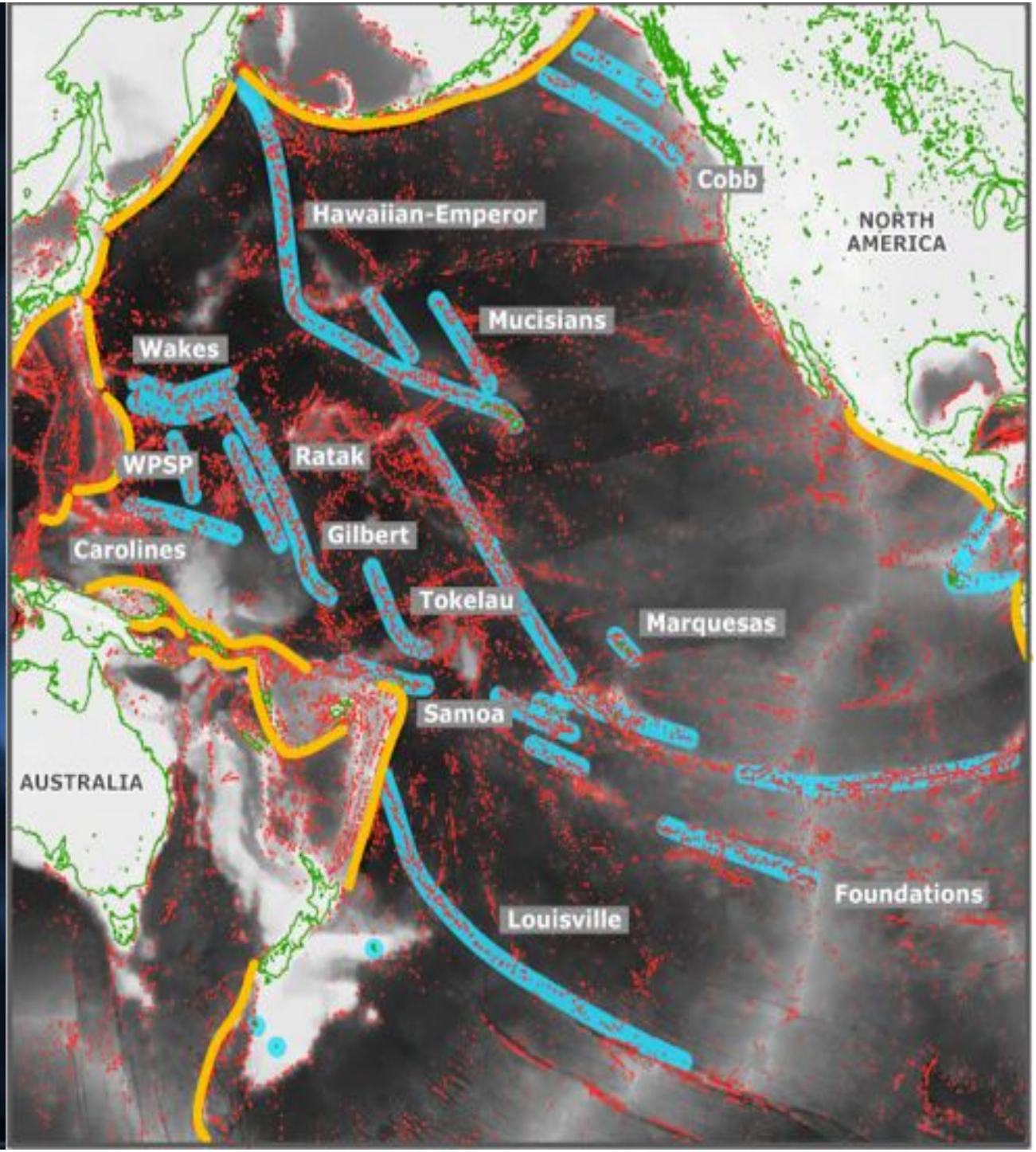
We'll mostly look at #1

Outline

- 1. Absolute plate motion and plume fixity
  - Techniques and issues
- 2. Moving plumes
  - Reasons for moving plumes
  - Moving plumes to improve the fit
- 3. Plate, plume motion and geochemistry
  - Geochemistry as a tool
  - Results/where we are

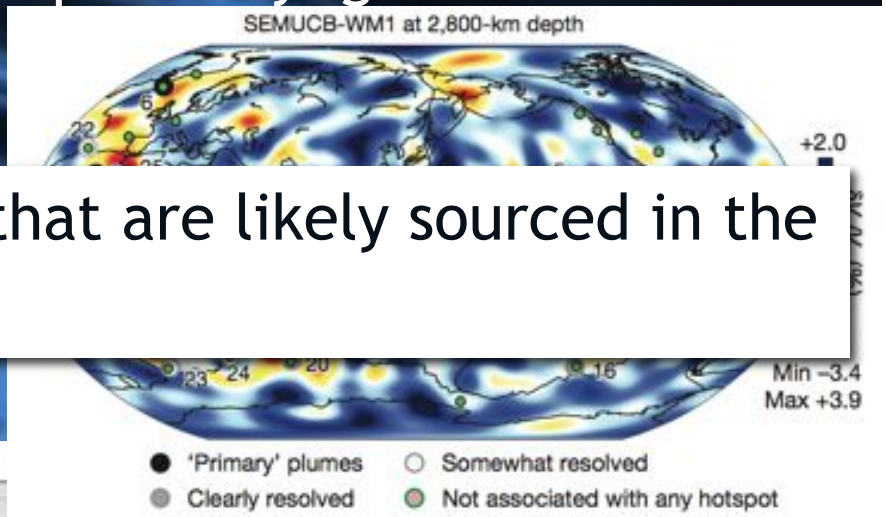
Tracks in the Pacific

- > 50,000 volcanoes in the Pacific basin
- Many in chains
- Many from plumes (?)

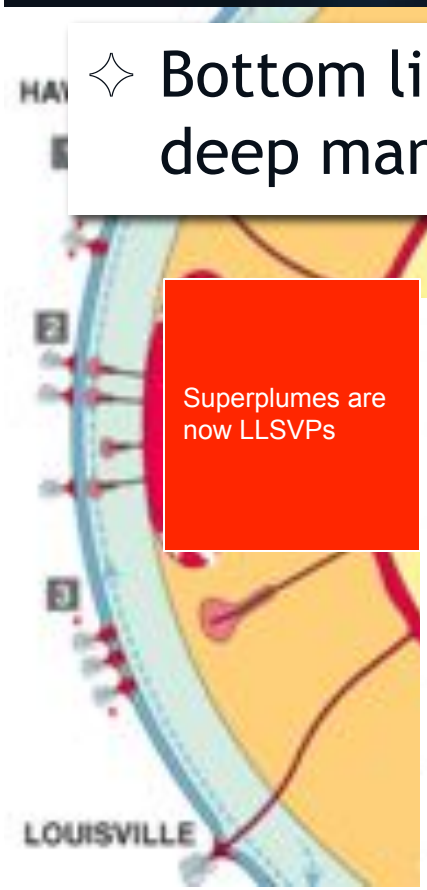


Telling plumes from “plumes”

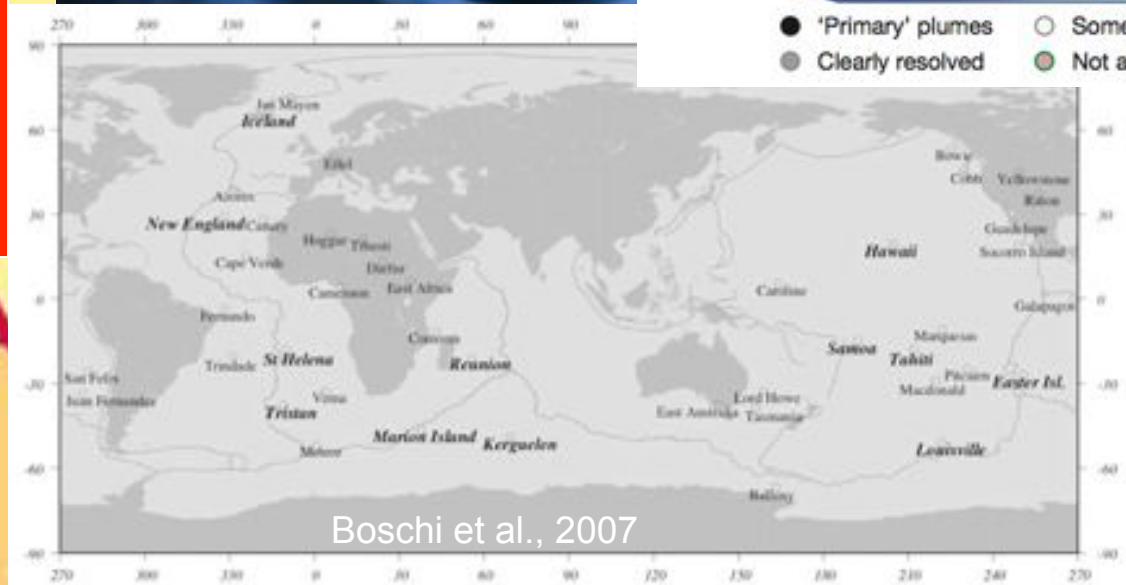
- Various opinions on what is a deep-derived plume vs. something shallow
- For absolute plate motion should probably ignore shallowest stuff



- Bottom line: there are plenty that are likely sourced in the deep mantle

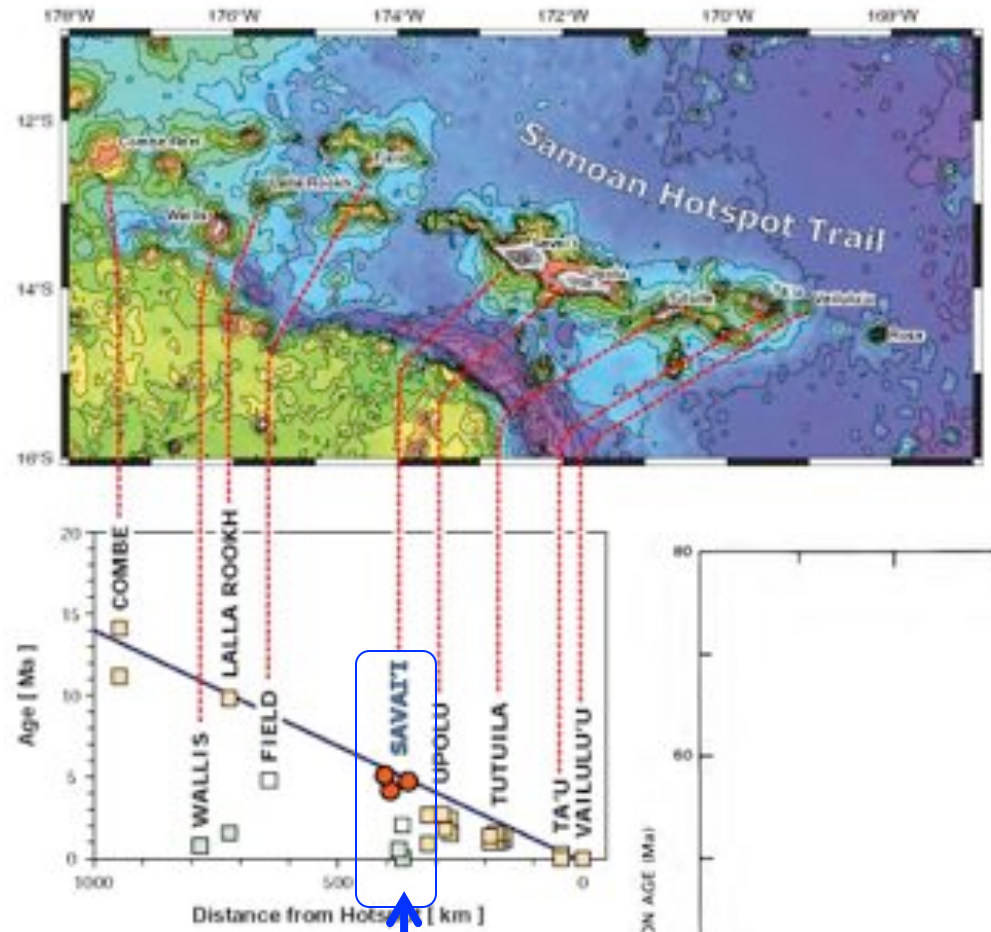


Superplumes are now LLSVPs



Boschi et al., 2007

French and Romanowicz, 2015

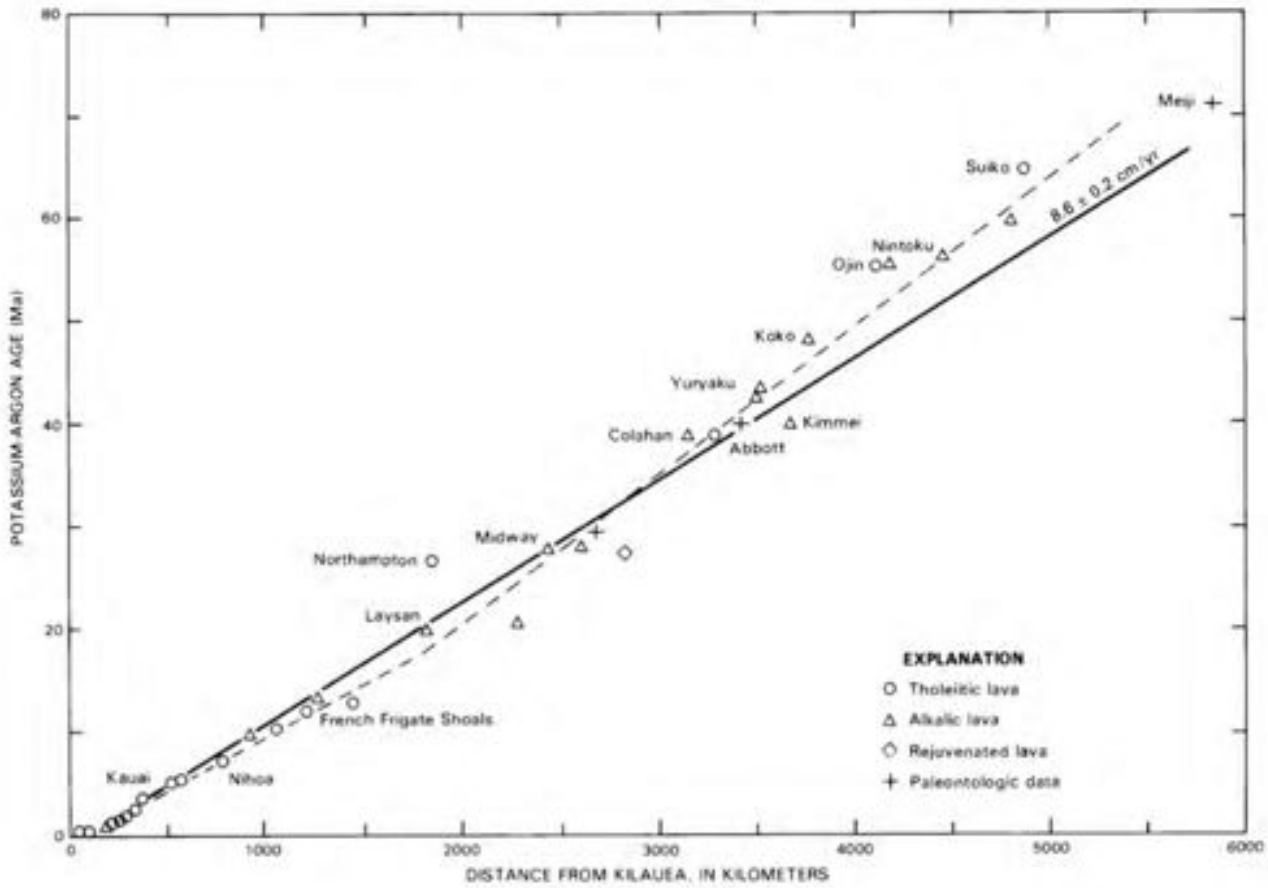


Yes, age progressive, but…

Clague and Dalrymple, 1987

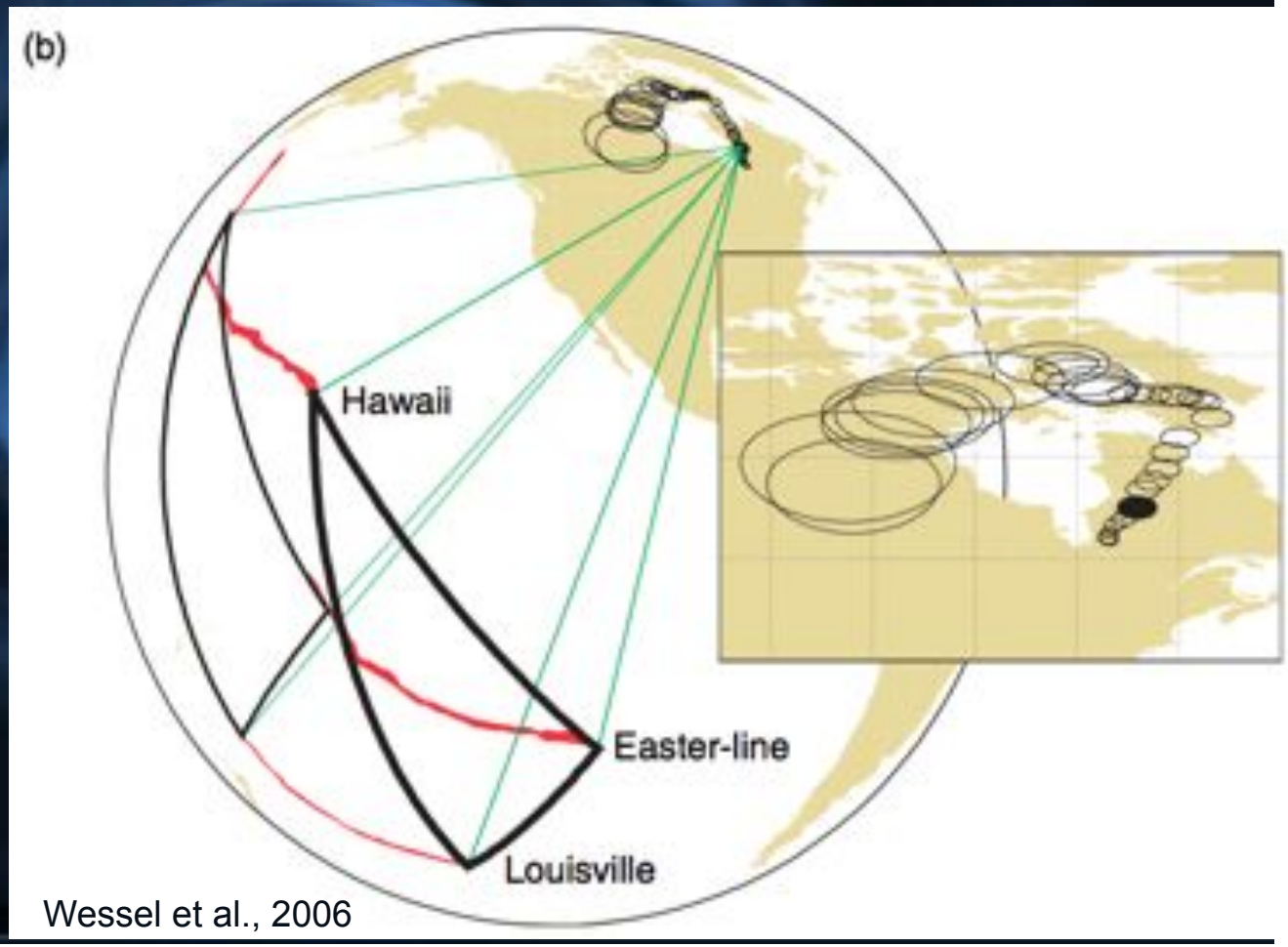
Koppers et al., 2008

- ✧ Activity can last ~5 Ma



1) Fixed plumes: maintain polygon

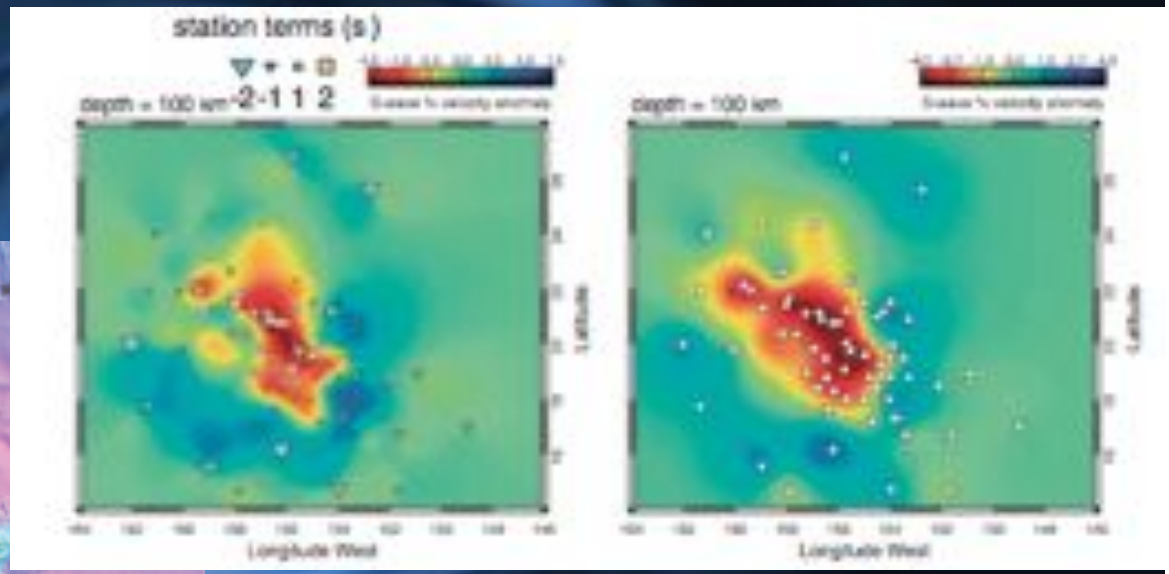
- Realize that if the plumes are fixed, polygon between them has to stay the same
- Find the Euler pole that rotates the polygon



