

Plume-lithosphere interaction

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Outline

- ✓ Definitions (plume, hotspot swell)
- ✓ Methodology for swells determination
- ✓ Some examples : Society, the classical hotspot

Long-lived hotspot trails: Hawaii, Walvis and St. Helena

Temporal evolution of buoyancy and volcanic fluxes along long-lived hotspot trails

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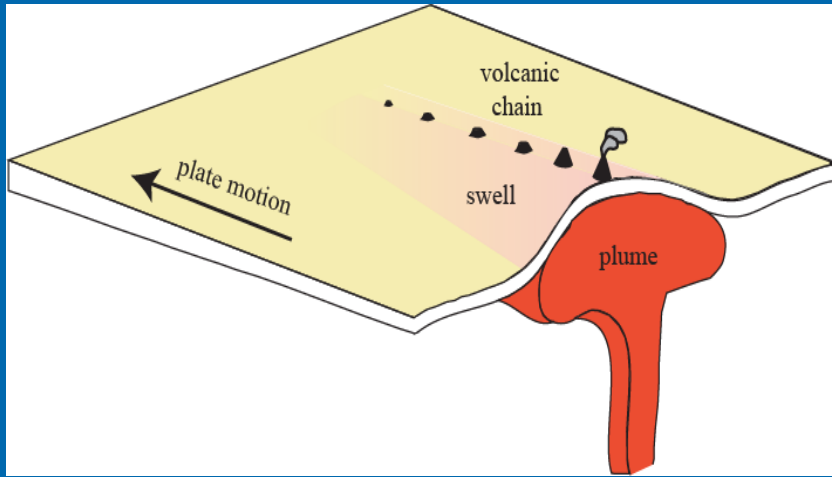
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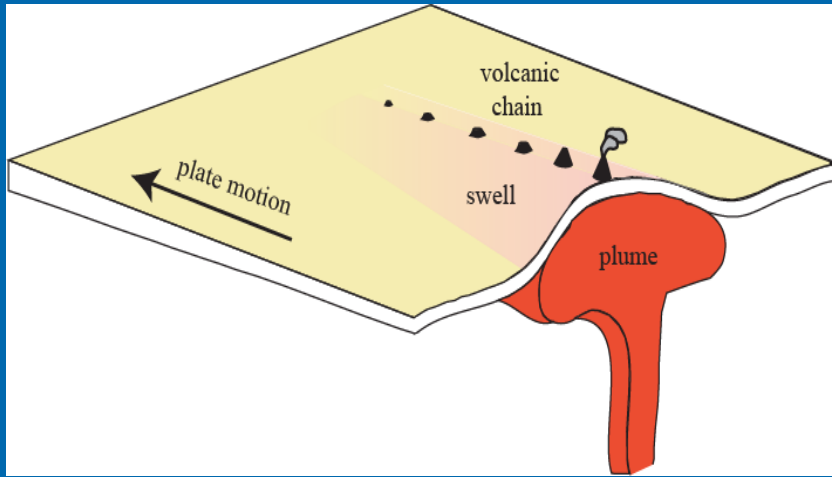
Temporal evolution of buoyancy and volcanic fluxes along long-lived hotspot trails

⇒ What is a plume?



A plume is an upwelling initiated by the destabilization of a boundary layer.

⇒ Plume origin?

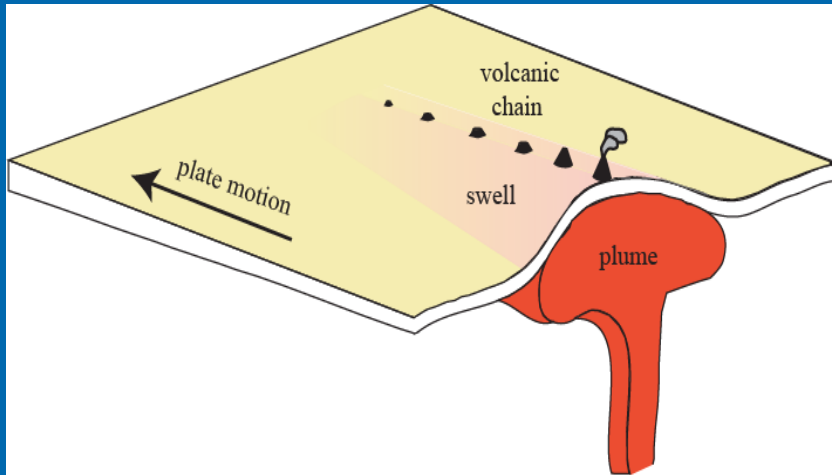


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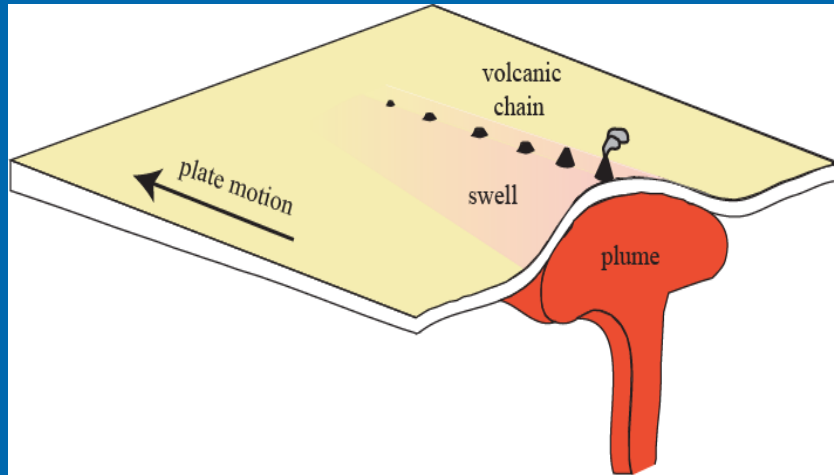
Several kinds of plumes coexist (Courtilot et al., 2003):

- *those which initiate at the CMB (primary plumes)*
- *those at the transition zone (secondary hot spots)*
- *the "Andersonian" plumes that may be due to a passive response to forms of lithospheric breakup*

⇒ Plume debate



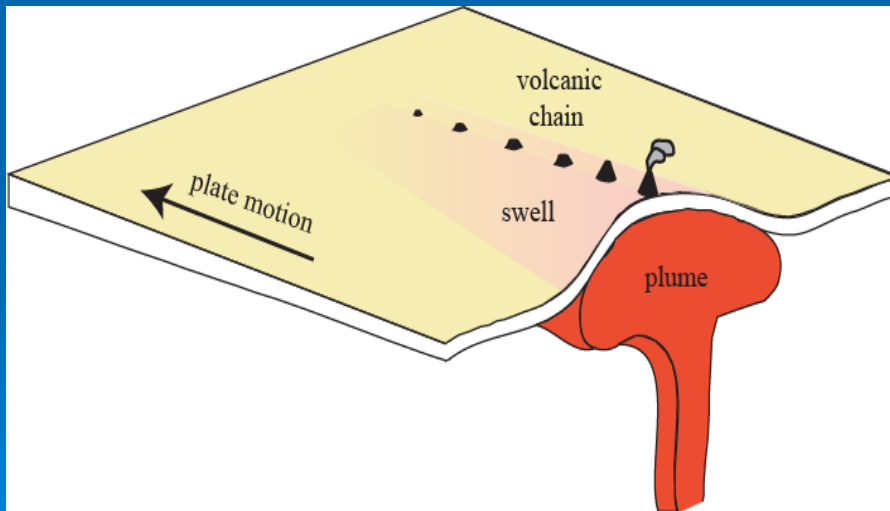
⇒ Plume debate



*Origin: - depth: destabilization of a boundary layer?
- mechanisms : thermal? chemical?*