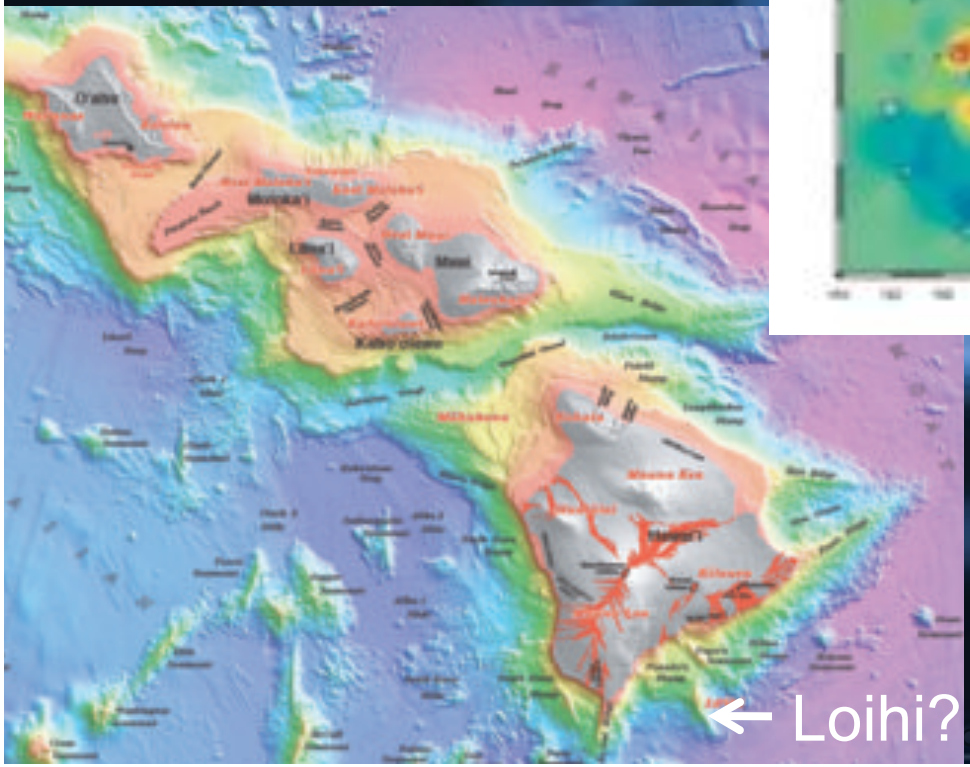
Wessel et al., 2006

1b) Continued…

- So where is the hotspot today? Example Hawaii:

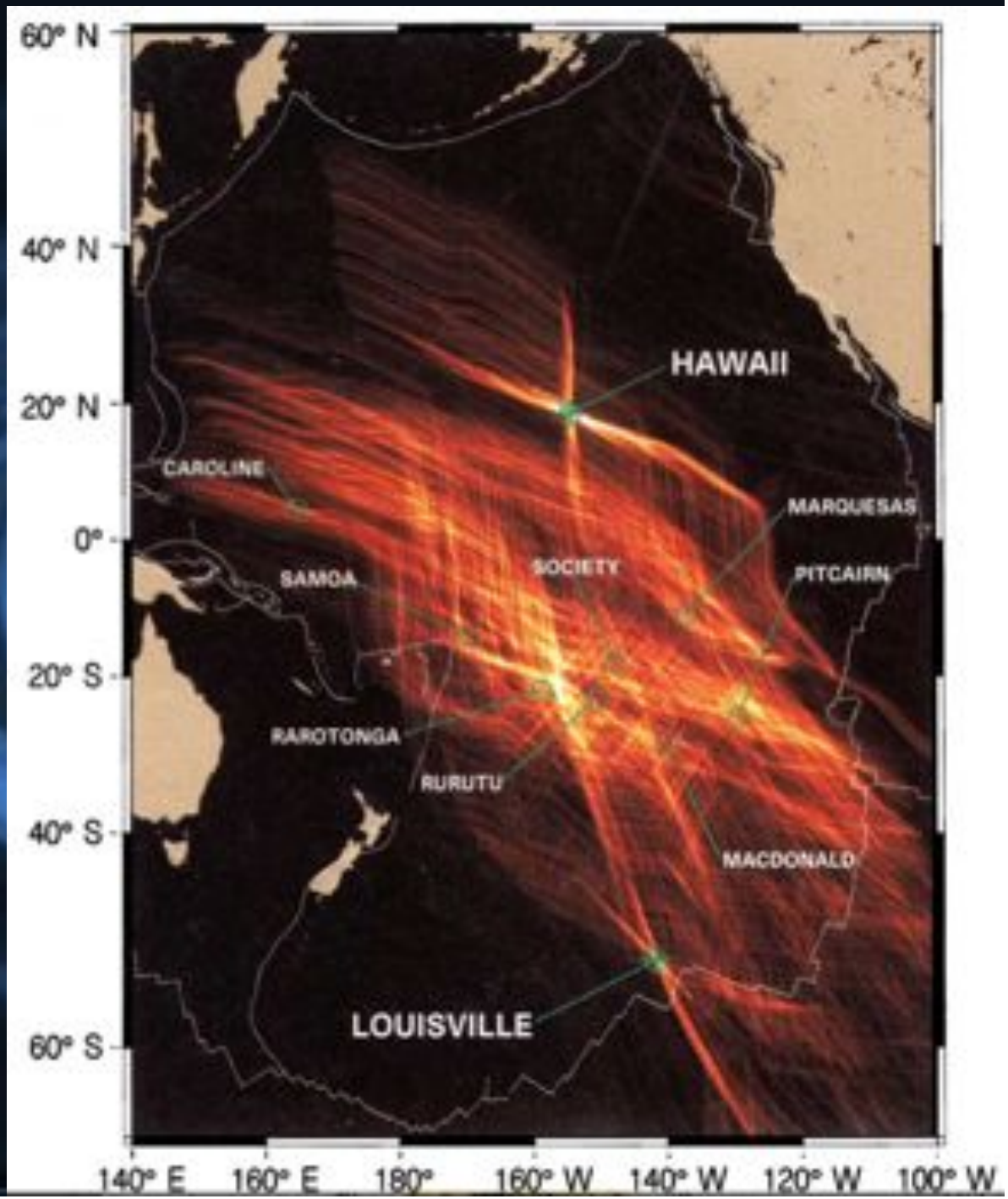


Wolfe et al., 2009



1b) Hotspotting

- Iterate toward a model that generates a clear intersection of "mantle flow" paths
- Effectively, this just iterates looking for the tightest cluster of "back-tracked" original eruptive locations

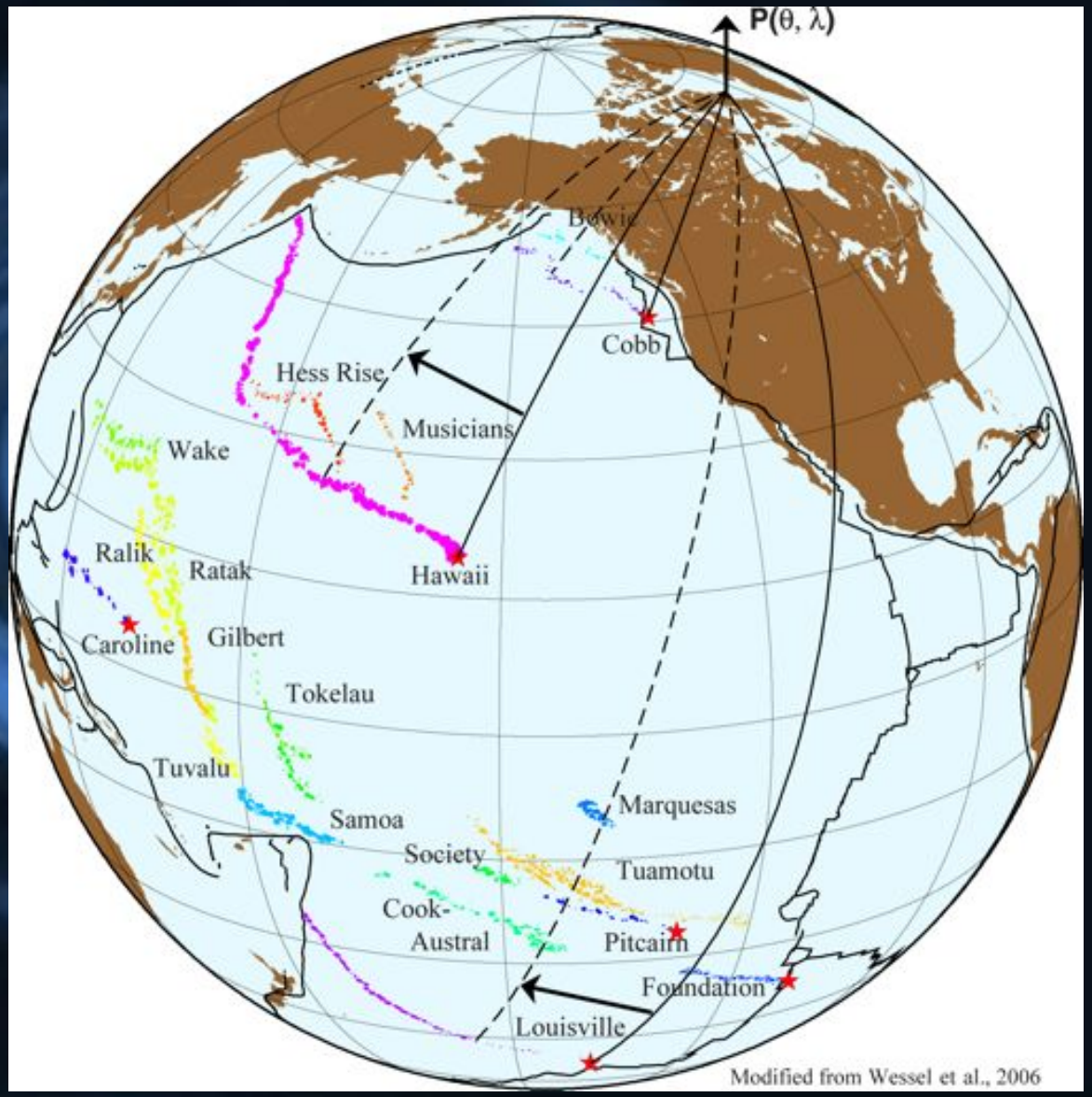


Wessel and Kroenke, 1997

Iteratively in Wessel et al., 2008

Available chains to fit rotations

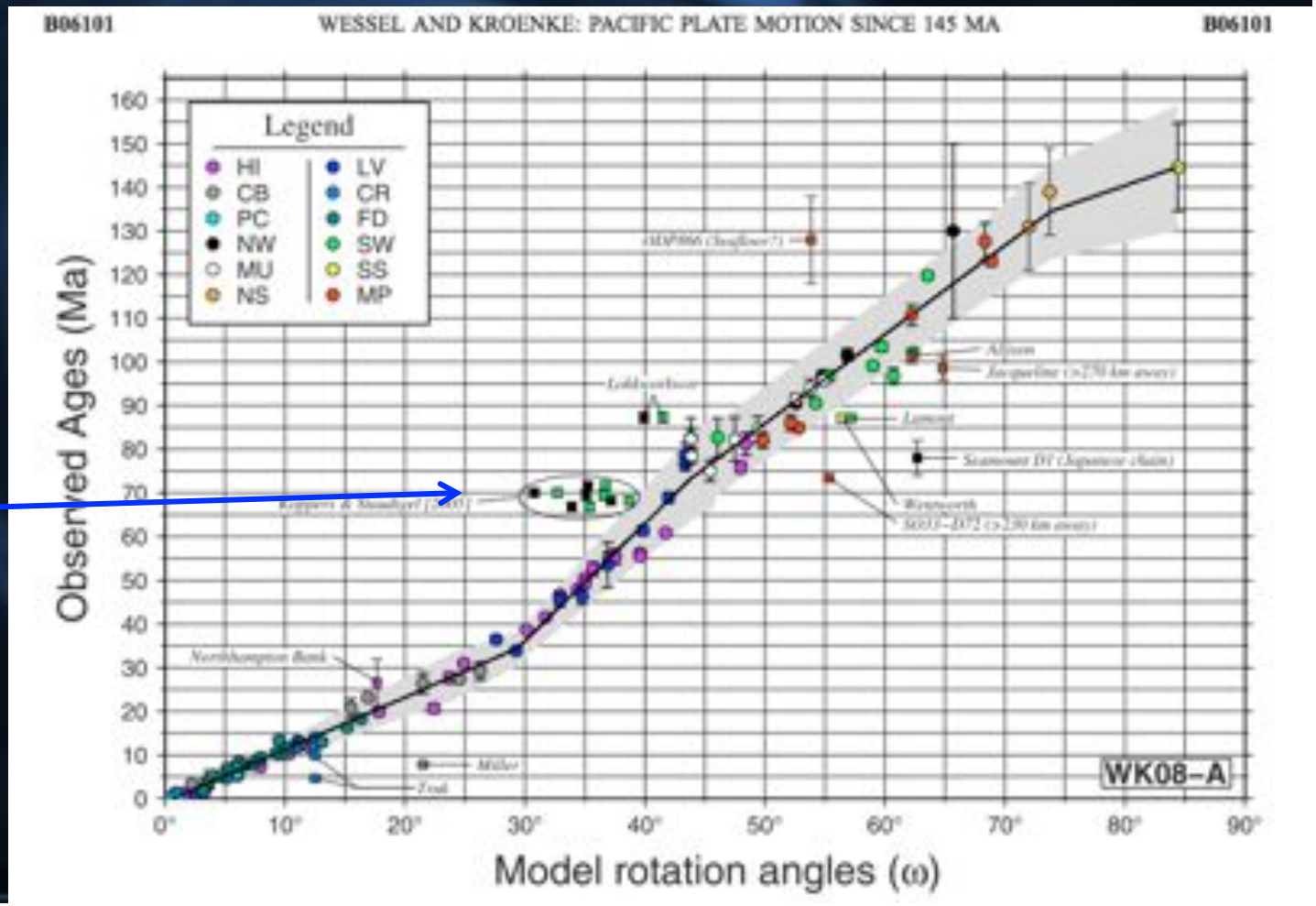
- Continuous to 80Ma: Hawaii, Louisville
- Shorter chains used from all over the central Pacific, few older ones from the W Pacific
- Note (for later): distance along track depends on distance to pole



Tie the rotations to time

- Plot known ages for the volcanoes you just got angles for
- Fit a curve through data to define Absolute Plate Motion Model

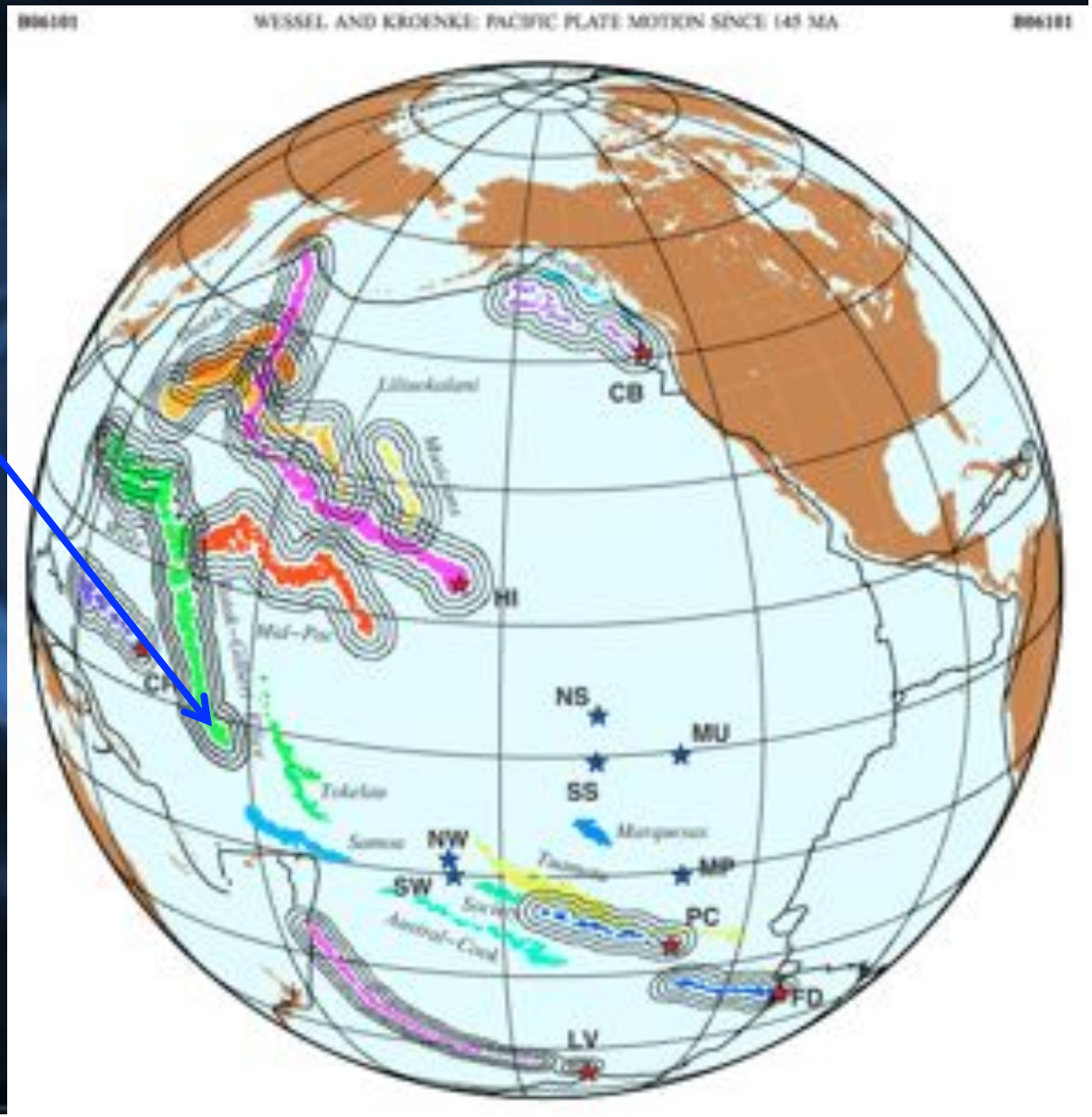
- Issue 1



Issue 1…

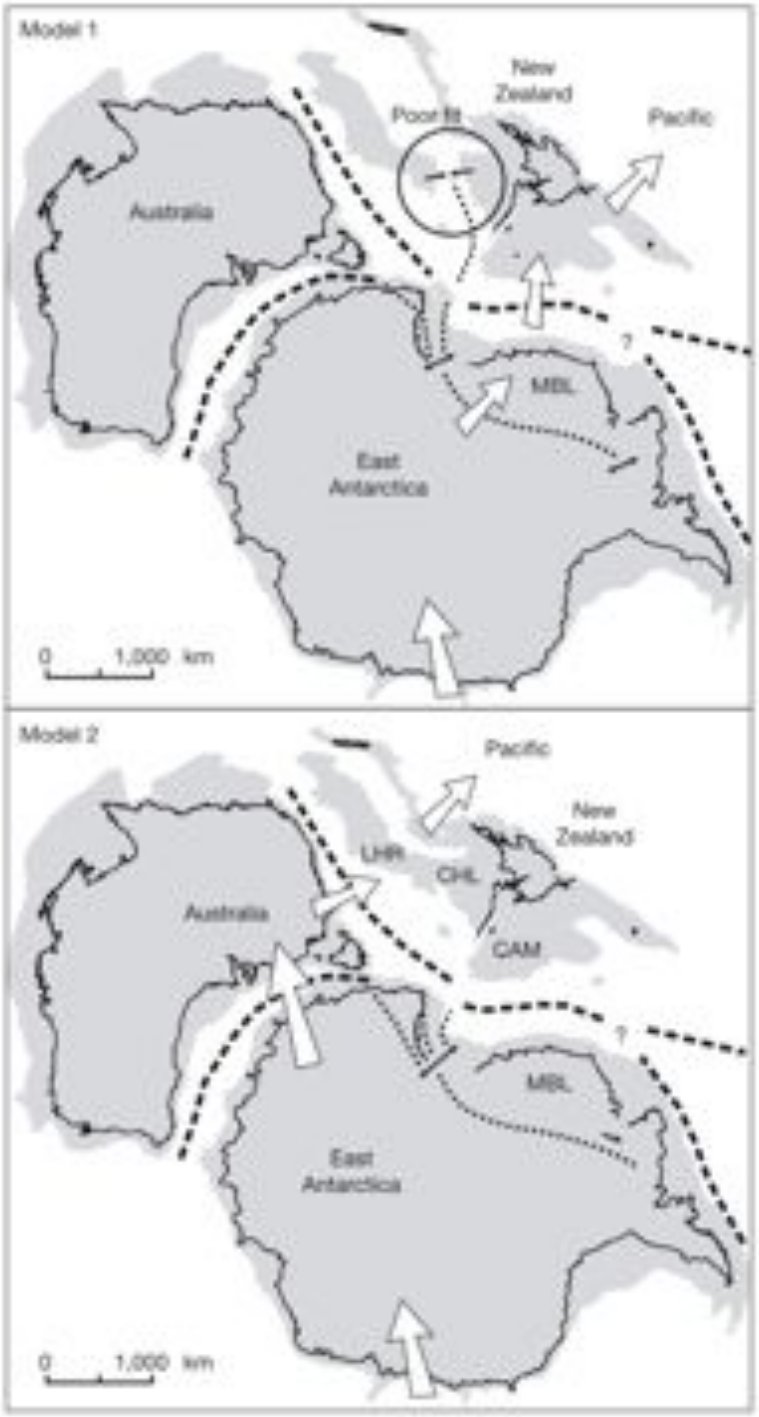
- Adding the age in later ignores prior knowledge
- What does that corner look like?

  or: what would you try to compare it to as similarly aged segment?



Issue 2

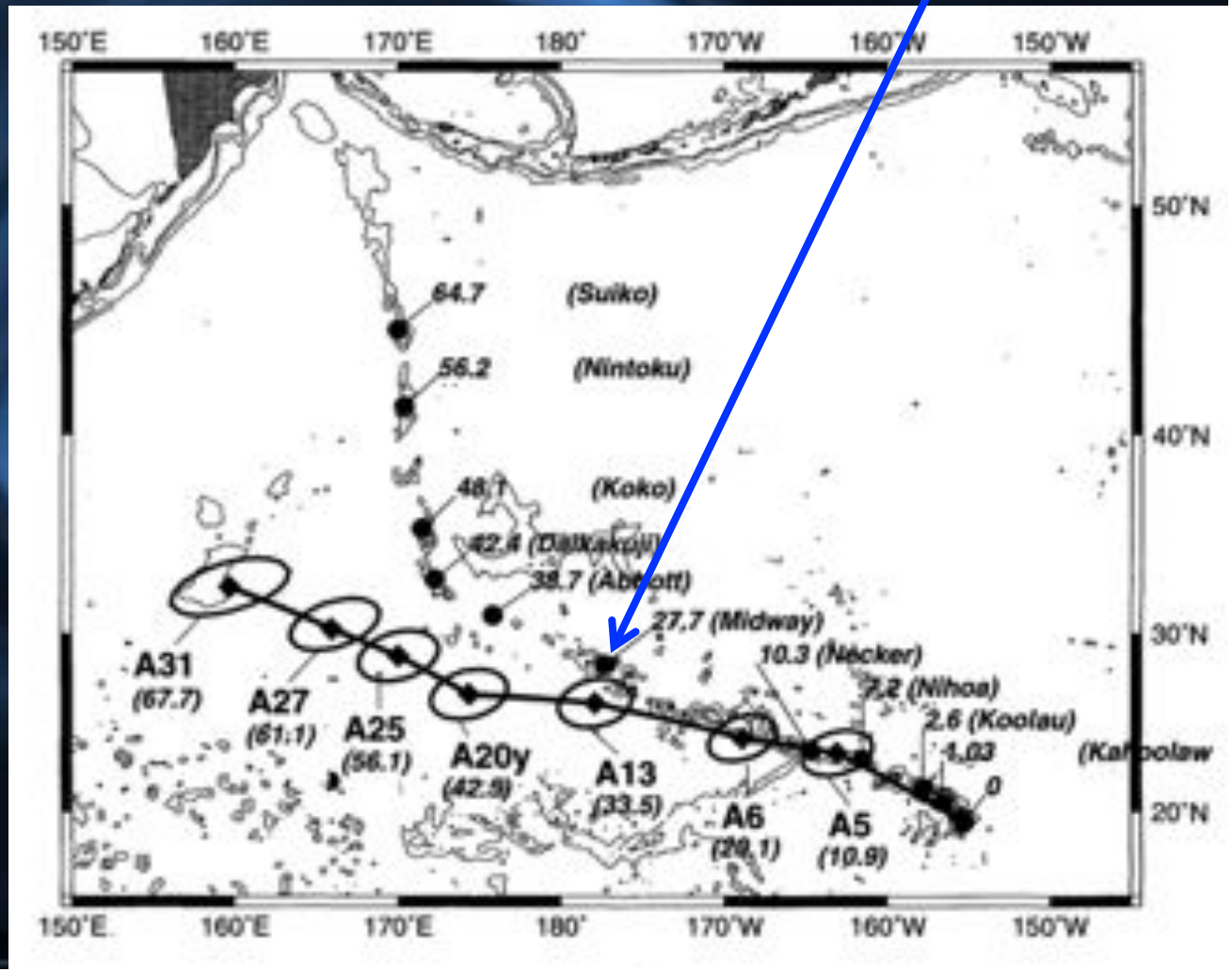
- If plumes are fixed wrt mantle, Absolute Plate Motion model in Atlantic can be translated to Pacific through a plate circuit
- If correct, should be able to predict Pacific hotspot trails like Hawaii…



Issue 2…

- Indo-Atlantic reference frame deviates strongly by ~30 Ma.
- So the Hawaii-Emperor Bend (HEB) is not predicted
- The strong bend also expected to correlate with major tectonic event

Nothing at ~43 Ma

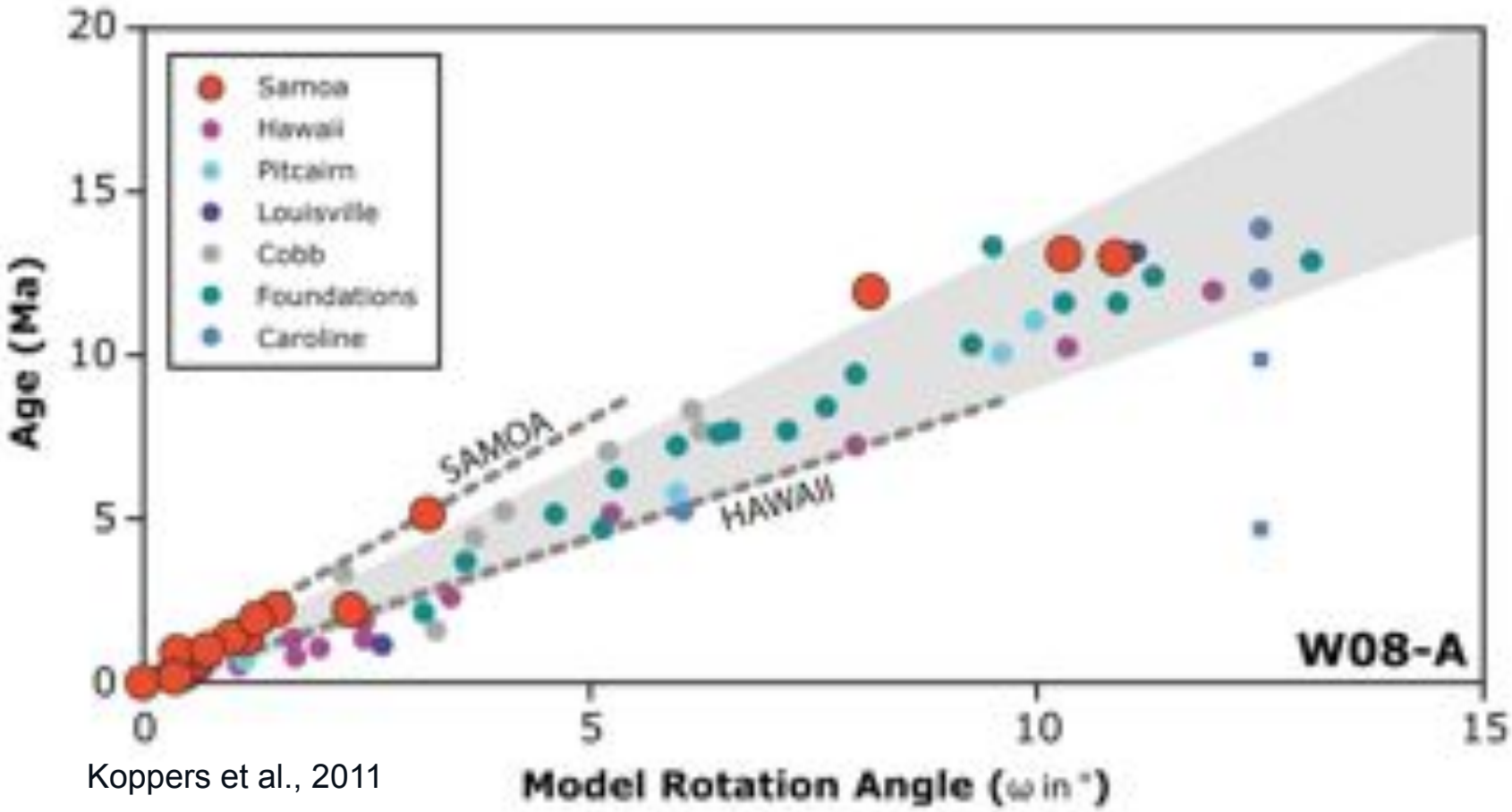


Cande et al., 1995

Issue 3

- ✧ The rotations are not the same:
- ✧ Plotting angle against age shows different slopes!

=> Plate is not rigid, or plumes are not fixed (your choice)



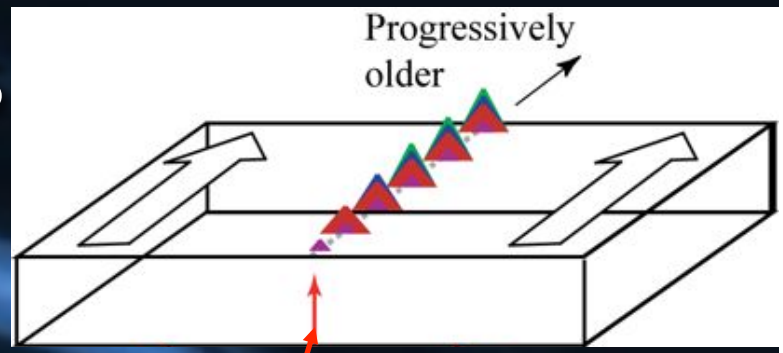
Koppers et al., 2011

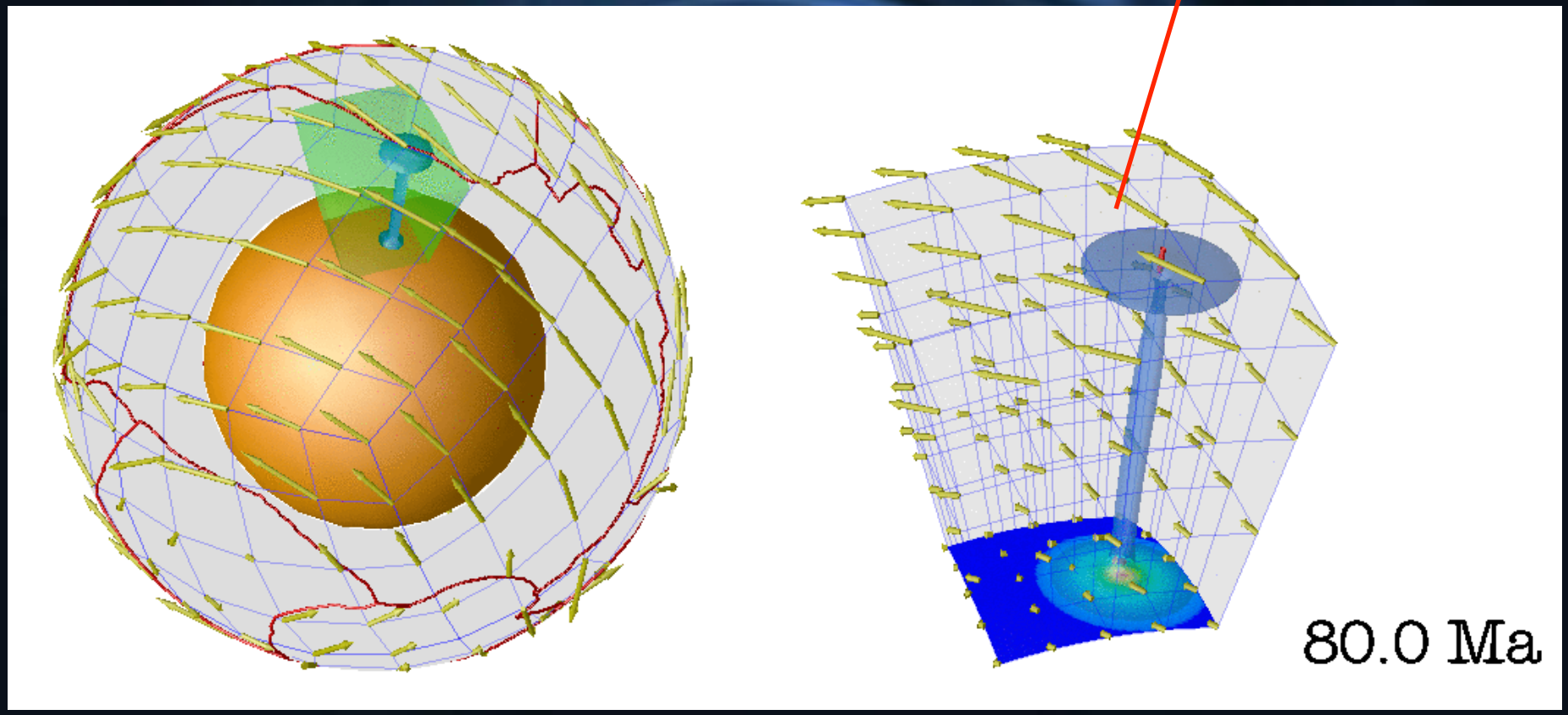
Outline

- 1. Absolute plate motion and plume fixity
  - Techniques and issues
- 2. Moving plumes
  - Reasons for moving plumes
  - Moving plumes to improve the fit
- 3. Plate, plume motion and geochemistry
  - Geochemistry as a tool
  - Results/where we are

Plume model adaptations

- Plume motion to explain track misfit (geometrically, or age)

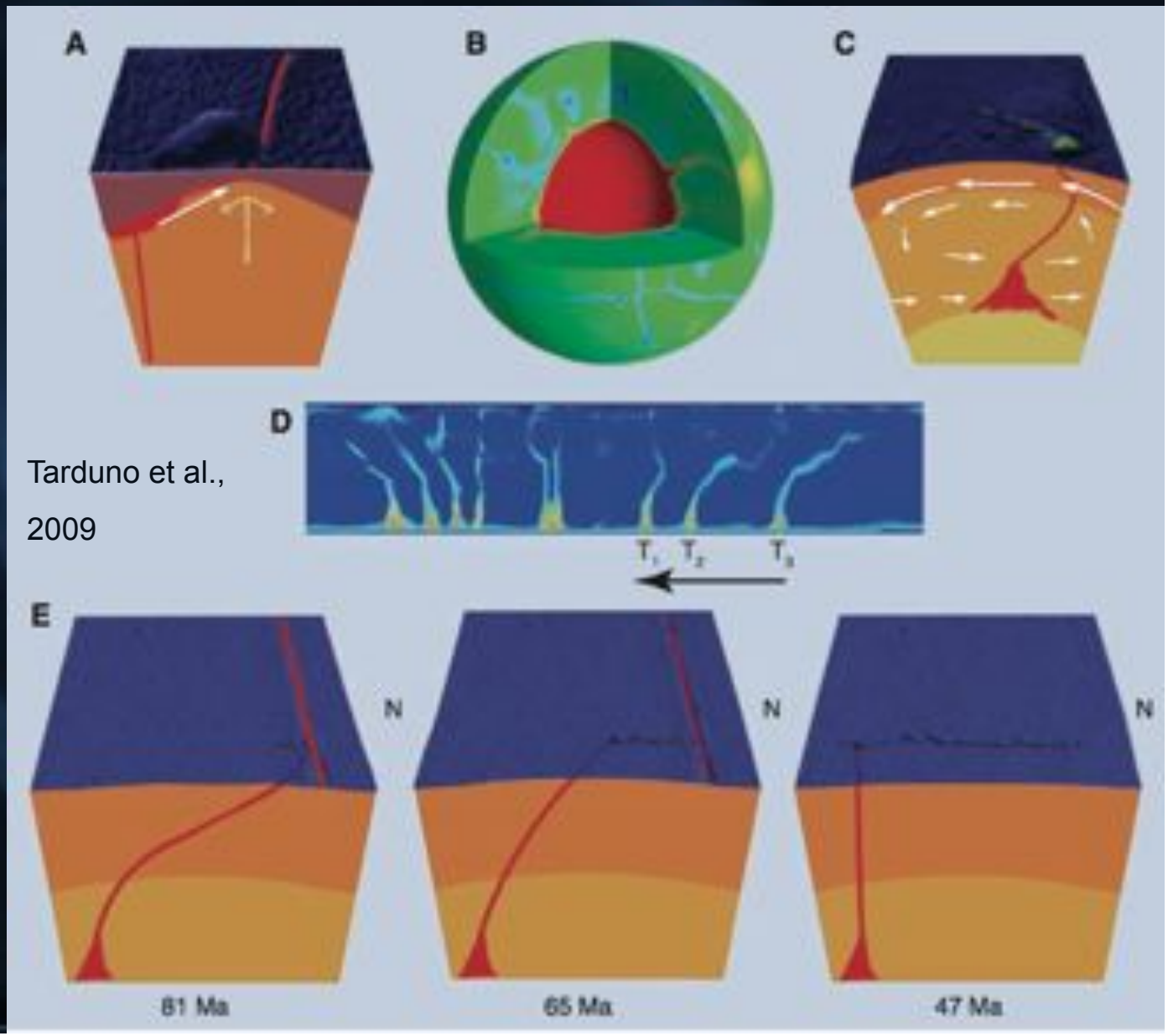




http://www.gps.caltech.edu/~gurnis/Movies/Animated_GIFs/Pyre_global-plume.gif

Proposed reasons for motion

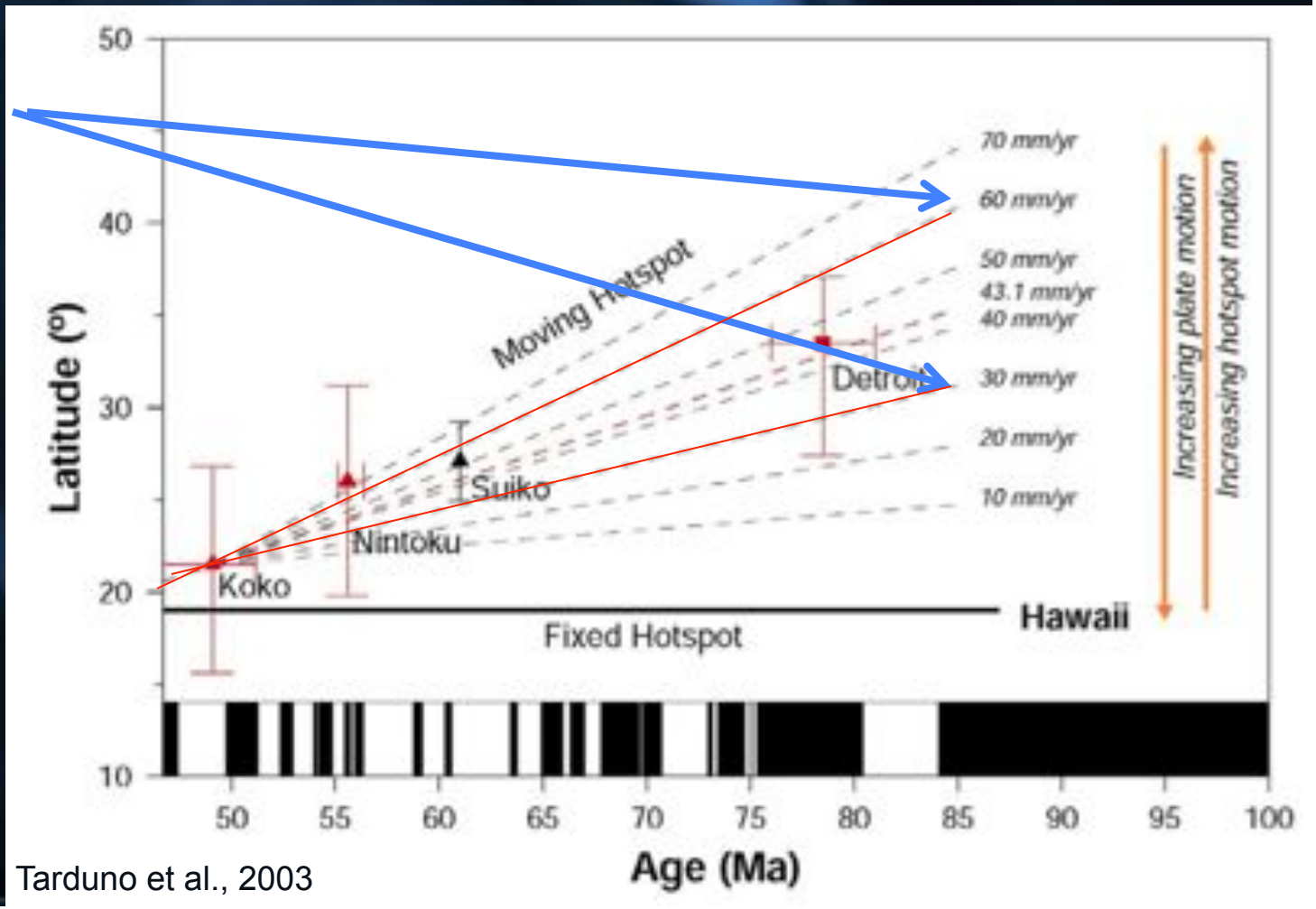
- Channeling
- Strong upper mantle flow
- Whole mantle flow
- Plume migration to a central upwelling
- Capture at a ridge