⇒ The hotspot concept

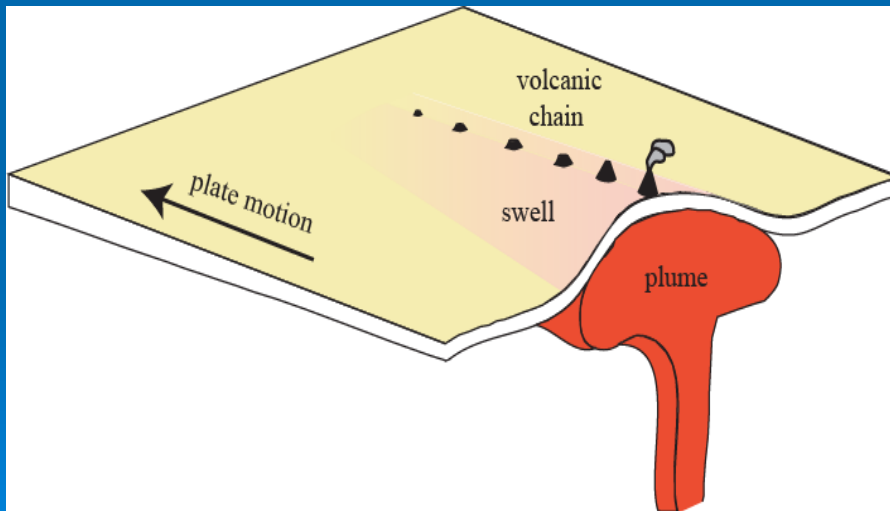
Hotspots tracks are due to the drifting of a plate over a stationary mantle source. The plate displacement pushes the old volcanoes away from the source as young volcanoes are formed above the source.



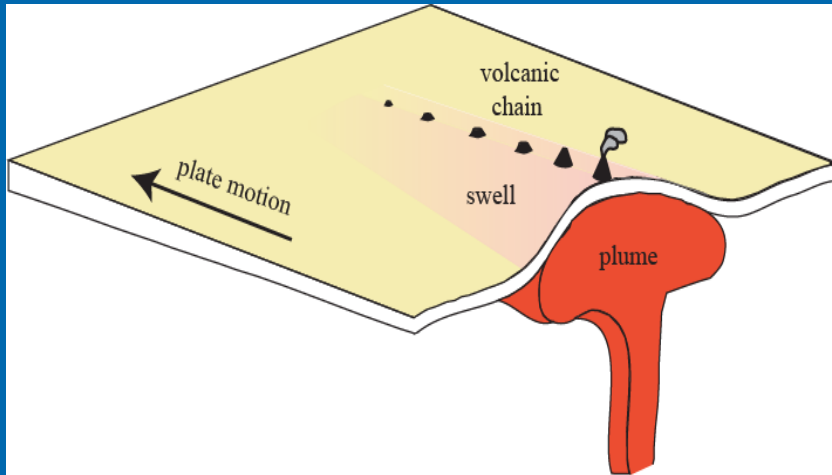
⇒ The hotspot concept

Two main surface manifestations:

- ✓ *volcanic chains*
- ✓ *swell*

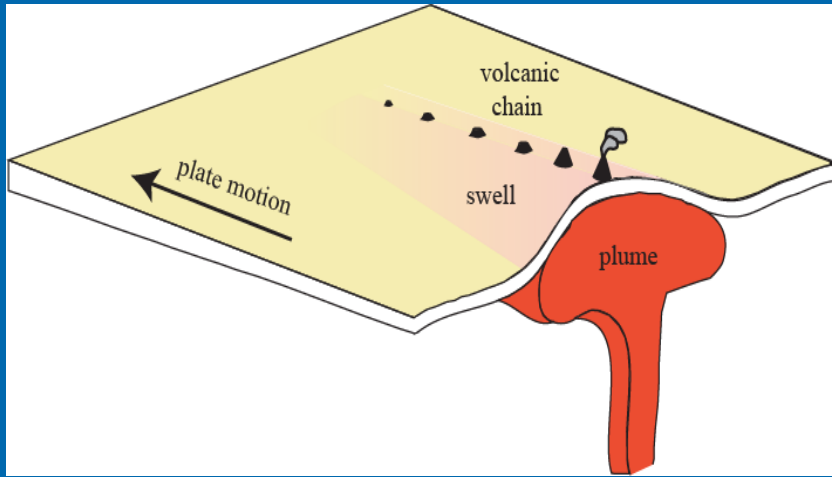


⇒ Chain characteristics



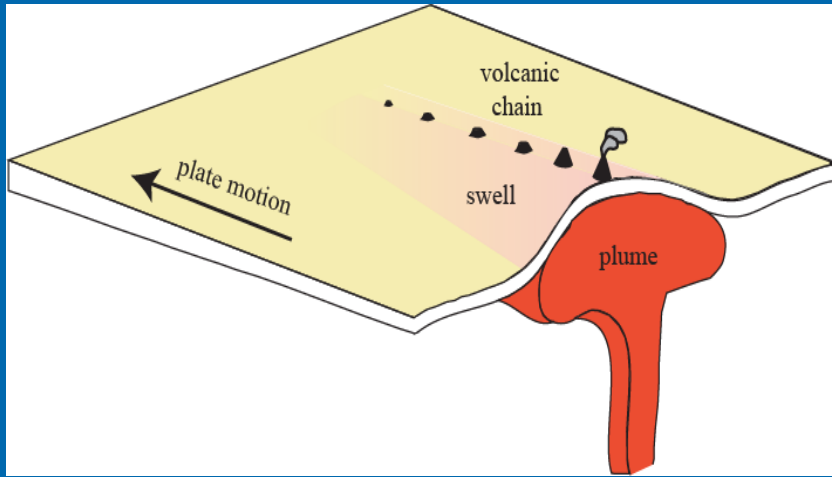
- ✓ *Linear volcanic chains*
- ✓ *Direction parallel to the plate motion direction*
- ✓ *Linear volcanism age progression*
- ✓ *The active volcanism situated above the source*