Tarduno et al., 2009

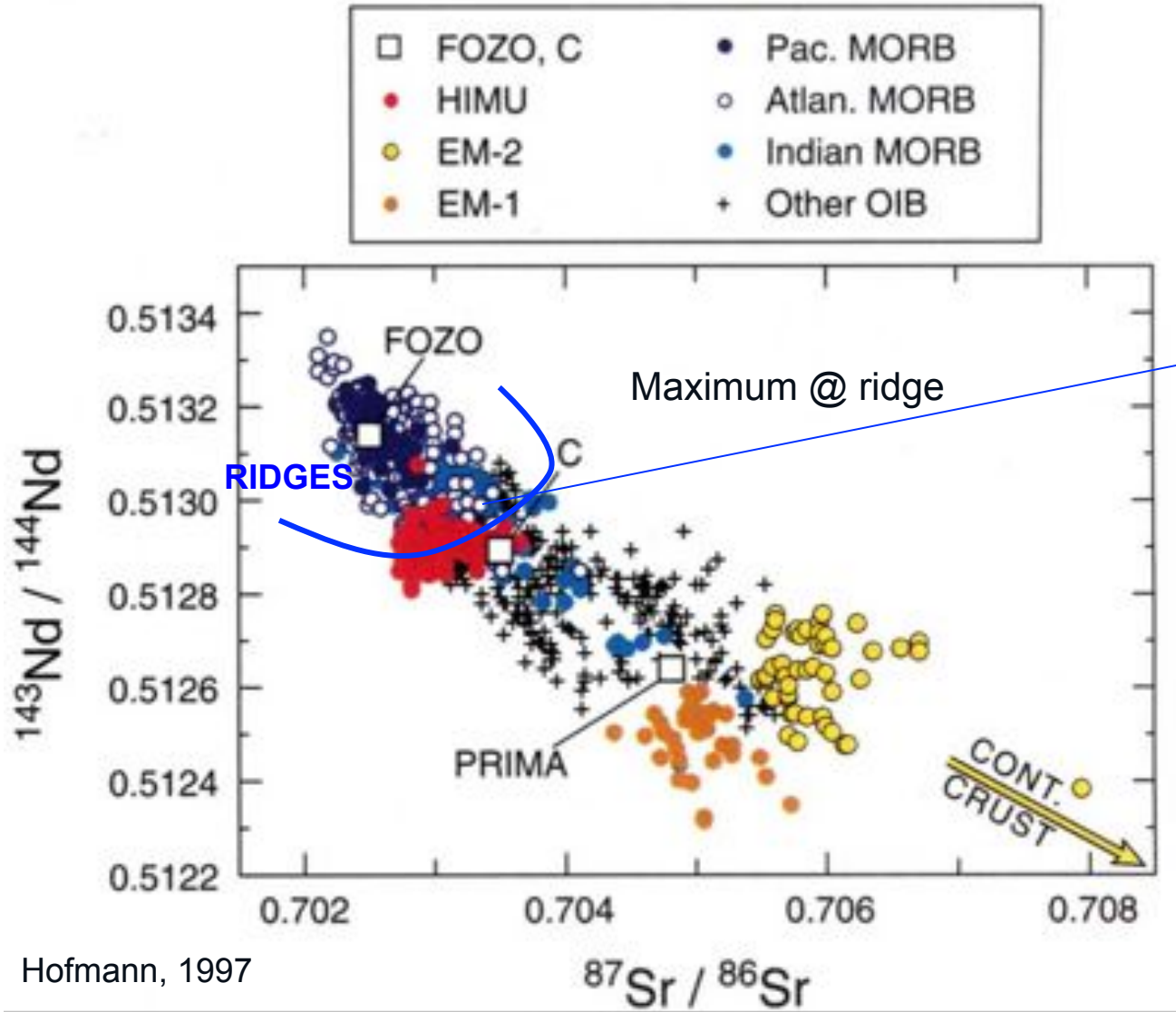
So is there any proof?

- Fixed plume should maintain paleomagnetic latitude (roughly, averaging and assuming little True polar wander)
- Drilling the Emperor chain suggests changing latitude with age >HEB
- Note range in mm/yr, total shift



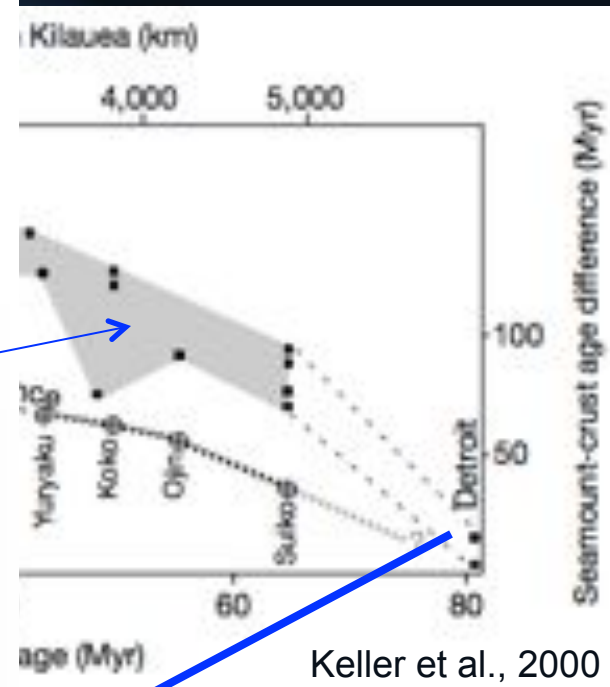
Tarduno et al., 2003

Option 1: proximity to ridges

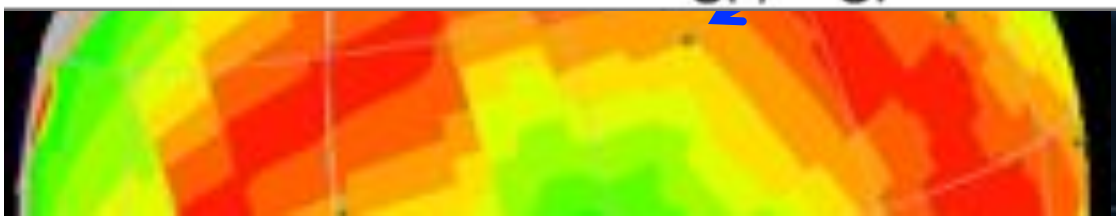


Hofmann, 1997

Maximum @ ridge



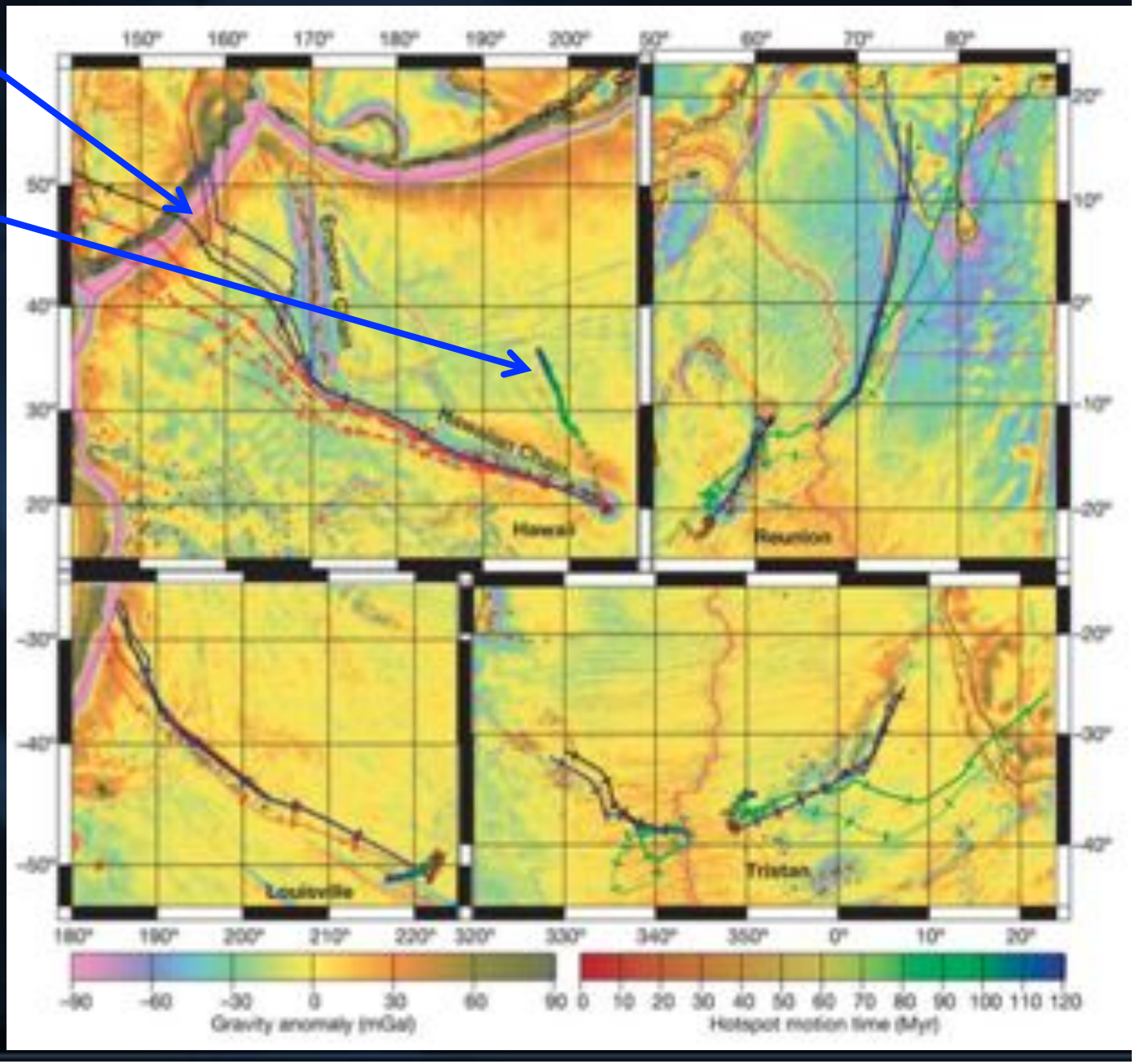
Keller et al., 2000



Large-scale plume motion helps

- Predicted path
- Predicted plume motion
- Allowing for plume motion, Indo-Atlantic APM works much better
- Still some differences near 80 ma

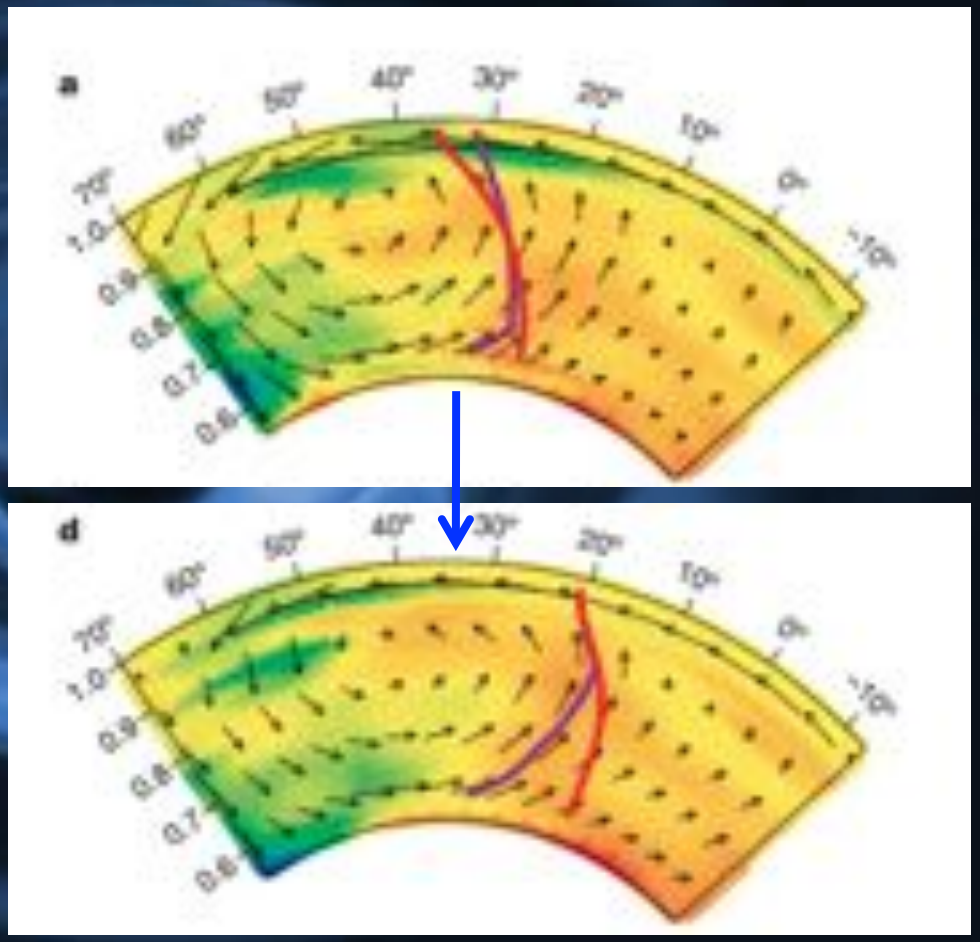
=> Compare fit Hawaii vs Louisville



Steinberger et al., 2004

So what's the motion based on?

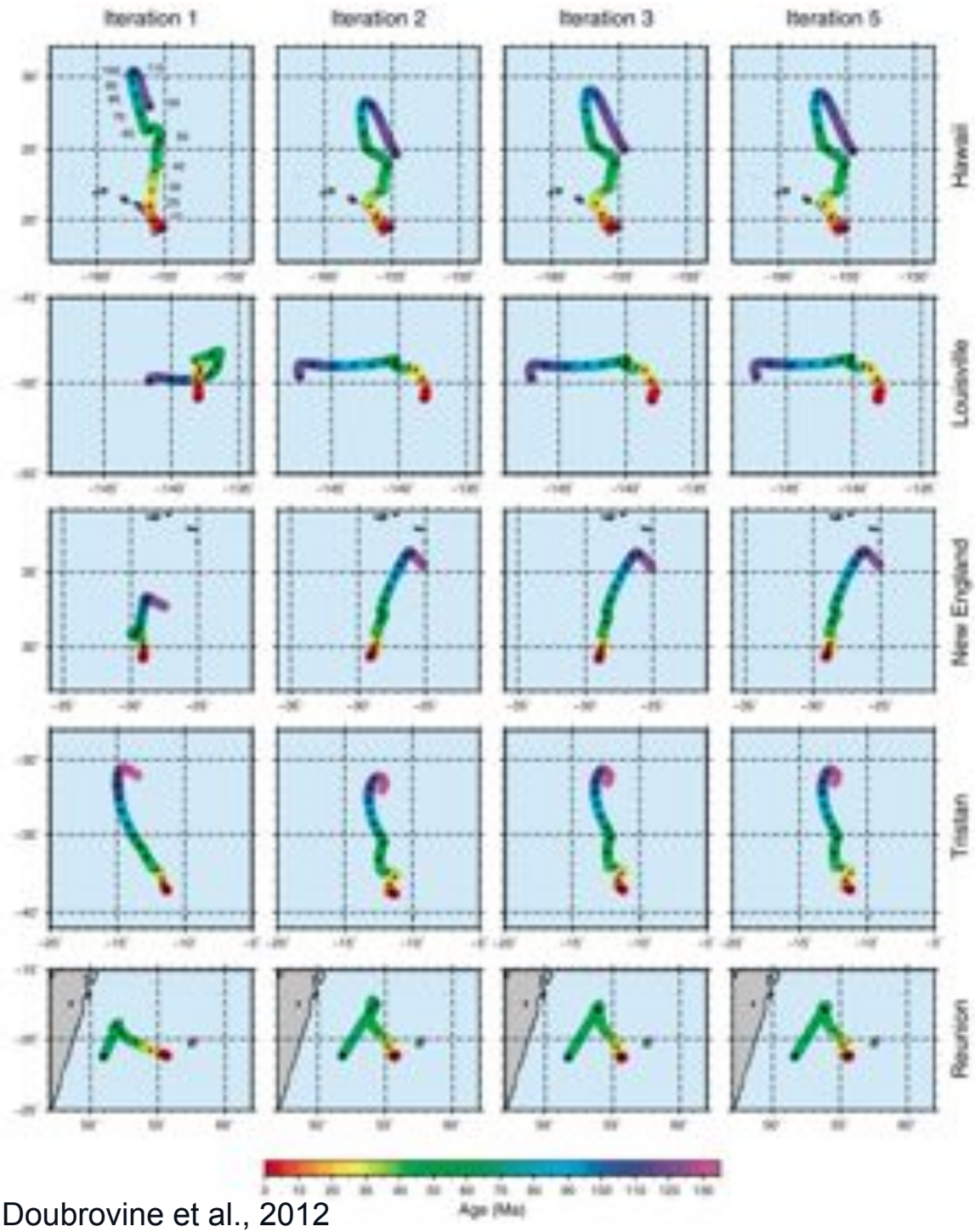
- Based on density from tomography, plate motion imposed, assumed viscosity structure
- 2 choices for plumes in the "mantle wind":
  - Fixed base (purple)
  - Moving base (red)



Steinberger et al., 2004

Recent models use global flow

- These come with a time-history of plume locations
- Tested with Indo-Atlantic hotspot predictions in Pacific



Doubrovine et al., 2012

So are the models any good?

✧ 1. Paleolatitude test suggests a mismatch > HEB

Palaeolatitude estimates (in ° S latitudes)							
2-cm archives	1σ	2σ	n	Discrete samples	1σ	2σ	n
40.4°S	37.9 42.5	35.9 45.1	21	42.9°S	38.6 47.4	35.0 54.7	9
52.3°S	46.9 61.6	43.5 76.0	28	47.0°S	44.0 51.5	41.4 57.5	28
51.5°S	48.2 54.8	45.2 57.6	8	49.8°S	47.4 52.2	45.2 54.8	8
54.2°S	49.4 60.2	45.2 74.3	12	52.3°S	43.0 60.0	34.8 75.2	3

Koppers et al., 2012

- ✧ Louisville shows <5° change in paleolatitude vs. Hawaii's 15°
- ✧ Any other effects?
- ✧ Constraints on plume source longitude?

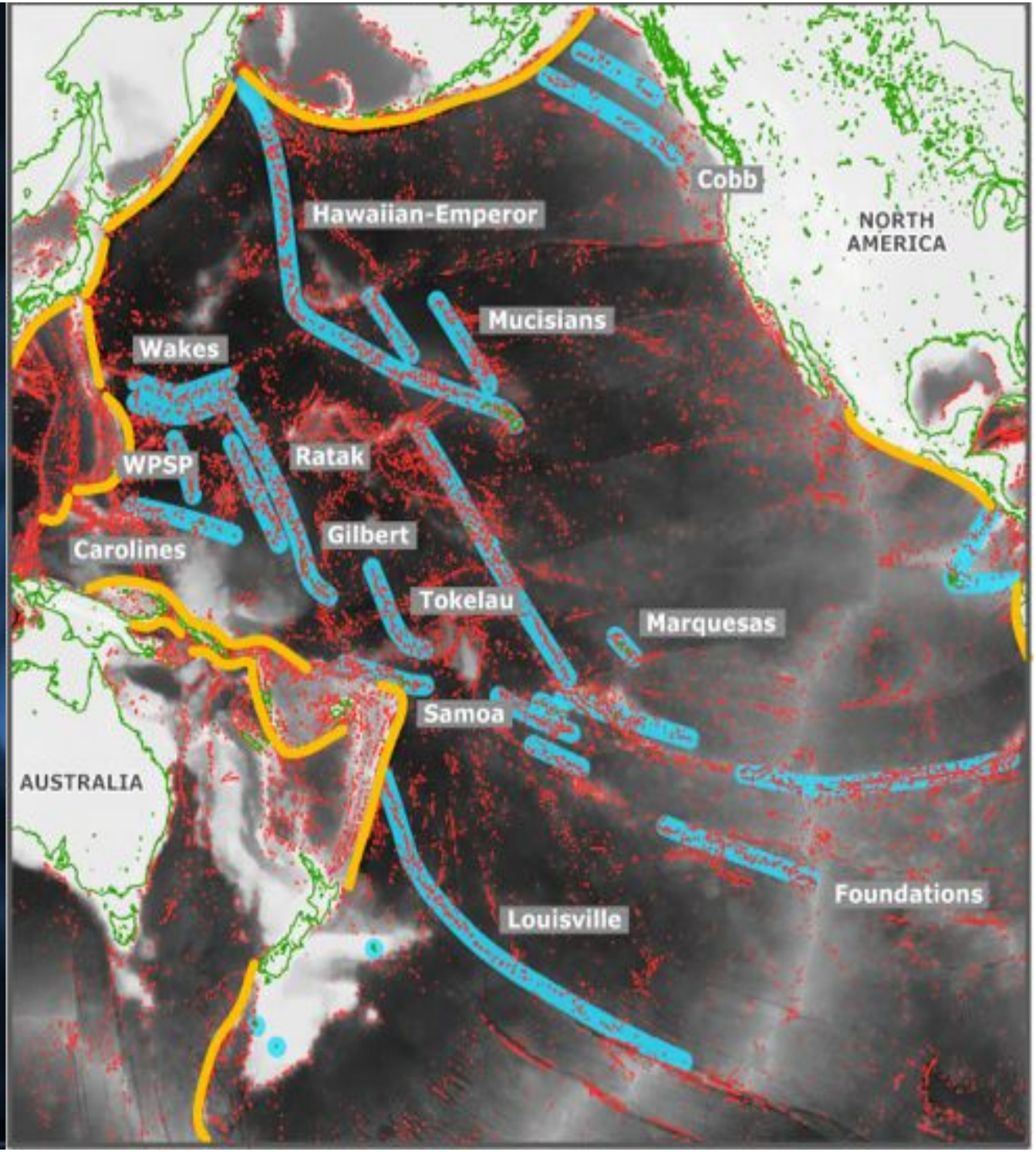
✧ 2. How about testing this a different way?

Outline

- 1. Absolute plate motion and plume fixity
  - Techniques and issues
- 2. Moving plumes
  - Reasons for moving plumes
  - Moving plumes to improve the fit
- 3. Plate, plume motion and geochemistry
  - Geochemistry as a tool
  - Results/where we are

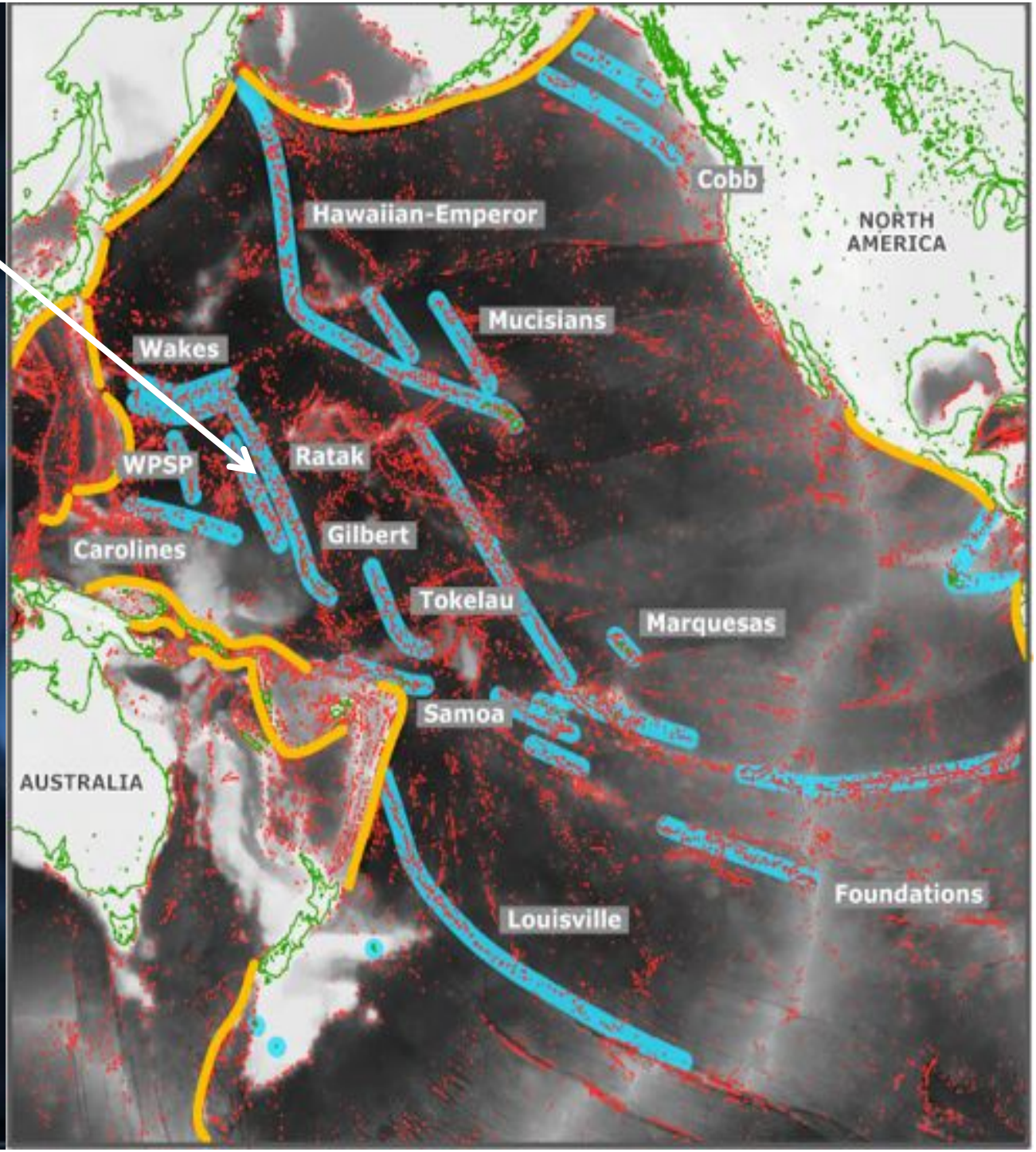
How about other tracks?

- Current models mostly depend on Hawaii, Louisville; but they don't agree at >HEB
- We need a 3rd long-lived hotspot!



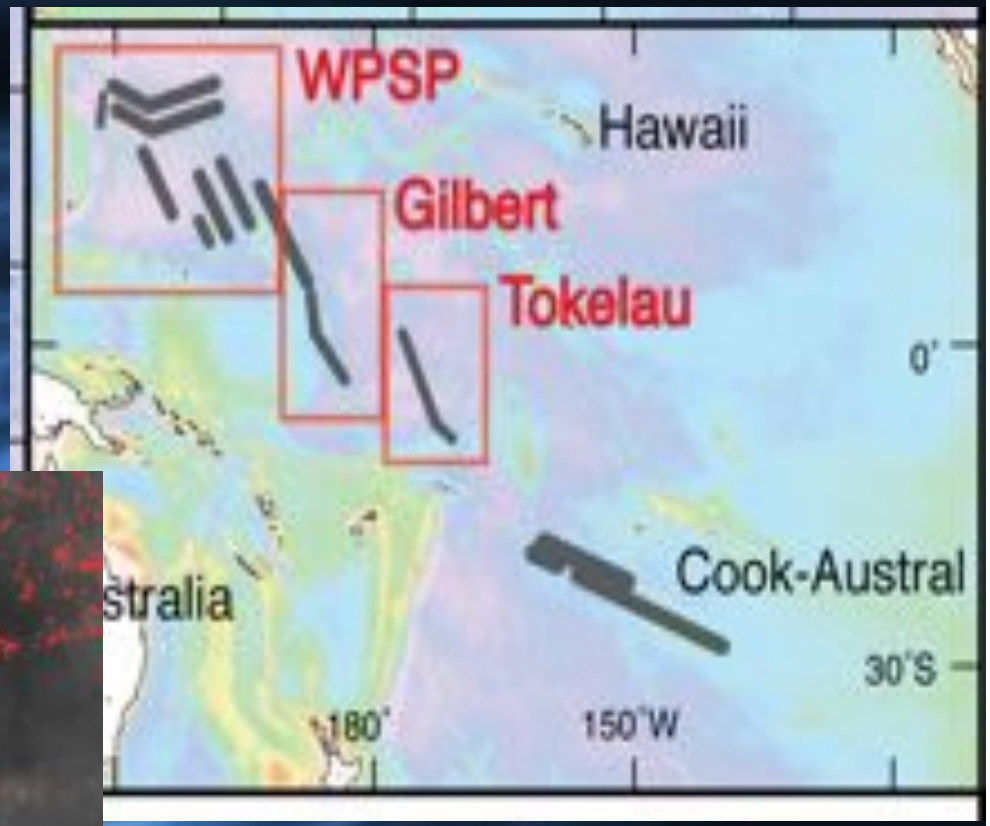
Where does the W Pacific stuff come from?

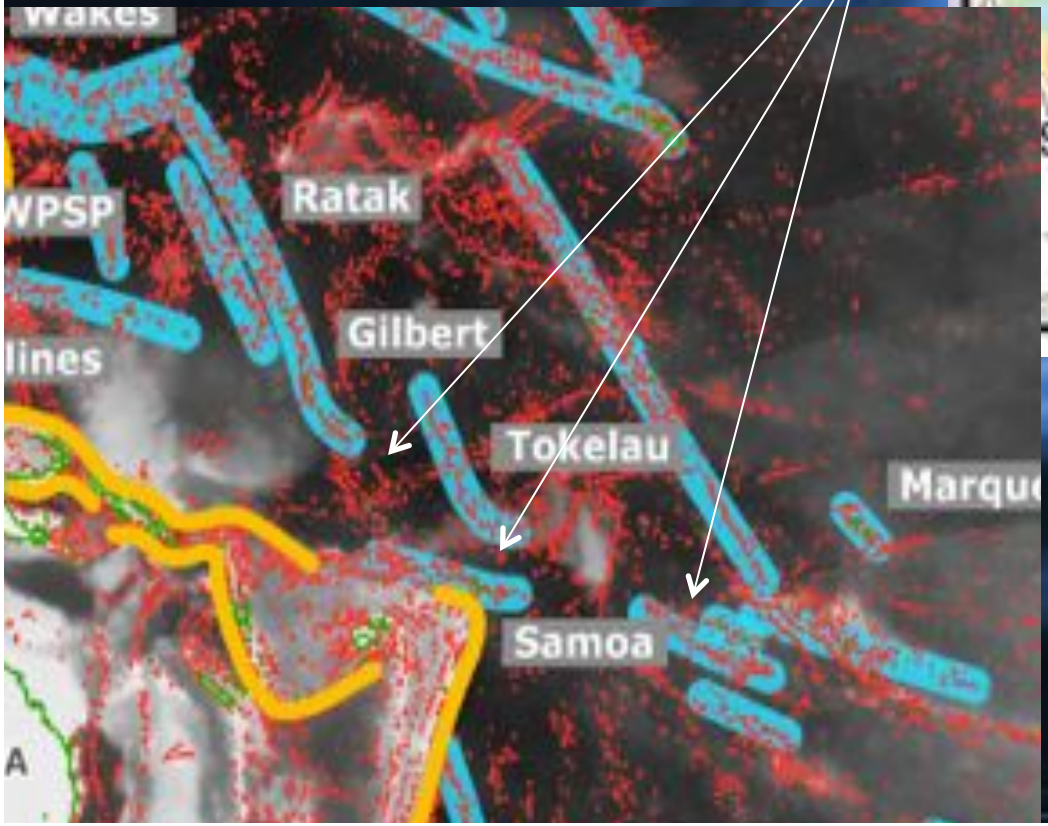
- Looks like the same orientation as Emperors and old Louisville
- Is there a young side to this?



Old suggestion is relation to Cook-Australs

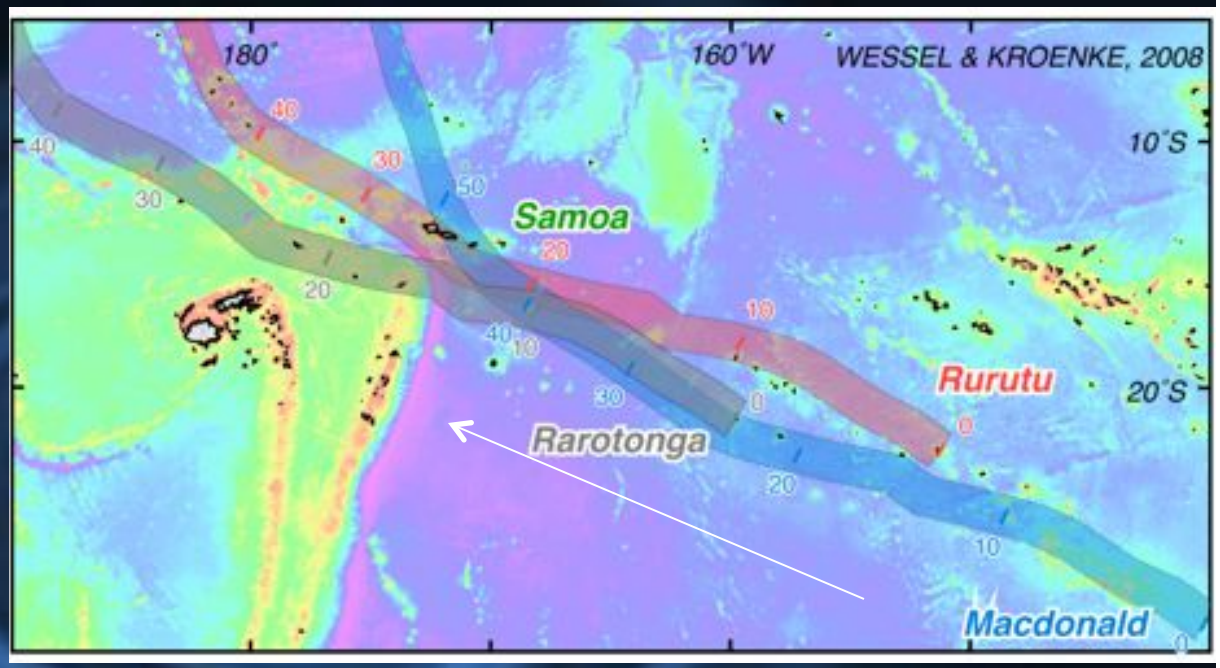
- Gilbert & Tokelau: these look right for geometry
- We need to take a closer look: look at all those dots



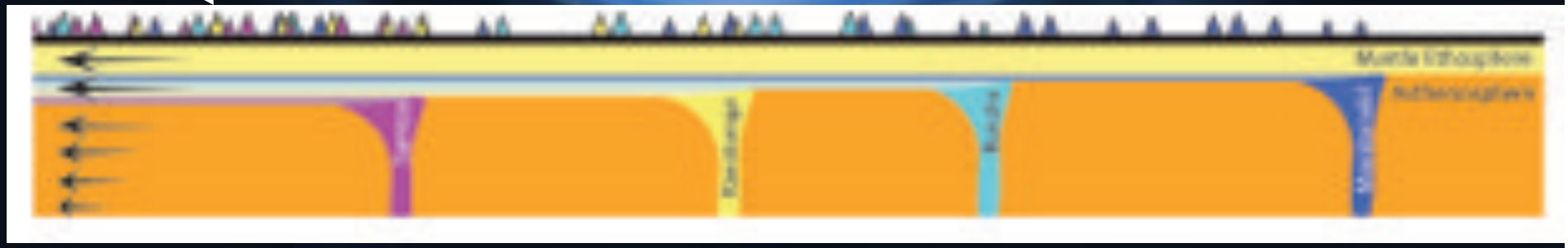


The hotspot highway

What happens when multiple plumes "line up" along plate motion?