⇒ Swell characteristics



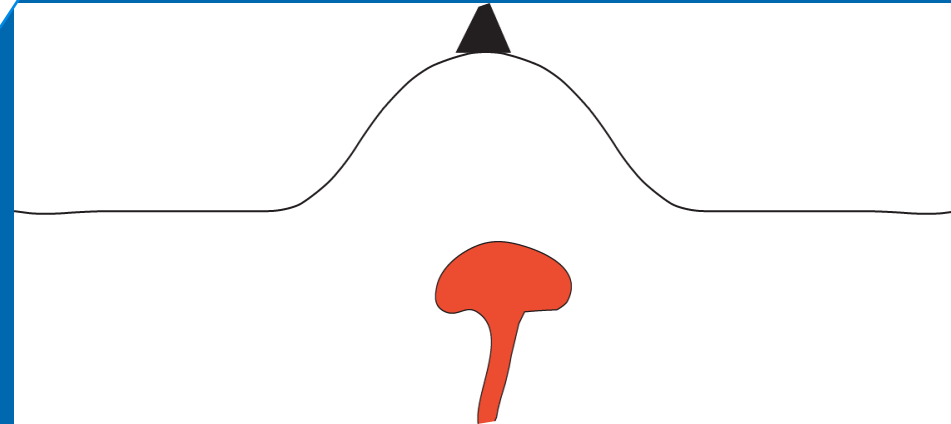
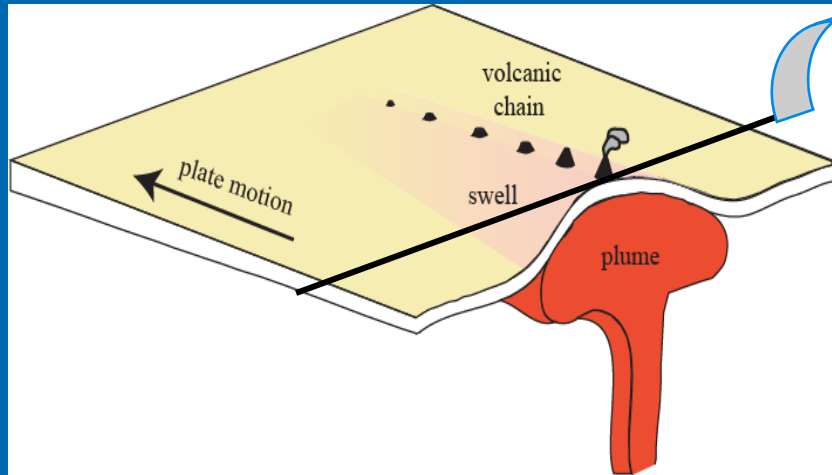
✓ *1000 km width*

⇒ Swell characteristics



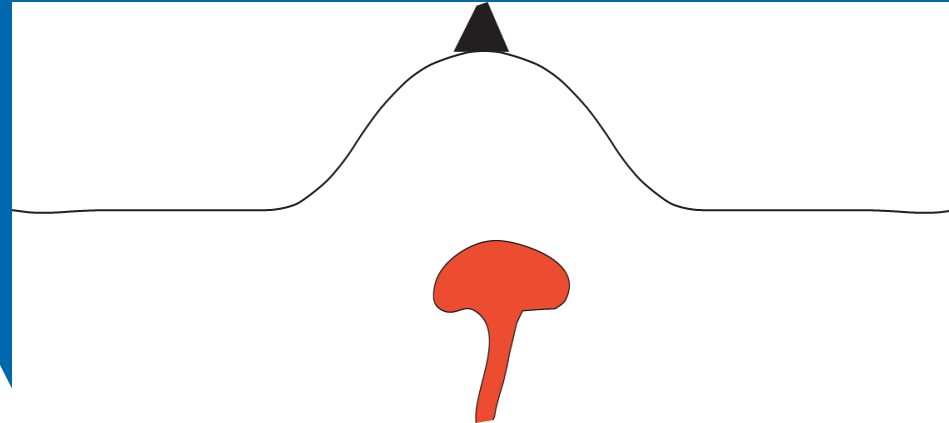
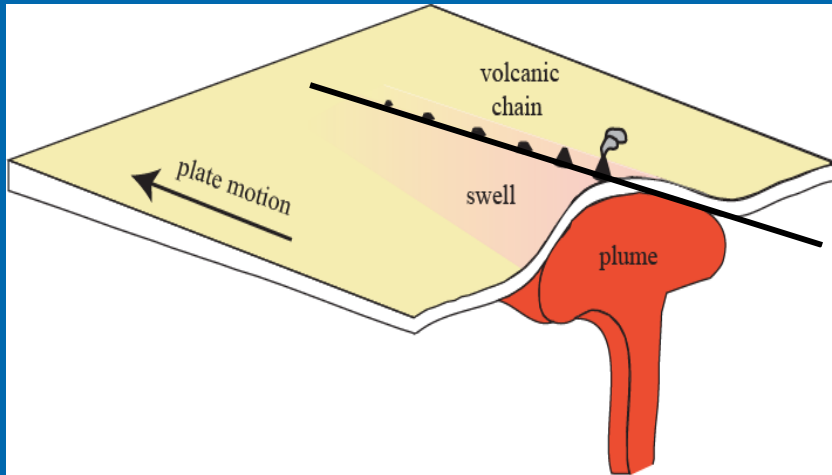
- ✓ *1000 km width*
- ✓ *1000 m height*

⇒ Swell characteristics

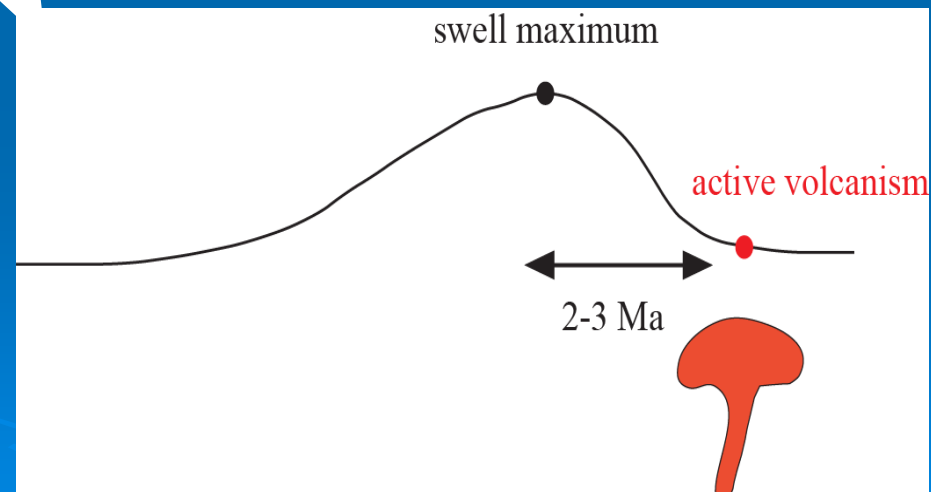


- ✓ *1000 km width*
- ✓ *1000 m height*
- ✓ *Amplitude maximal along the main axis*