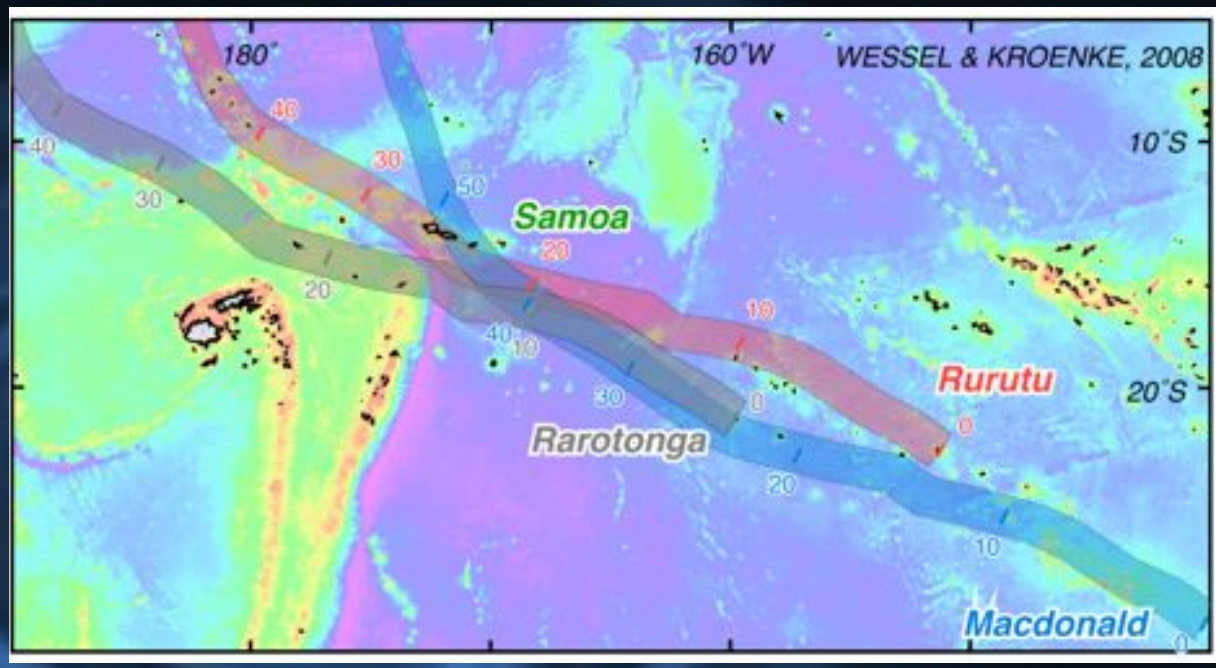
Rush hour

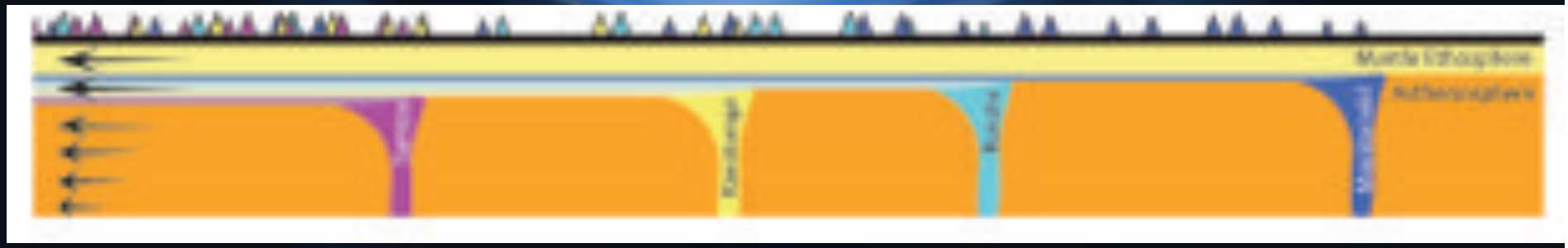


Jackson et al., 2010

How to tell these apart

The actual rocks are not rainbow-colored, so we need compositions and ages

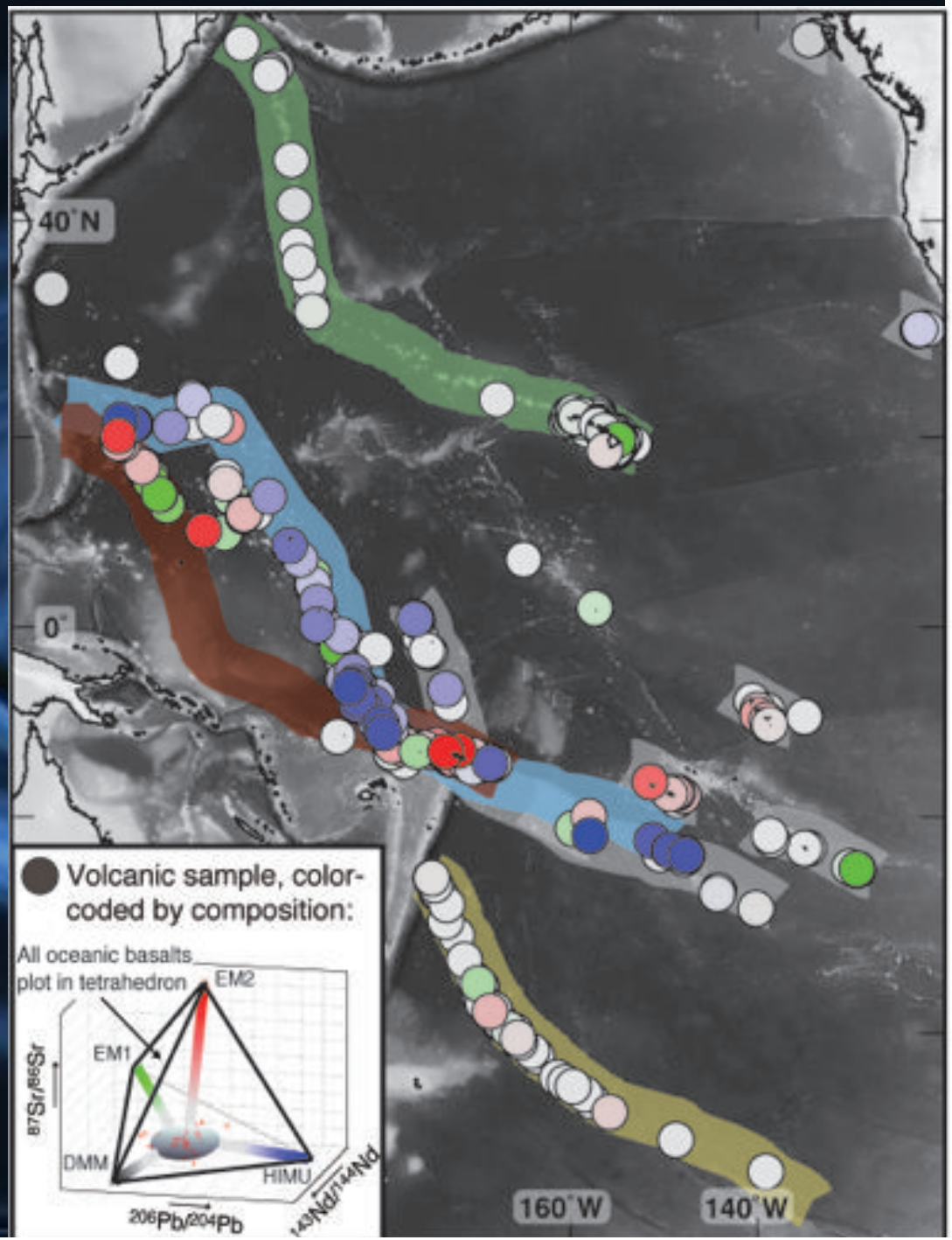




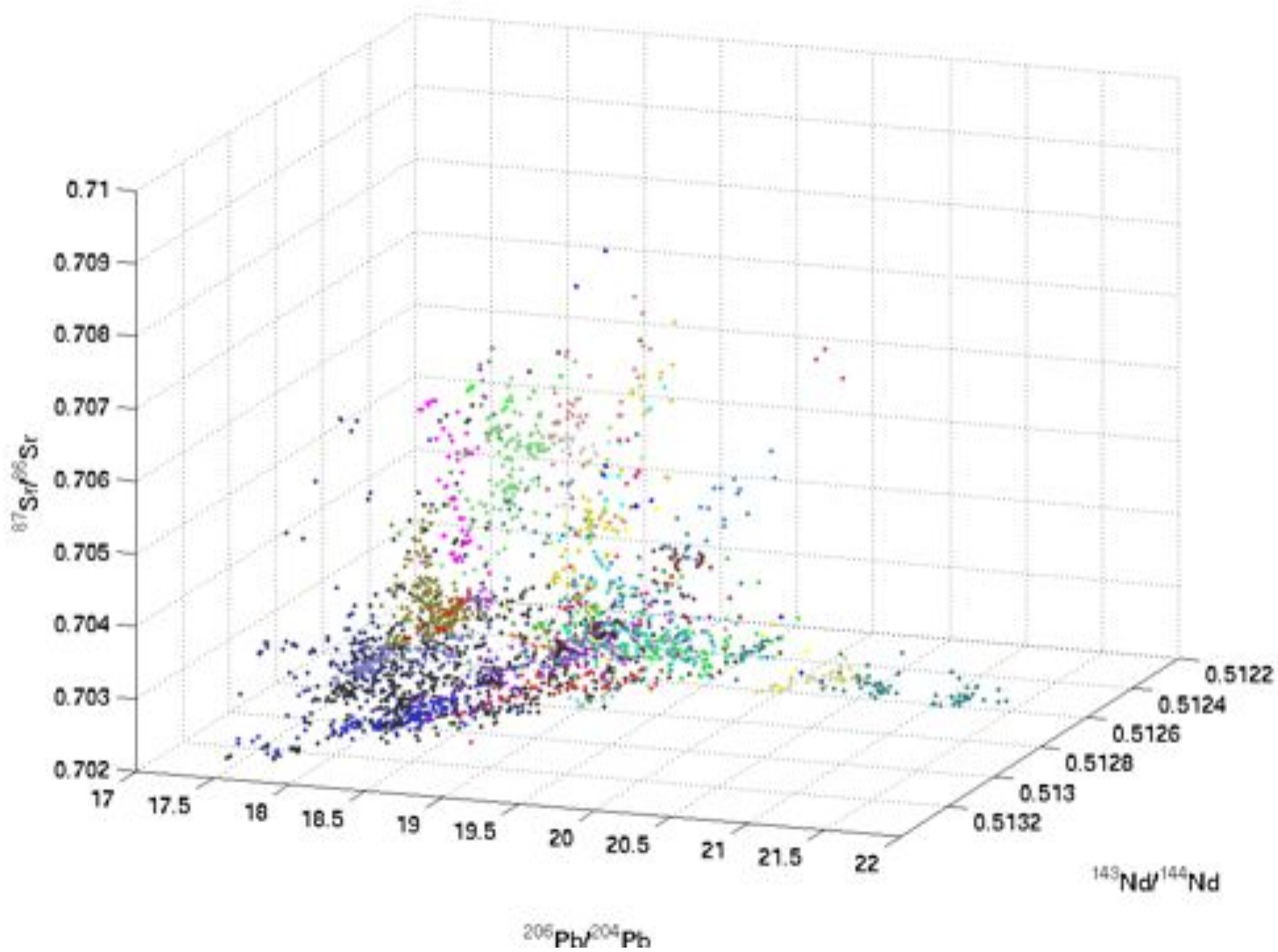
Jackson et al., 2010

Color-coded by isotopes

- Anything stand out?
- What color do I need to tell from what?

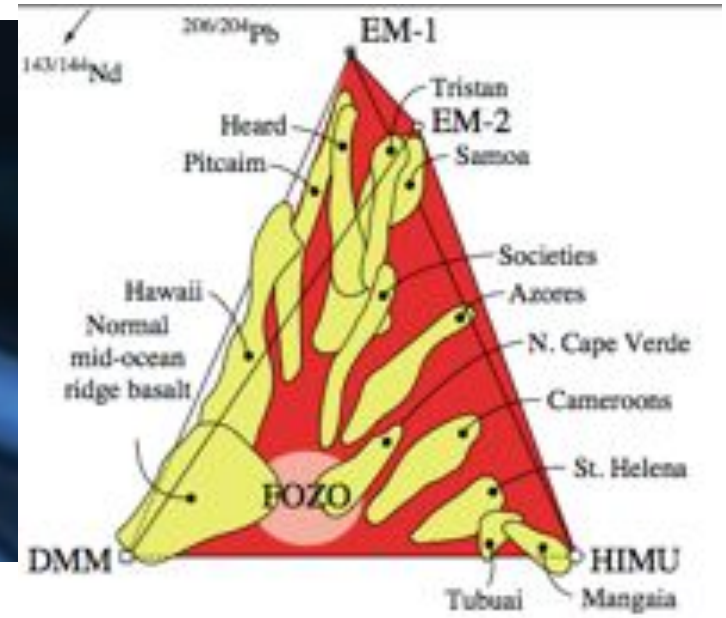


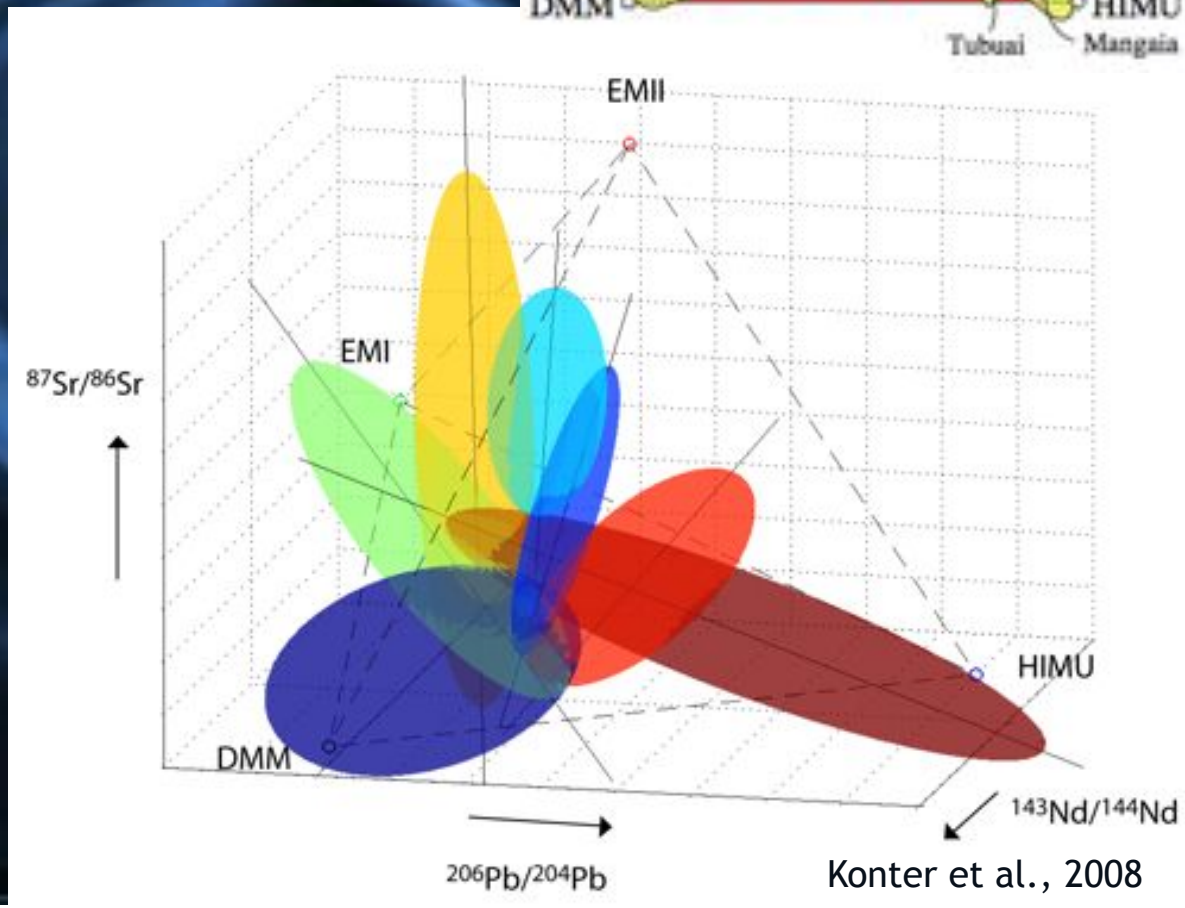
Color coding using distribution of Isotopic Data



Finding A Robust Center

- C and FOZO were "hand-picked" as centers
- Fit trendline to each chain
- For each line find point closest to every other line: pseudo-intersections





Konter et al., 2008

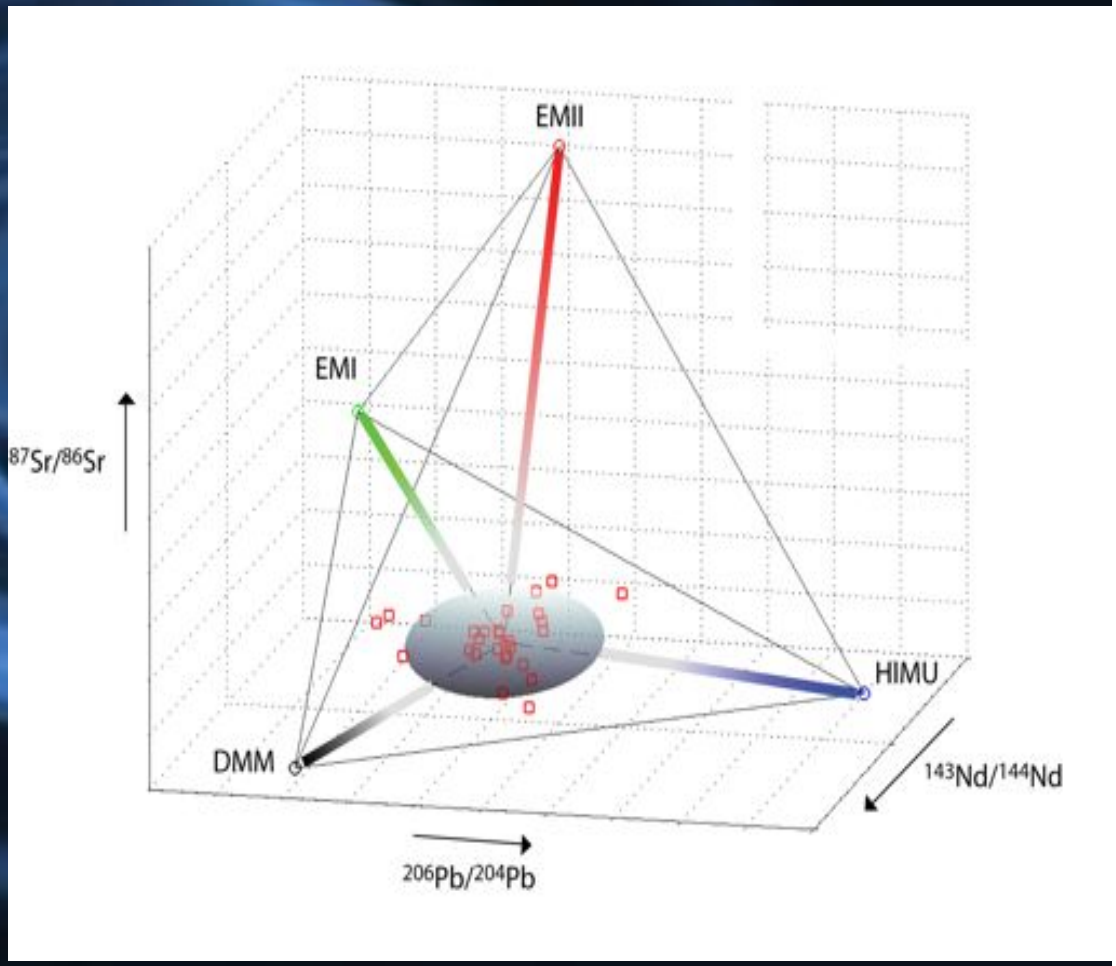
Compositional Color-Coding

- ✧ Pseudo-intersections define center:

=> Median is center, 2σ its uncertainty

- ✧ Define color scales from edge of central ellipsoid to corners of tetrahedron

=> Project each sample onto closest colorbar and plot on the map!



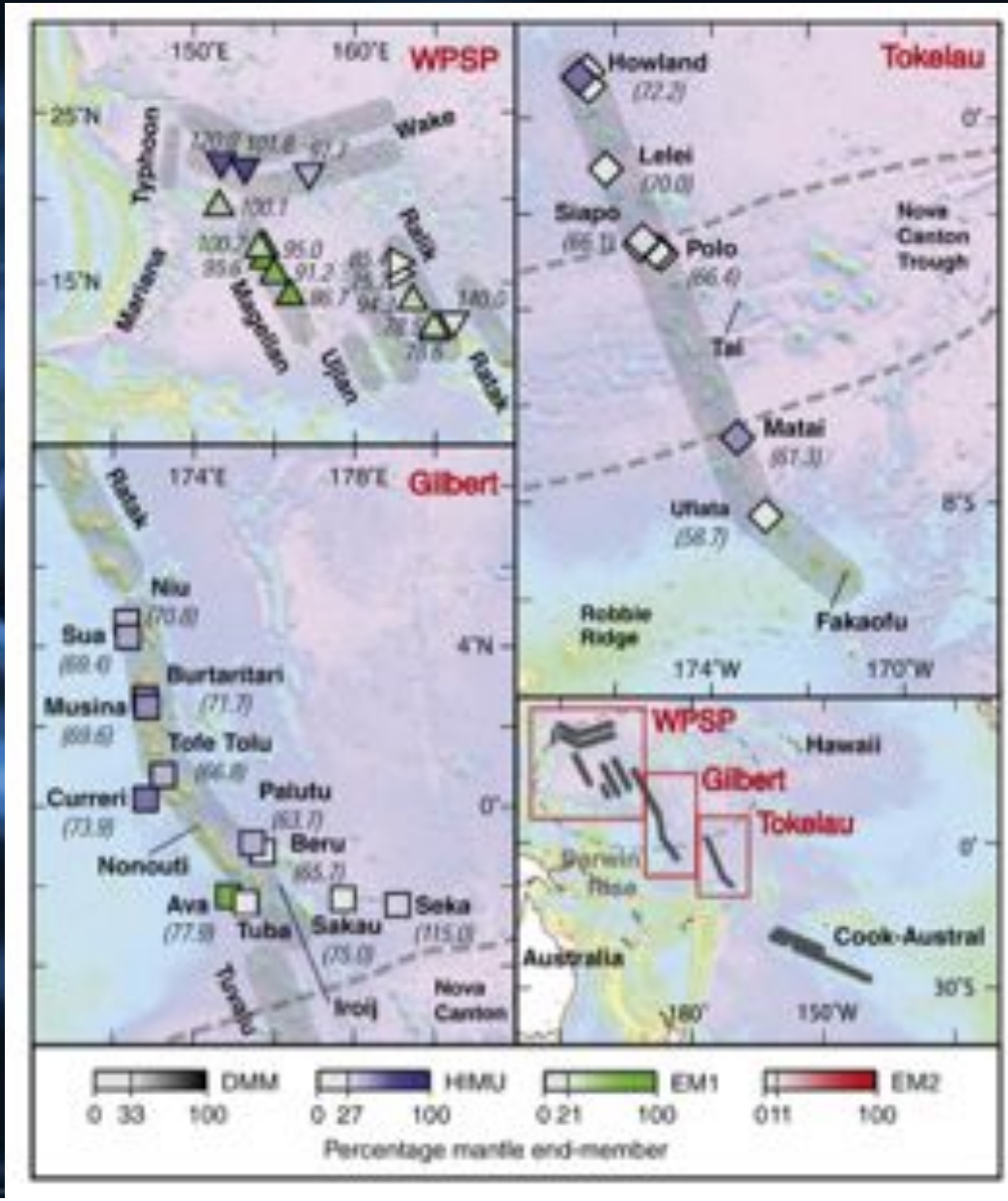
Konter et al., 2008

Geochemistry of W Pacific Seamounts

Konter et al., 2008

- ✧ Austral-Cook is mostly blue/HIMU
- ✧ Gilbert & Tokelau: intermediate-HIMU (light blue)
- ✧ W Pac: chains either intermediate-HIMU (light blue) or intermediate-EM1 (light green)