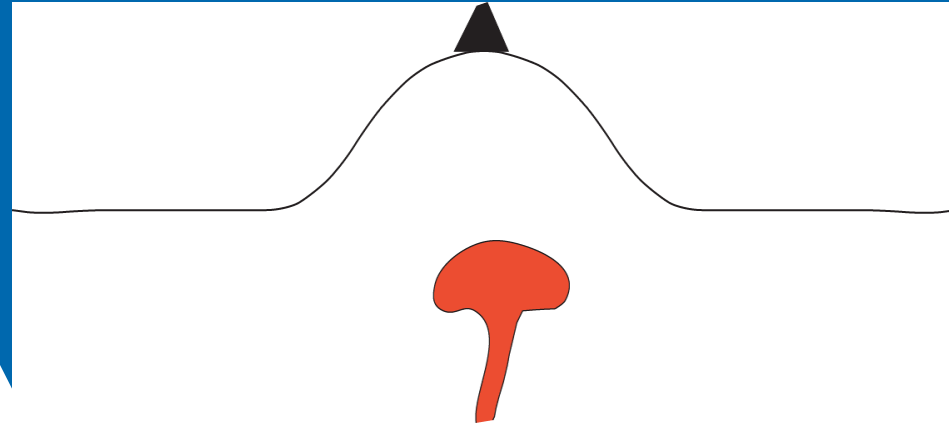
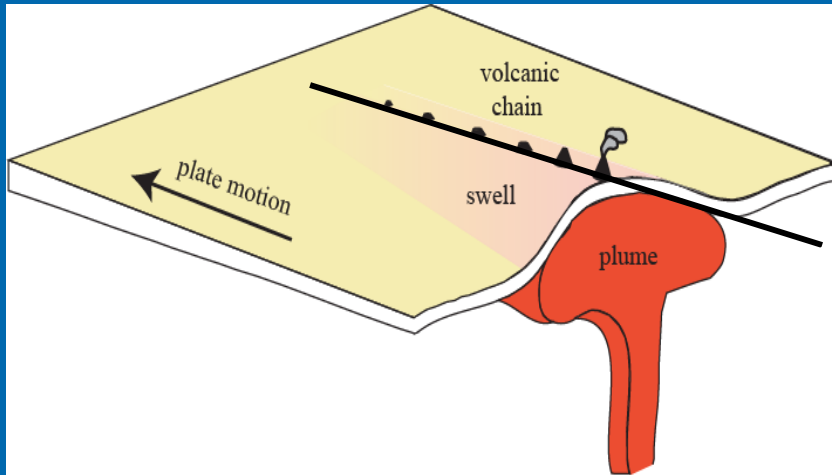
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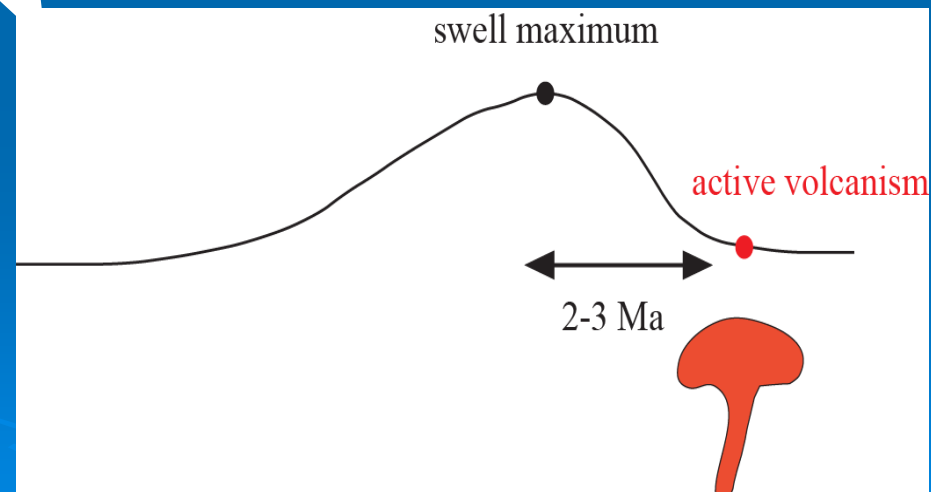
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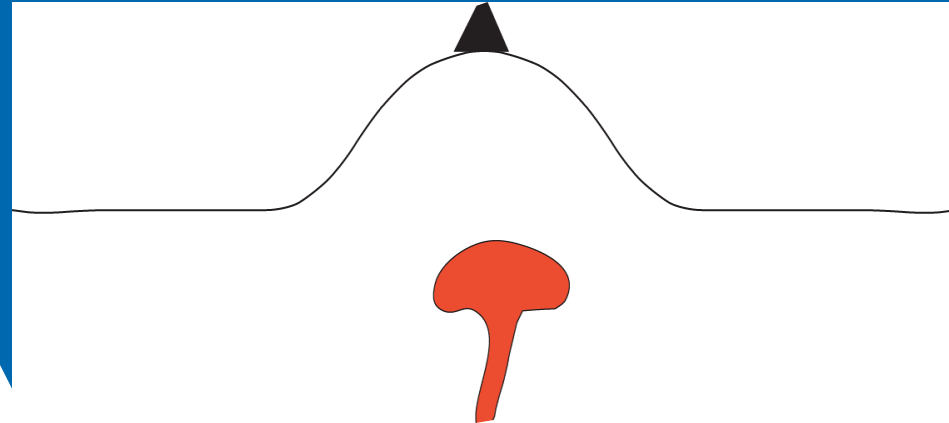
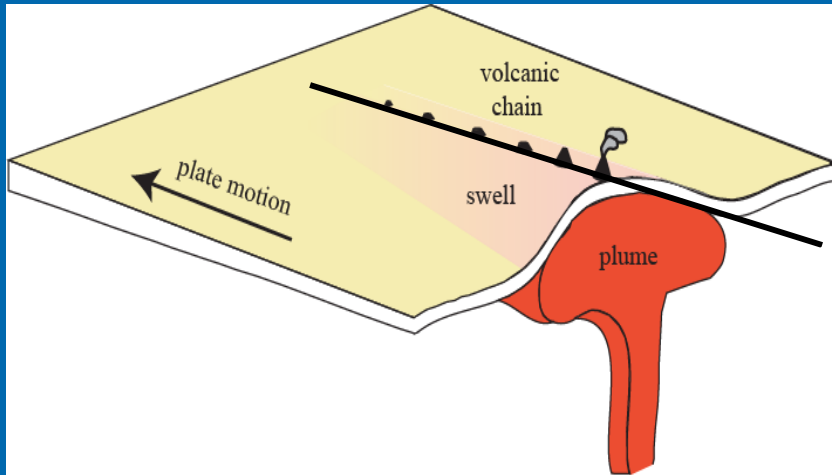
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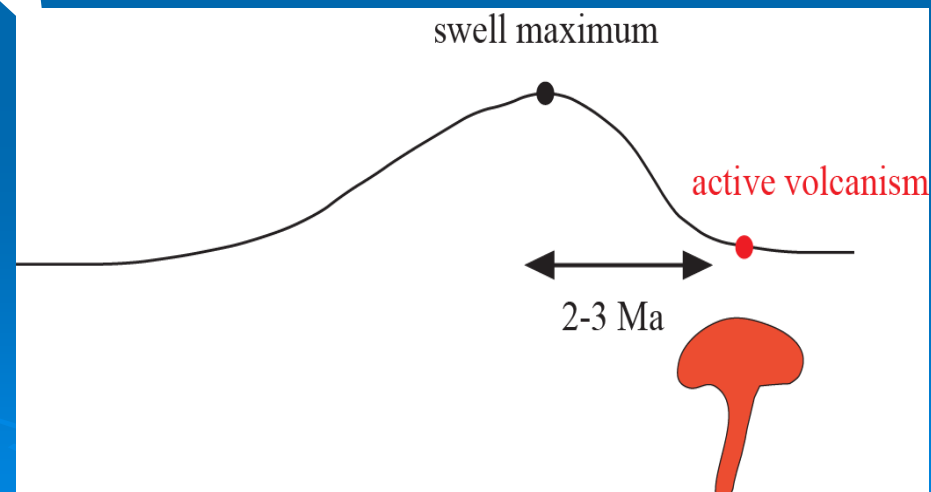
- ✓ 1000 km width
- ✓ 1000 m height
- ✓ Amplitude maximal along the main axis
- ✓ Maximal amplitude 2-3 Ma downstream from the active volcanism



⇒ Swell characteristics



- ✓ 1000 km width
- ✓ 1000 m height
- ✓ Amplitude maximal along the main axis
- ✓ Maximal amplitude 2-3 Ma downstream from the active volcanism
- ✓ Subsidence of the swell along the oldest part of the chain (cooling down)



Outline

✓ Definitions (plume, hotspot swell)

✓ Methodology for swells determination

✓ Some examples : Society, the classical hotspot

Long-lived hotspot trails: Hawaii, Walvis and St. Helena

Temporal evolution of buoyancy and volcanic fluxes along long-lived hotspot trails

⇒ Methodology for swell determination

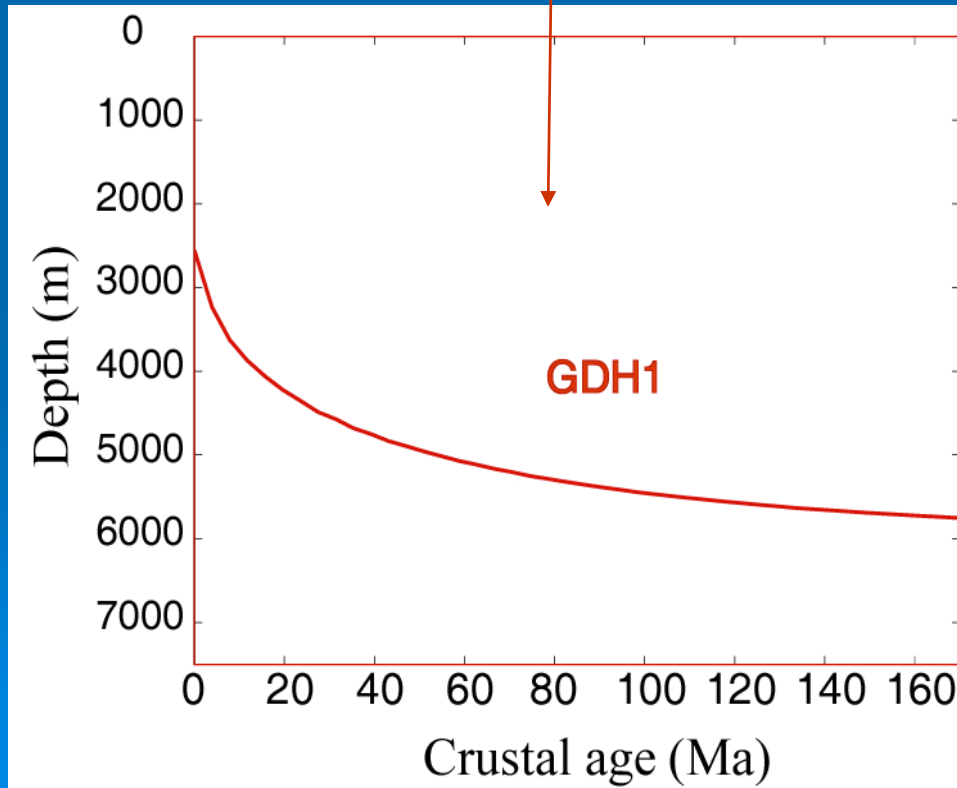
✓ *depth anomaly*

$$\Delta d = d_{obs} - d_{GDH1}$$

⇒ Methodology for swell determination

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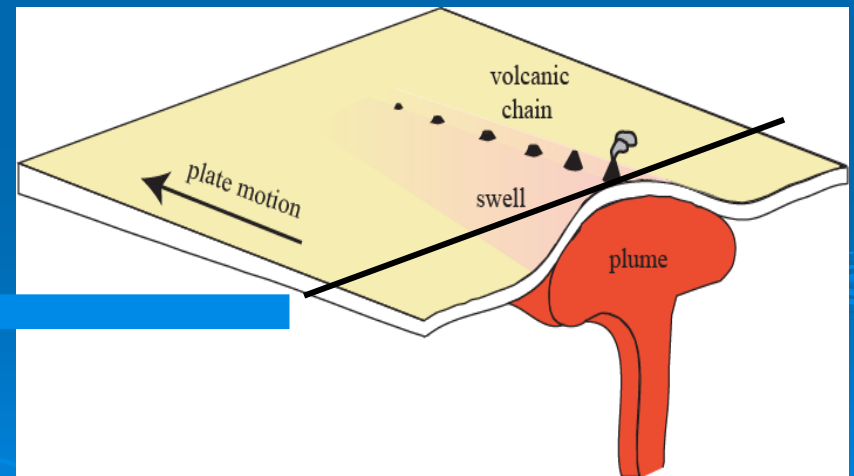
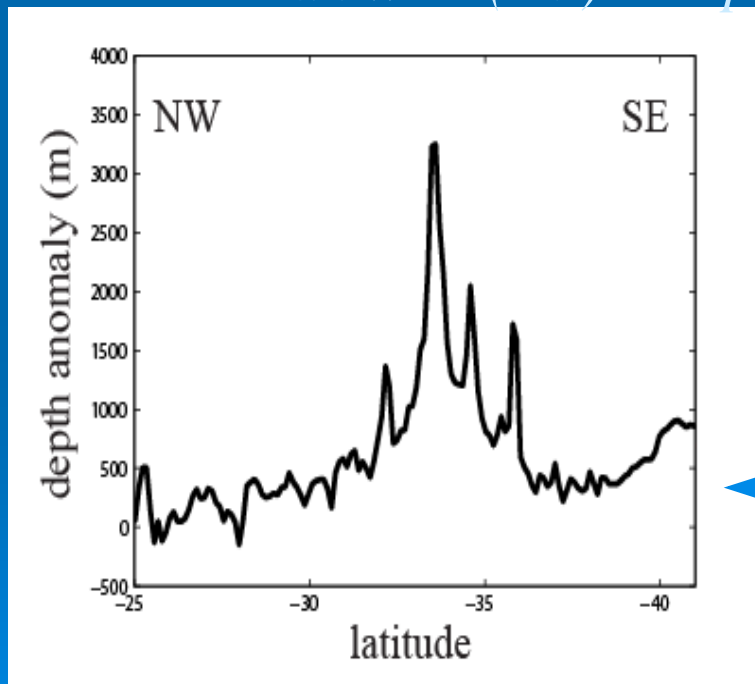