➔ This works, if the ages are right

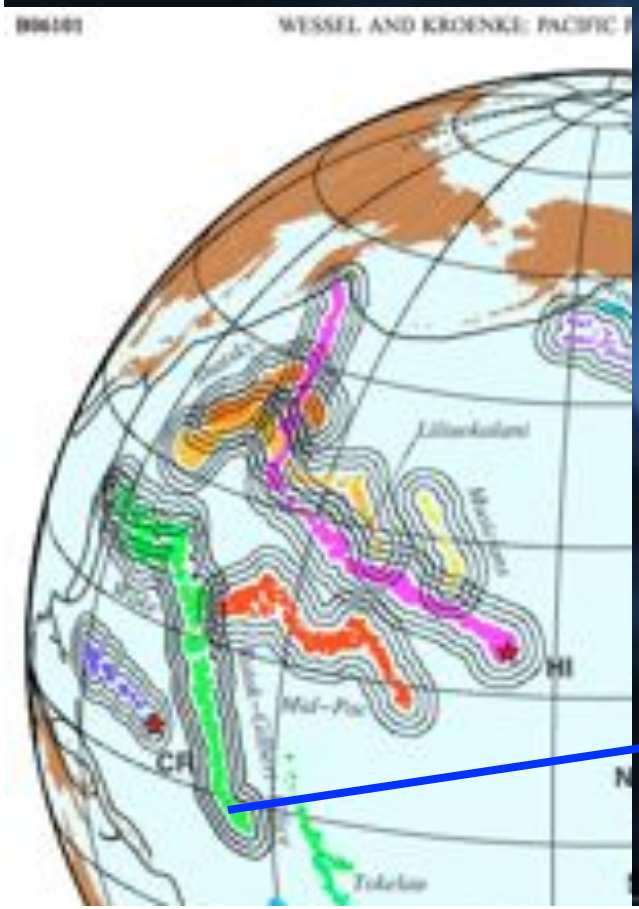


Going back: not a bend, but used in APM

- ✧ Isotopes not HIMU
- ✧ Ages are >>10 Ma different

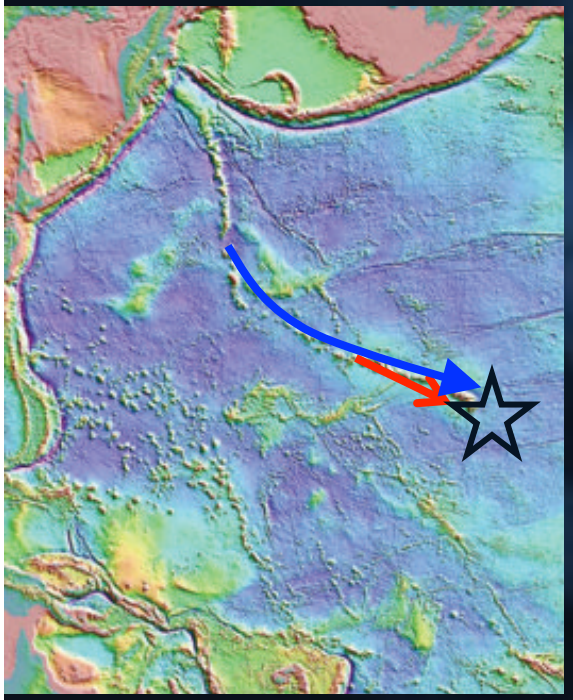
=> it's a chain crossing

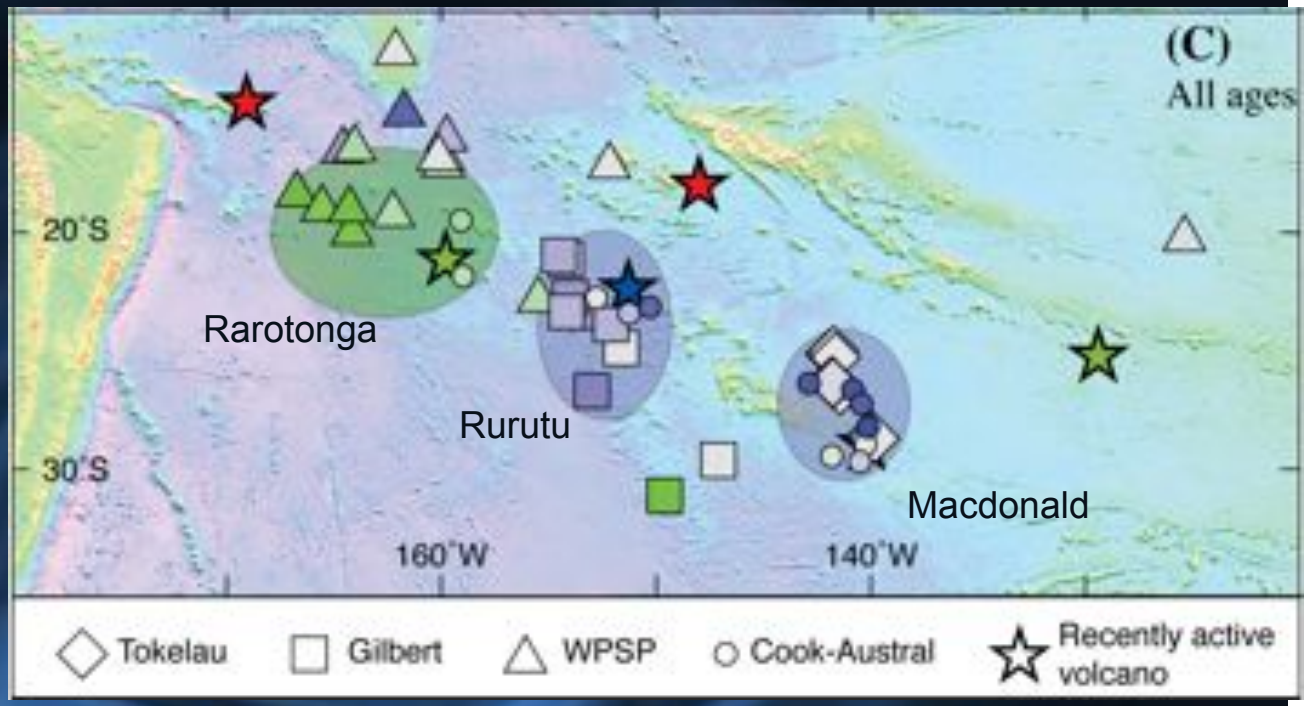
Konter et al., 2008



Collapse ages with back-tracking

- Back-tracking:
  - With APM+age, rotate to original eruptive locations

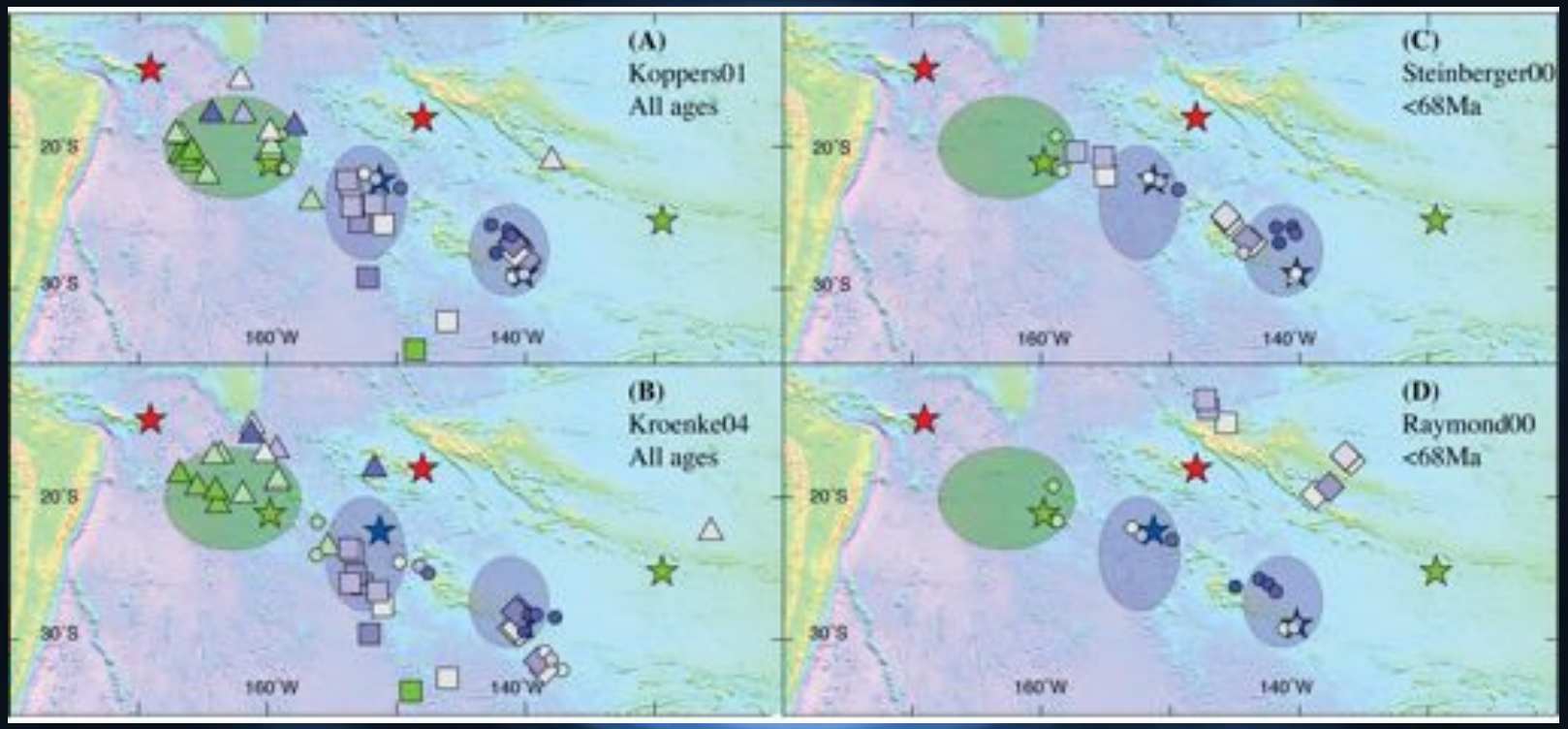




Konter et al., 2008

- Clusters of original eruptive locations:
  - Gilbert around Rurutu,
  - Tokelau around Macdonald,
  - Magellan/Ralik around Rarotonga,
  - older seamounts N of Rarotonga, Rurutu

Reconstructions with Other APMs

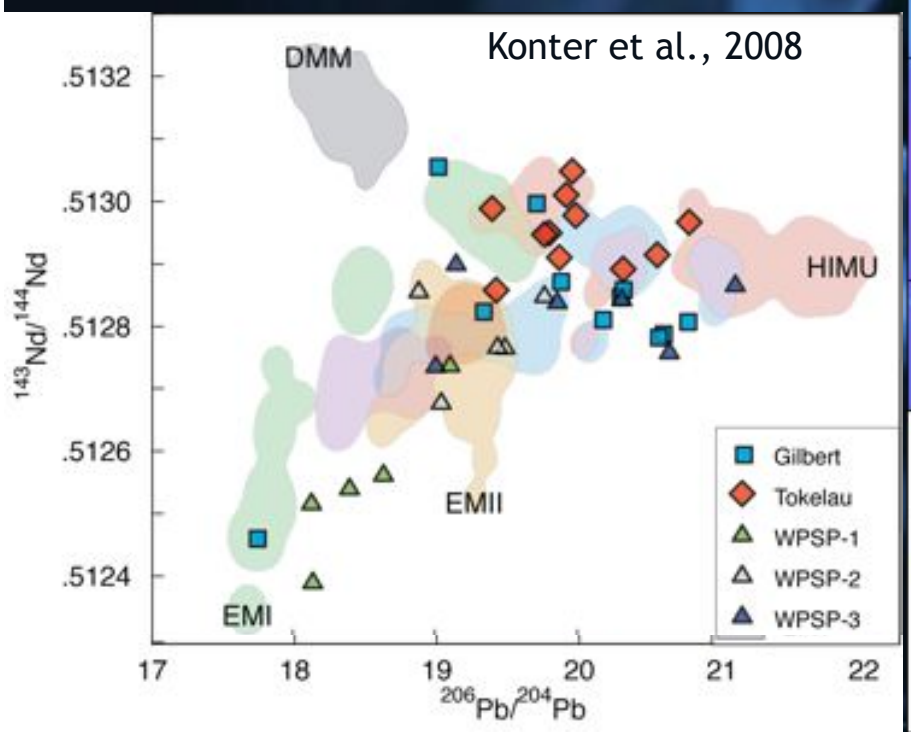


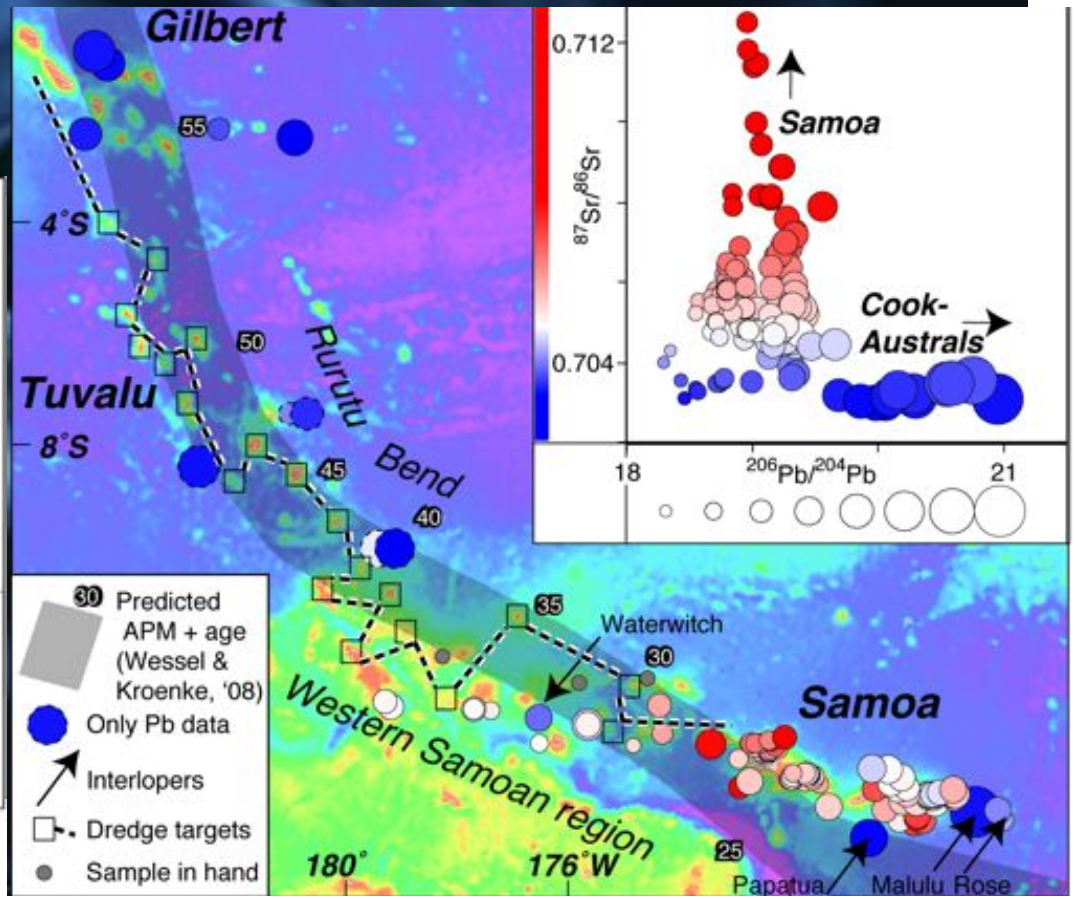
Konter et al., 2008

- ✧ A & B similar models, similar results
- ✧ C & D Indo-Atlantic Hotspots require plume motion

That was older, now the HEB time

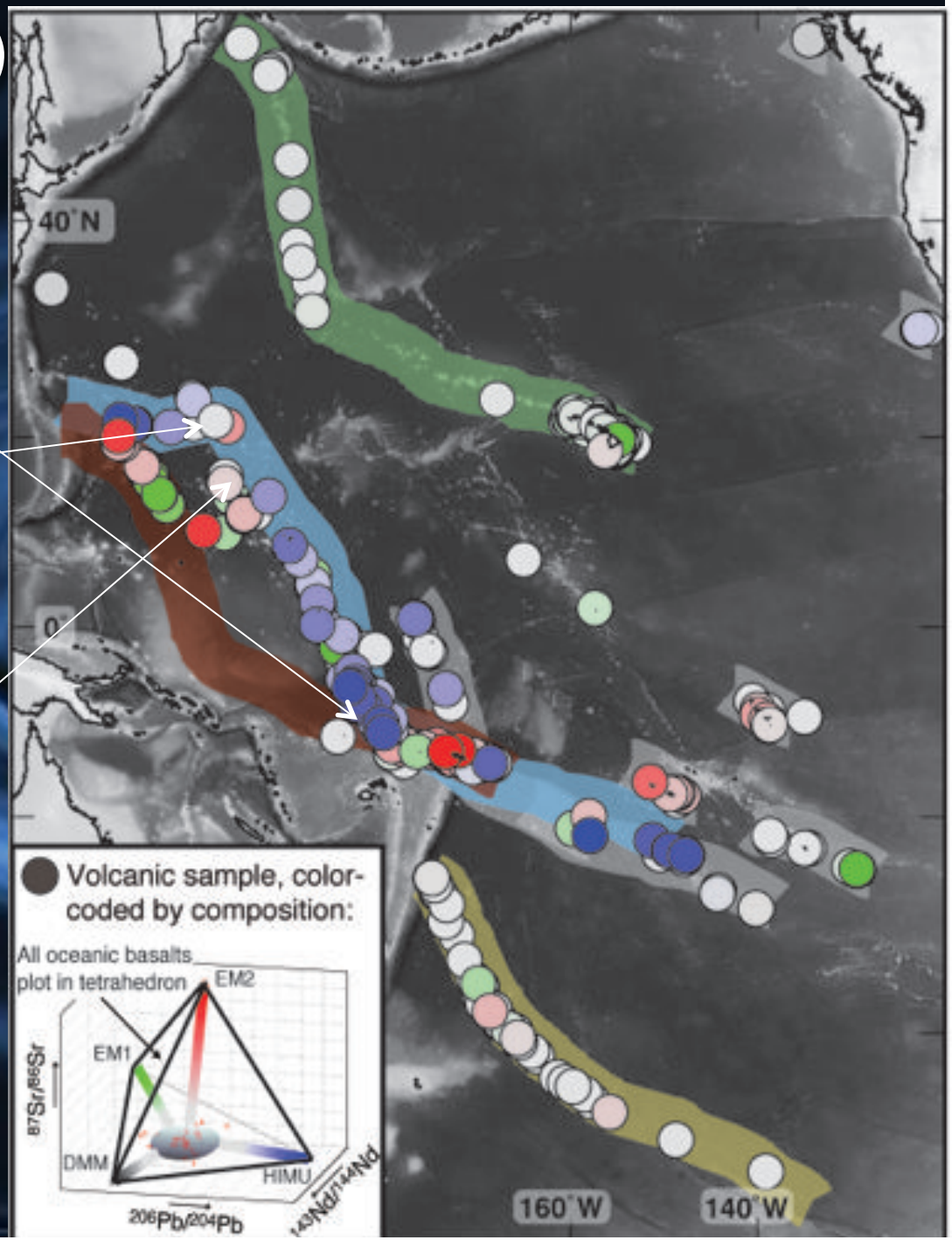
- ✧ Gilbert and Tokelau match range in Rurutu and Macdonald HS resp.
- ✧ To trace Rurutu through its HEB, need to tell it from Samoa
- ⇒ This is great: we need to distinguish two end-members!
- ⇒ Blue vs Red (déjà vu?)





Rurutu (Cook-Austral) tracks into W Pacific

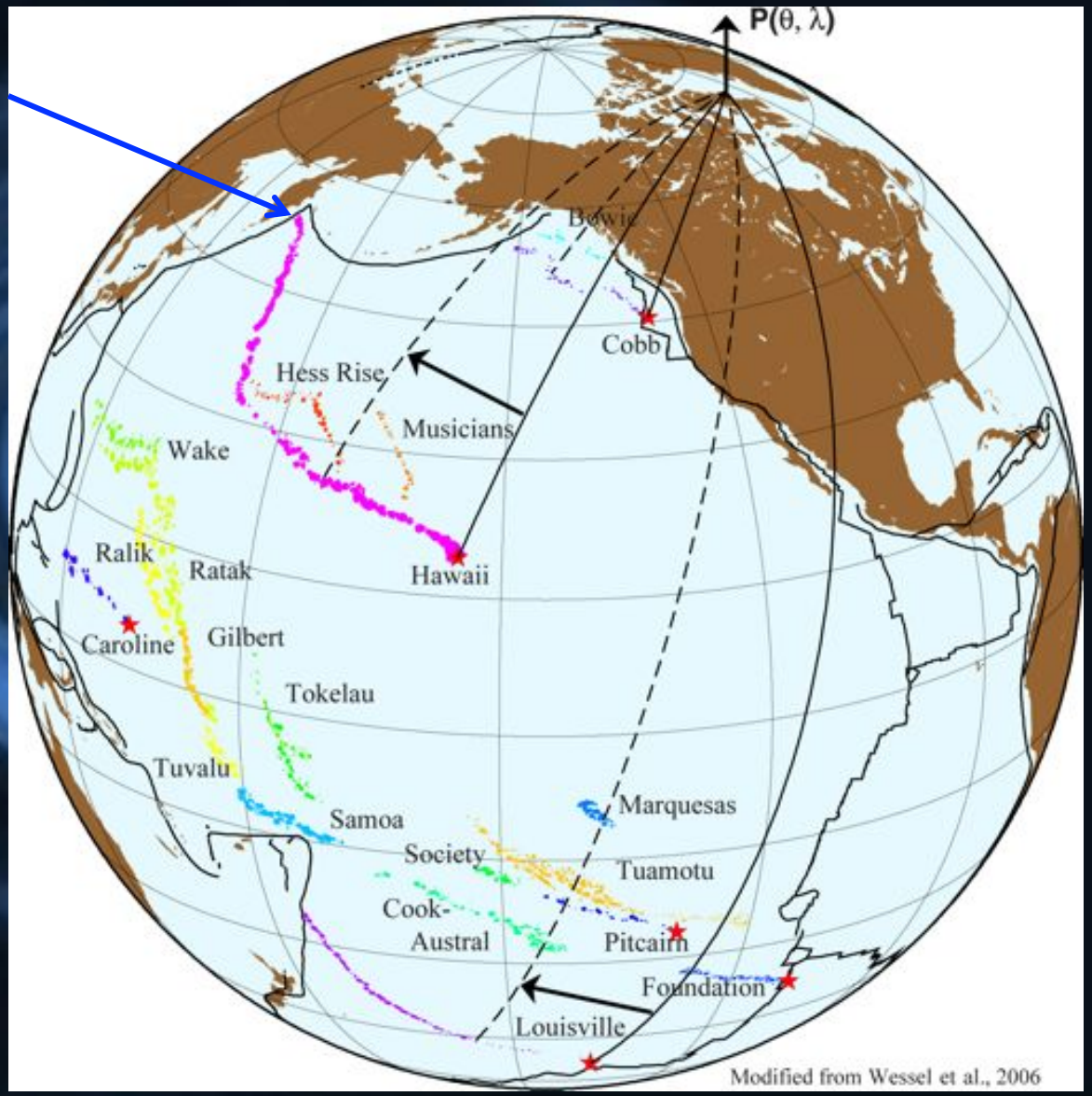
- New data show a new HEB
- One more problem: where I draw the continuing track does not follow APMs
- Predicted track turns west earlier/south
- There are no volcanoes there



APMs Issue 4

- ✧ Continuous to 80Ma: Hawaii, Louisville

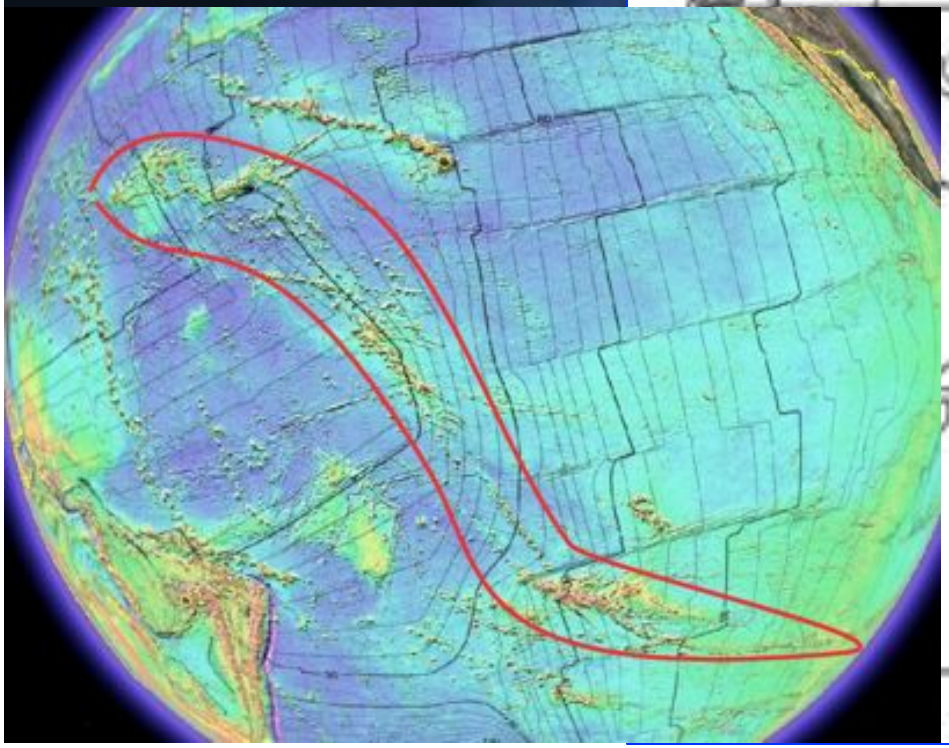
=> How to go further back in time?