⇒ Methodology for swell determination

- ✓ *depth anomaly*
- ✓ *filtering (MiFil method)*
to separate the volcanoes (H_v)
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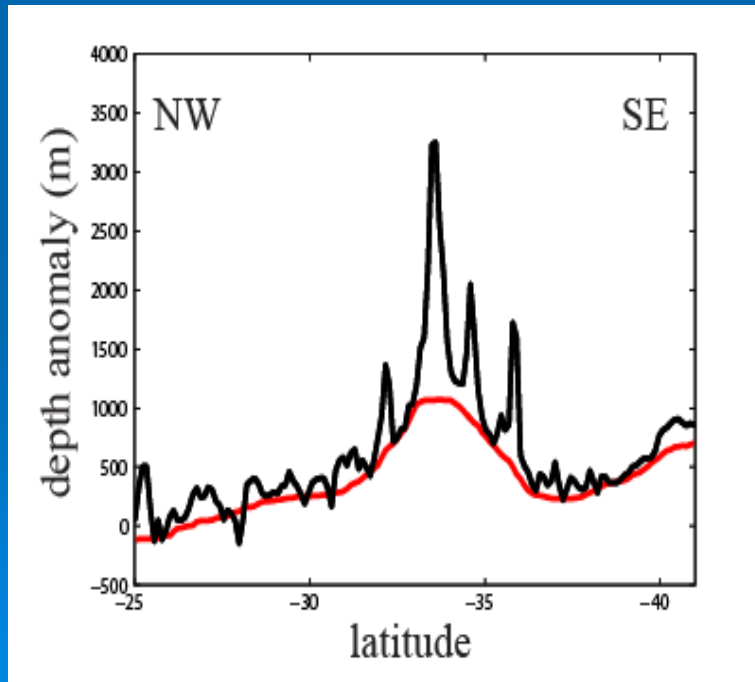
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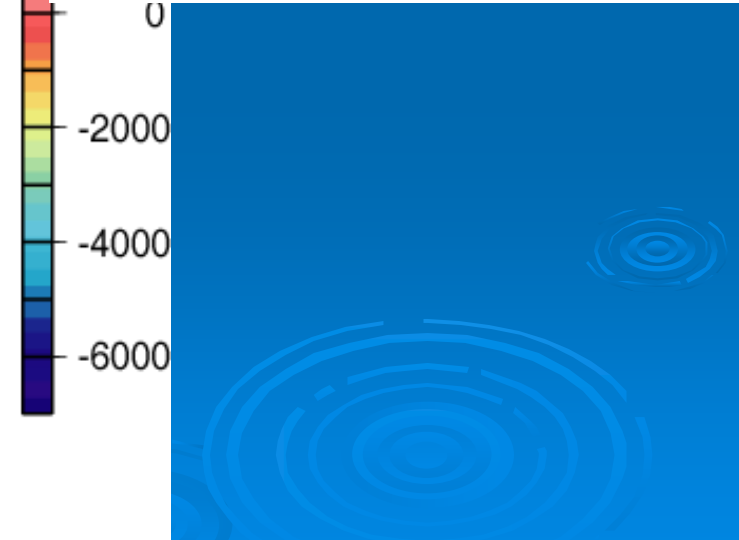
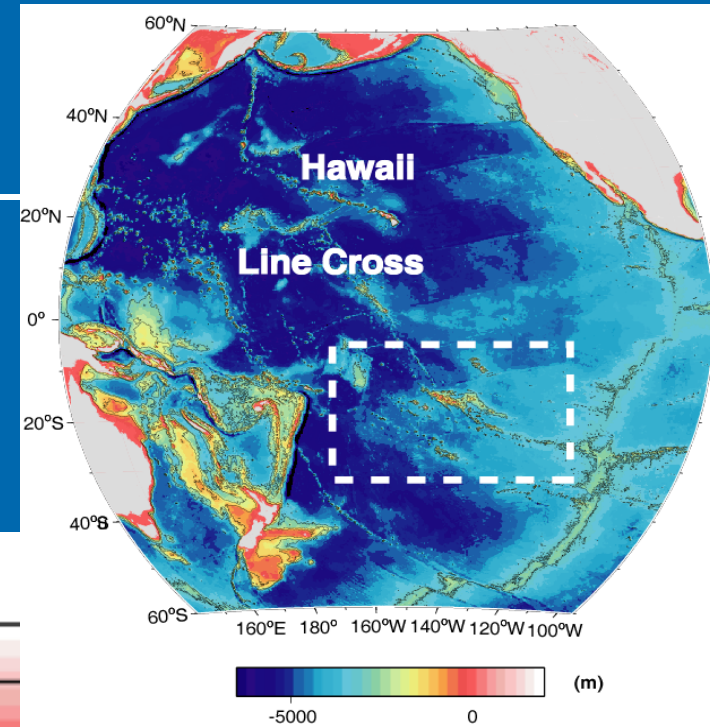
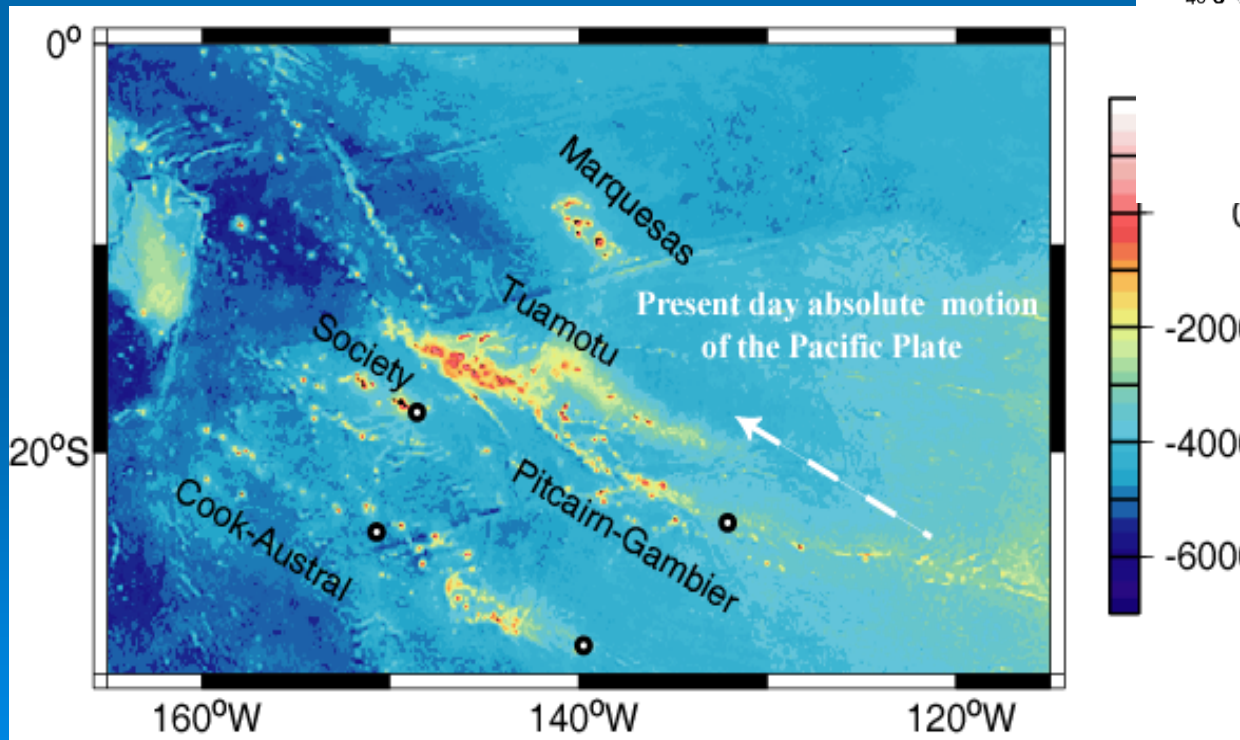
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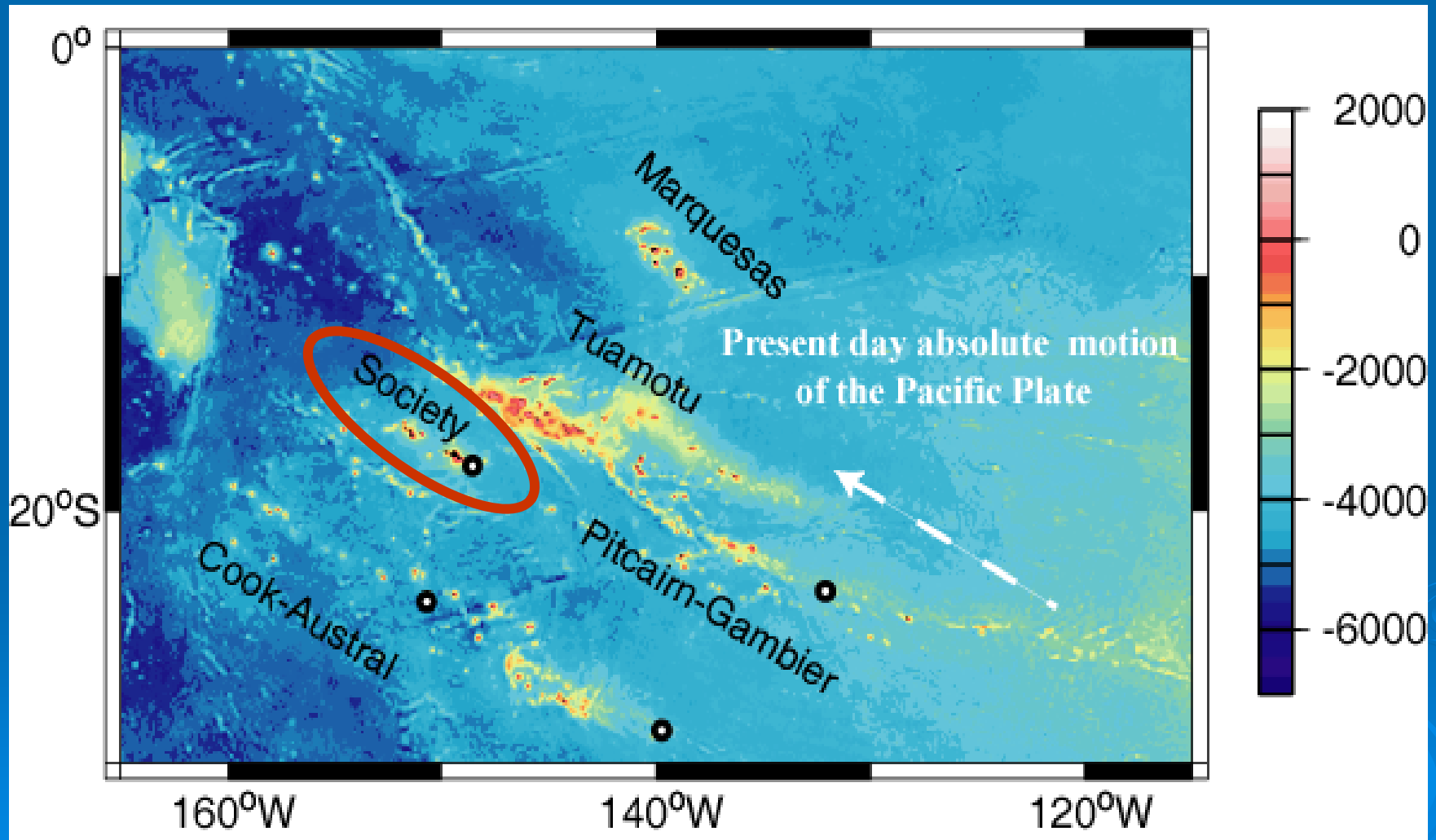
Temporal evolution of buoyancy and volcanic fluxes along long-lived hotspot trails