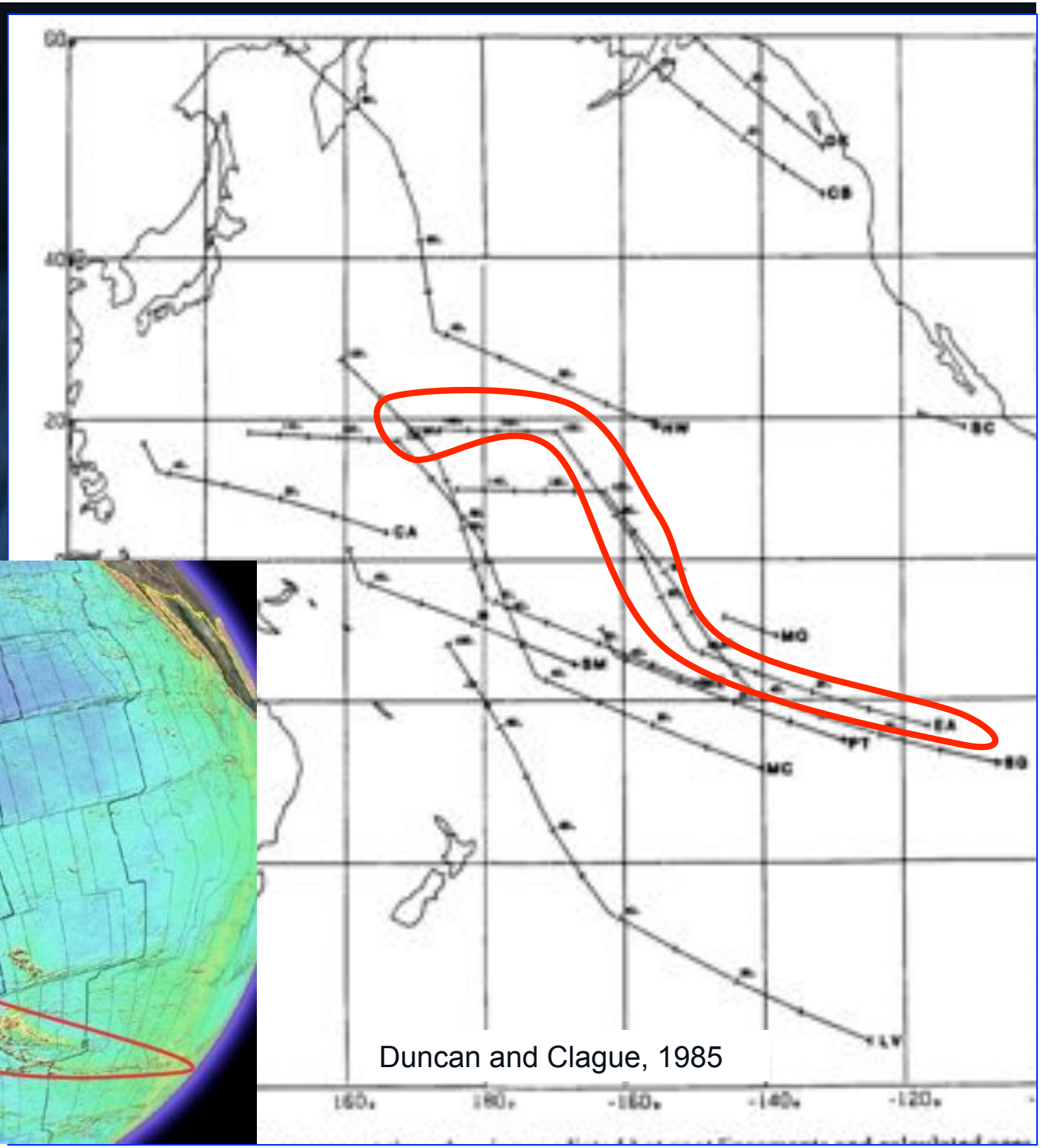


Modified from Wessel et al., 2006

Issue 4..

- Proposed use of Easter to Line Islands into Mid-Pacific Mountains

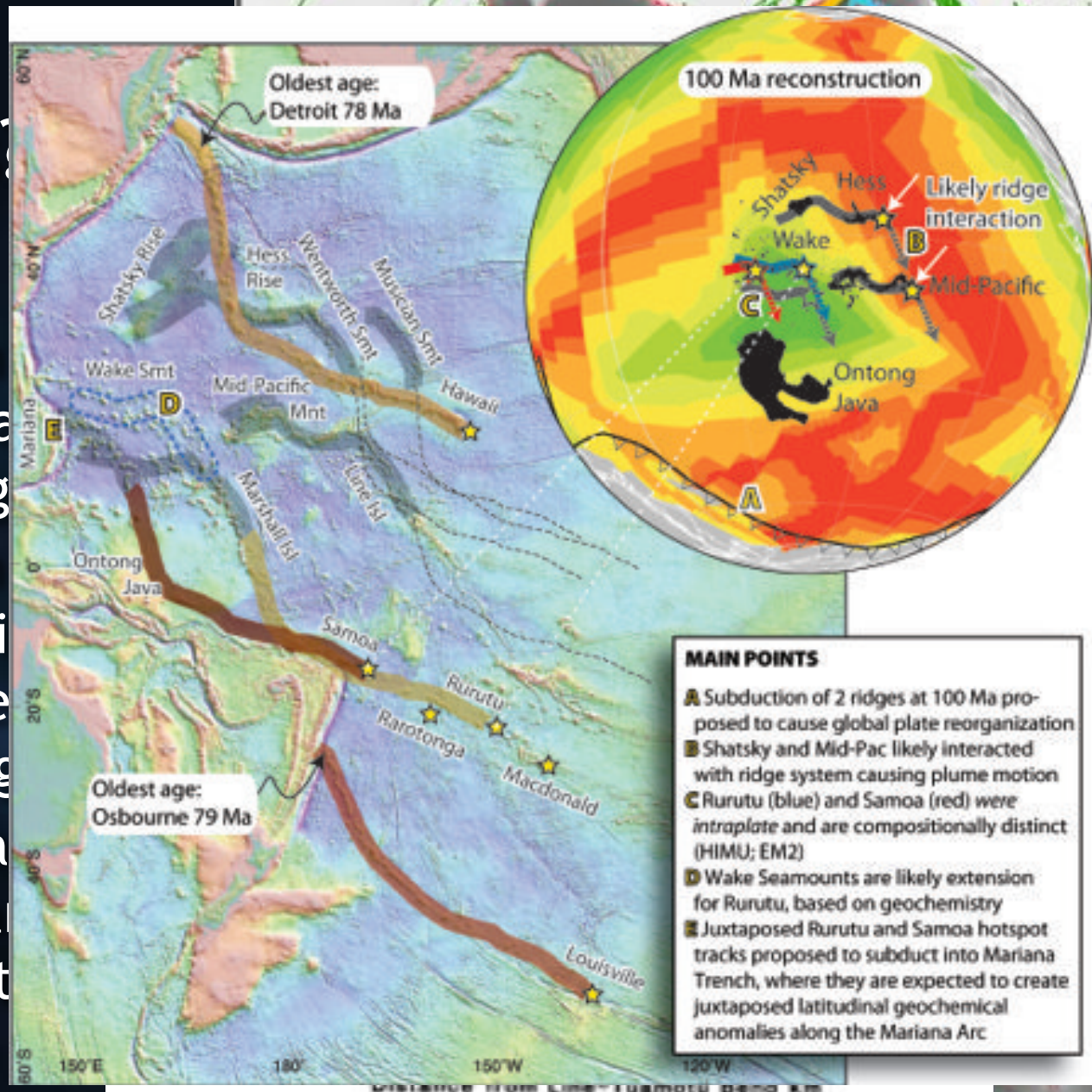




Duncan and Clague, 1985

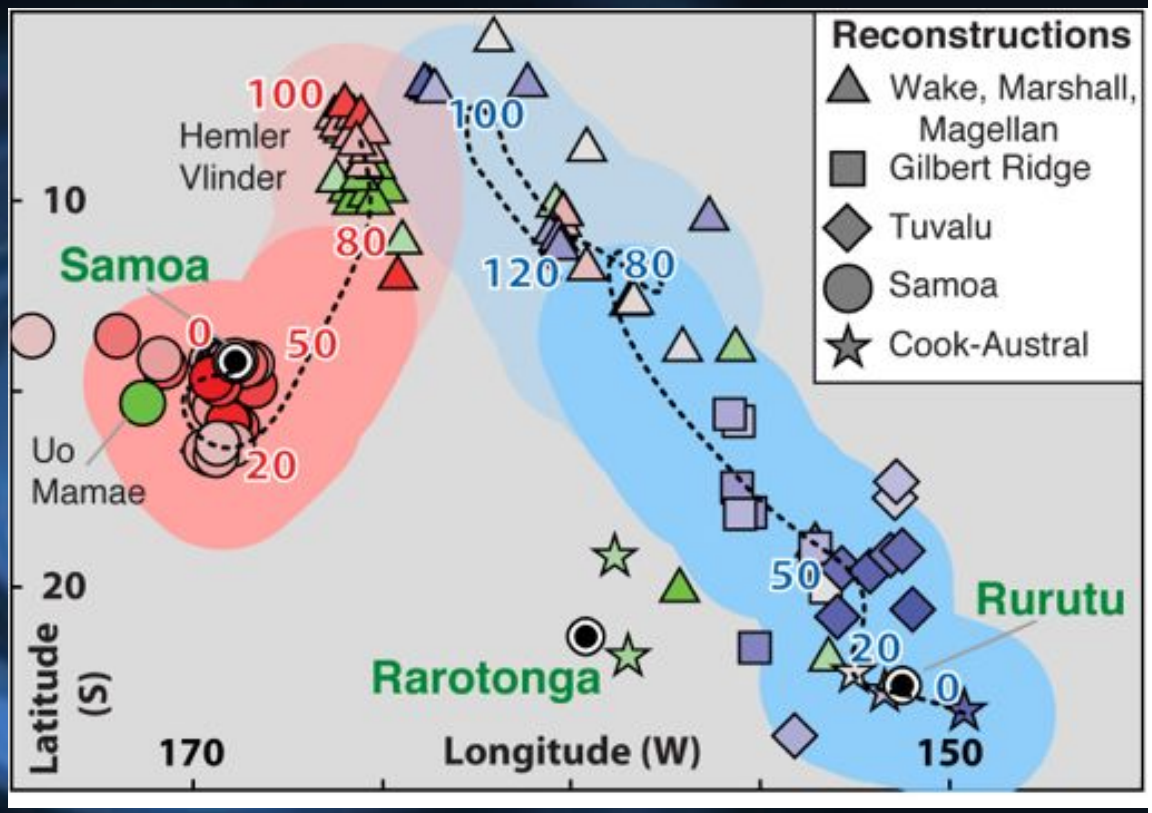
Line Islands:

- Problem complica age prog
- Problem oldest Li Islands e near ridg
- Rurutu a Samoa a intraplat



Back-tracked reconstructions again

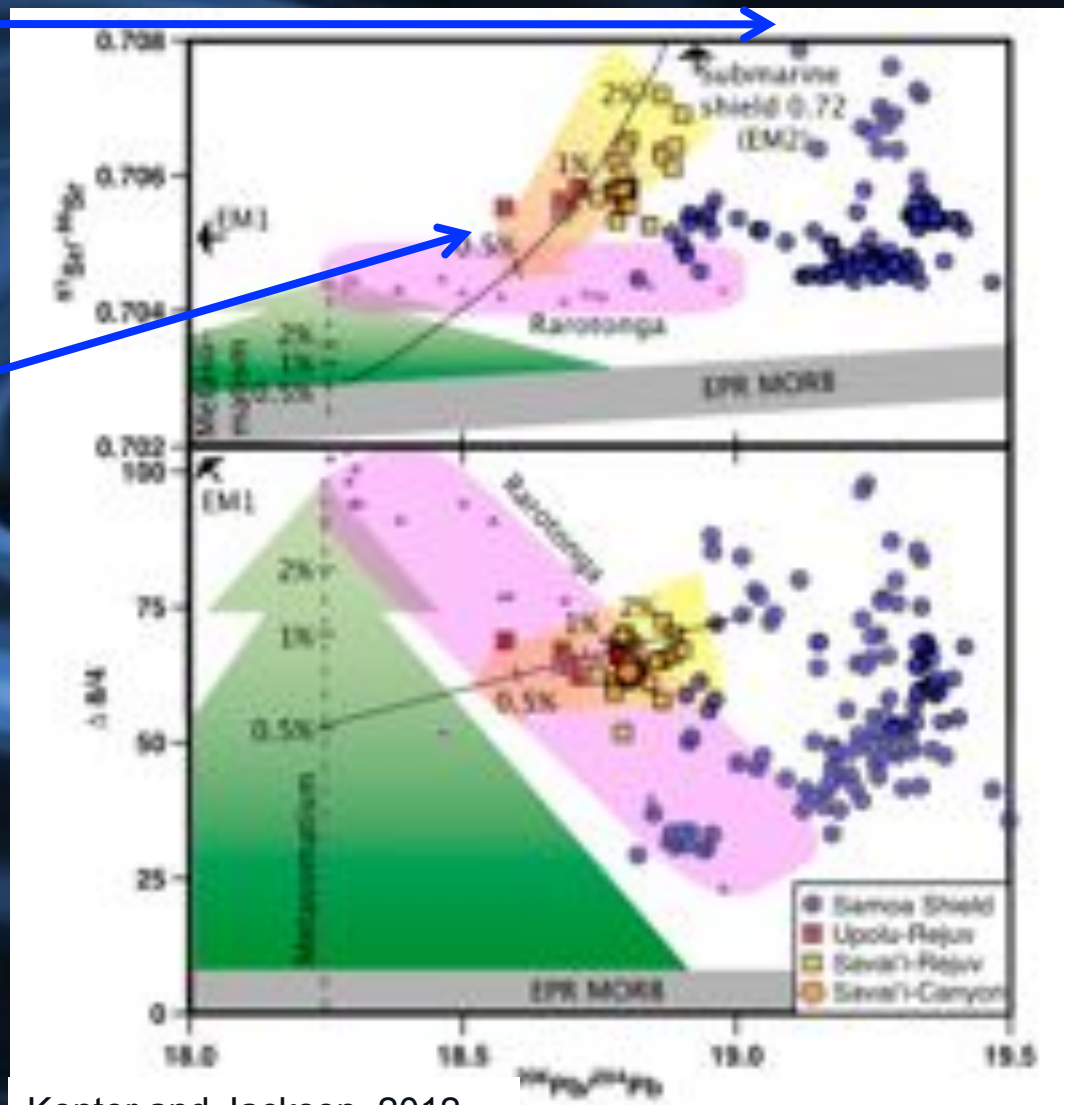
- ✧ Since APMs don't run far enough N, seamounts >80 Ma may need to shift south in backtracking
- ✧ BUT same for every plume
- ⇒ Get rough paths through time:
- ⇒ This maps *relative* source motion of Samoa vs. Rurutu in an APM reference frame!



Green (EM1) dots in red (EM2) Samoa

- ✧ Majority of Samoa plots along trend to EM2
- ✧ BUT late stage volcanism trends to a *mixture* with EM1 (green dots on maps)
- ✧ These melts may be from flexure-induced melting

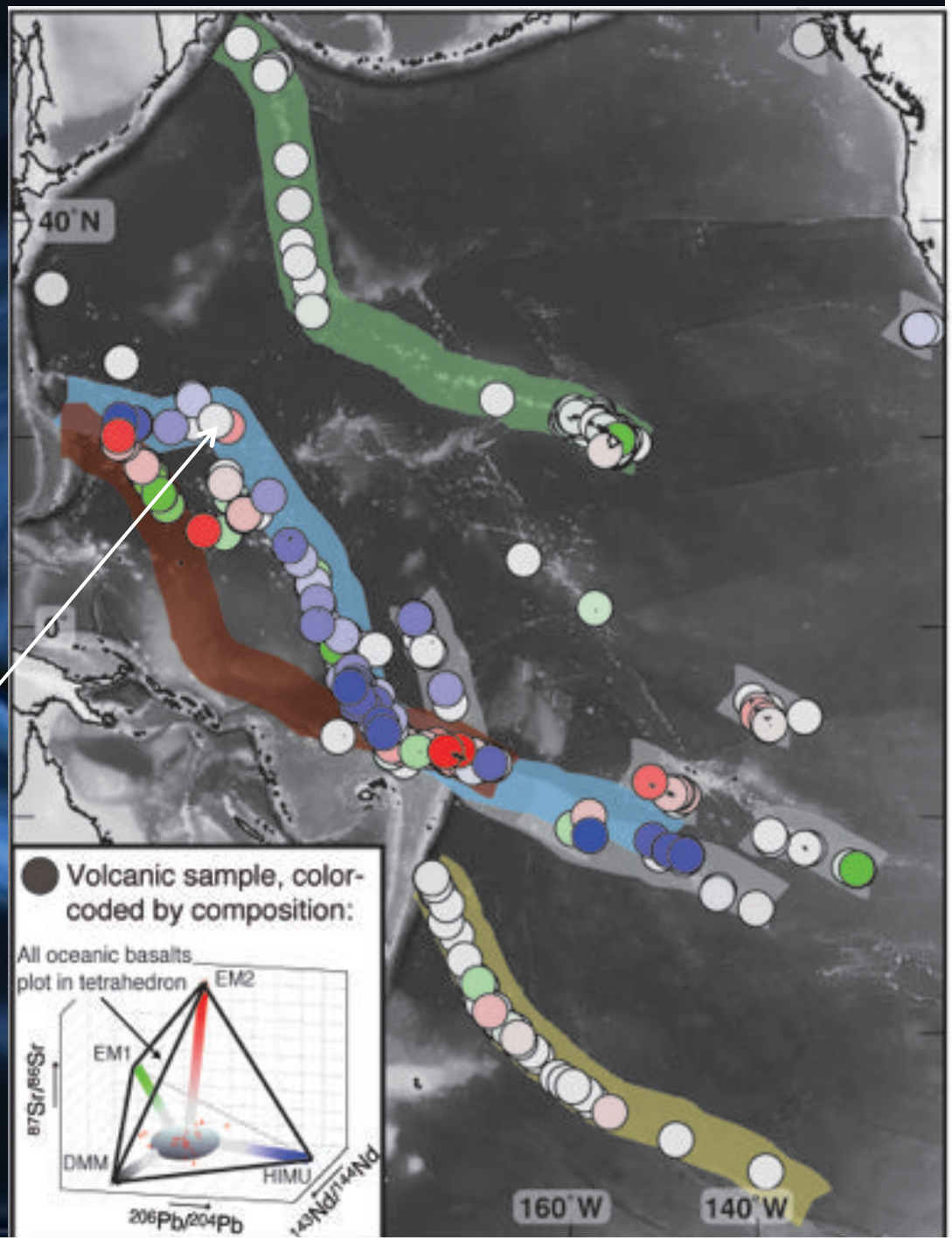
⇒ Samoa can be red or green!



Konter and Jackson, 2012

The new anchors

- 2 chains go back to at least 100 Ma:
  - Rurutu, which has an HEB
  - Samoa, partly "hidden" under Ontong-Java
- There's another HEB around 100Ma
- Tests, missing pieces…



Summary

- Plenty of leeway in APM construction
- Connection >80 Ma likely incorrect
- BUT new datasets from last decade on Rurutu and Samoa provide new long-term tracks
- Reconstructed eruptive locations define a relative plume motion pattern

Thanks


off the mark
by Mark Parisi
www.offthemark.com
offthemark.com
INACTIVE VOLCANOES