French Polynesia

Numerous geophysical anomalies among which a high concentration of volcanism



⇒ Society

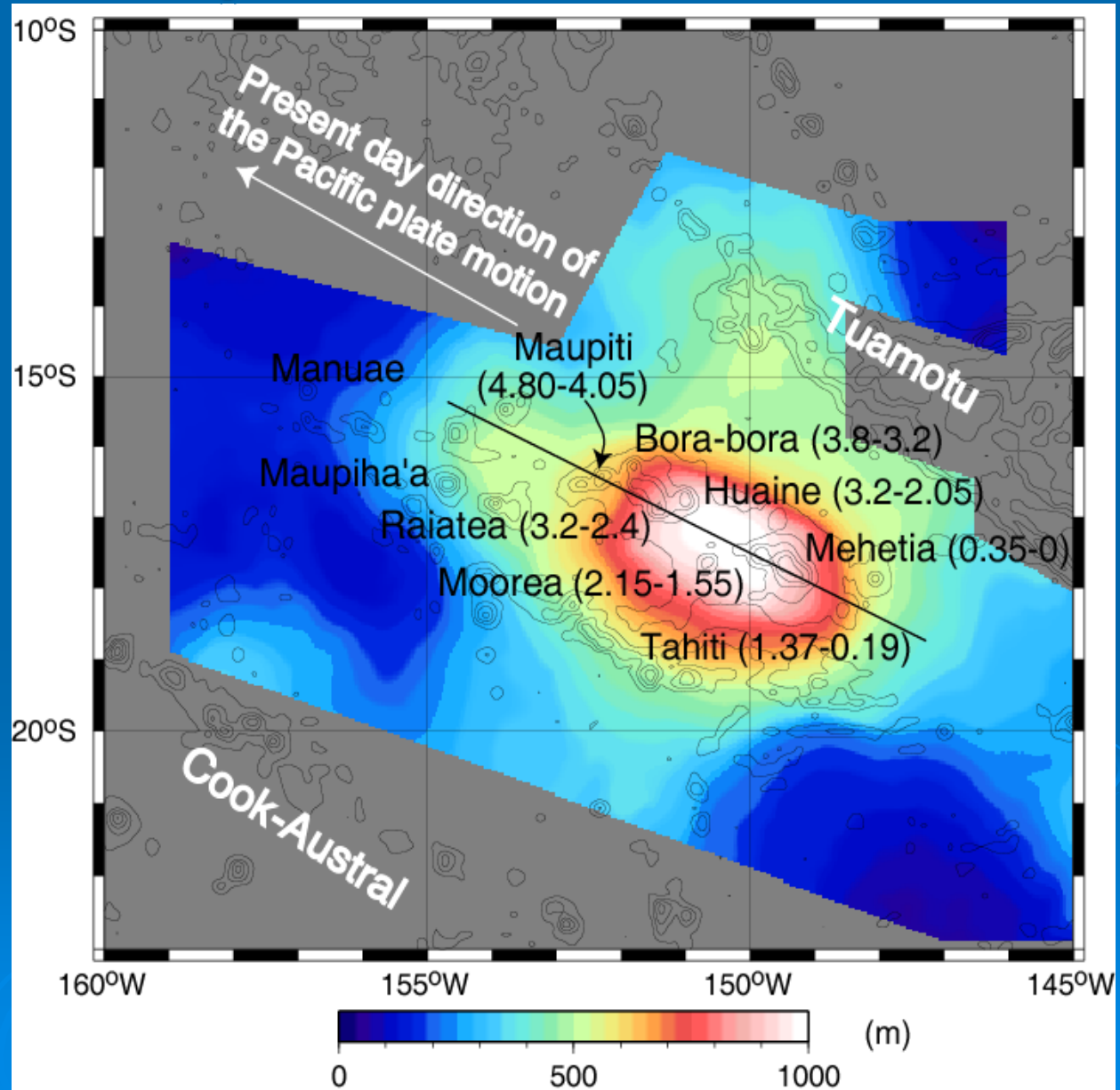


⇒ Society

Classical swell

Parameters

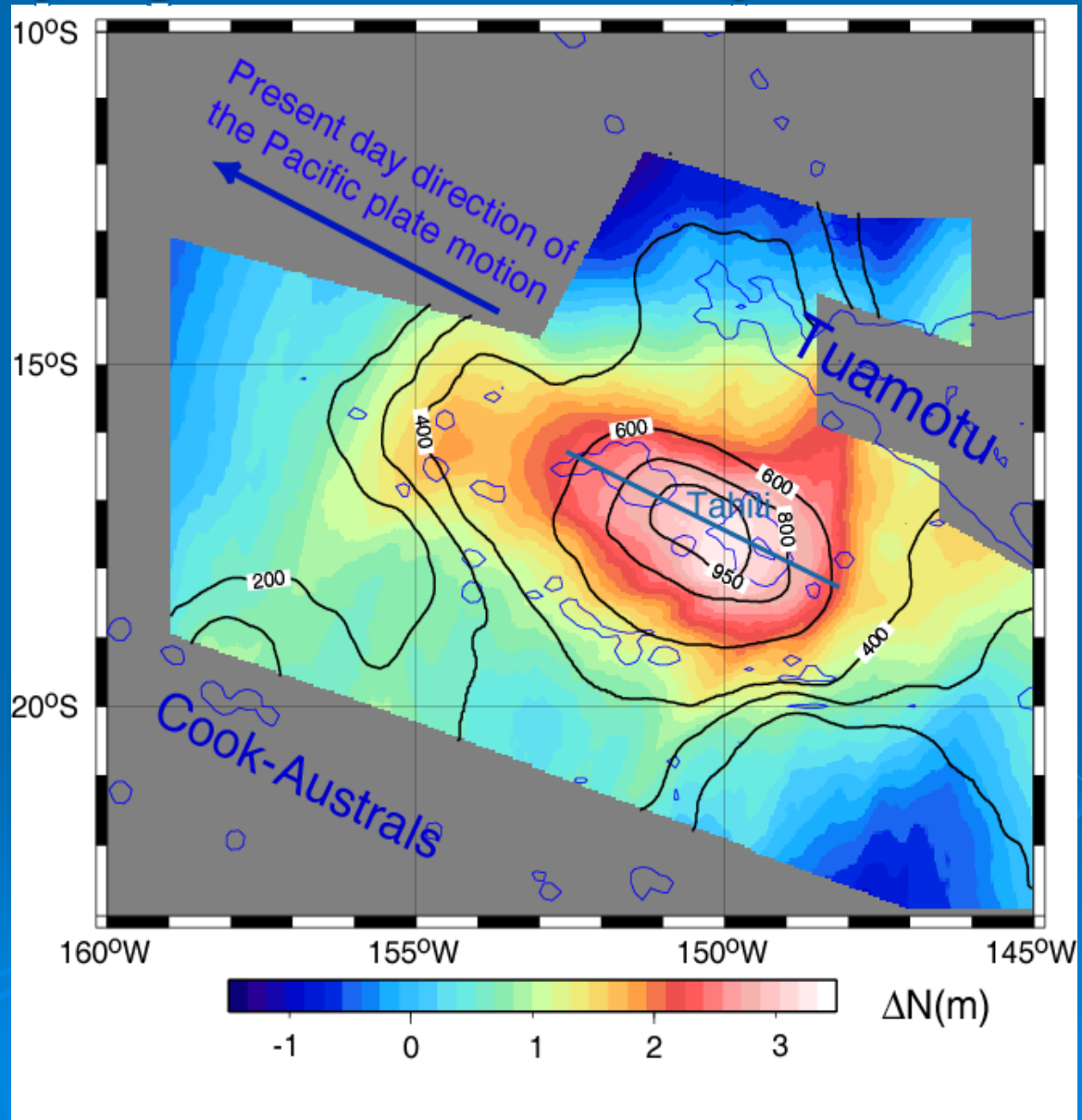
- $\lambda \sim 1000$ km
- amplitude ~ 1000 m



⇒ Society: geoid anomaly

- Good correlation with the depth anomaly

• $d_{\text{comp}} \sim 40 \text{ km}$



Outline

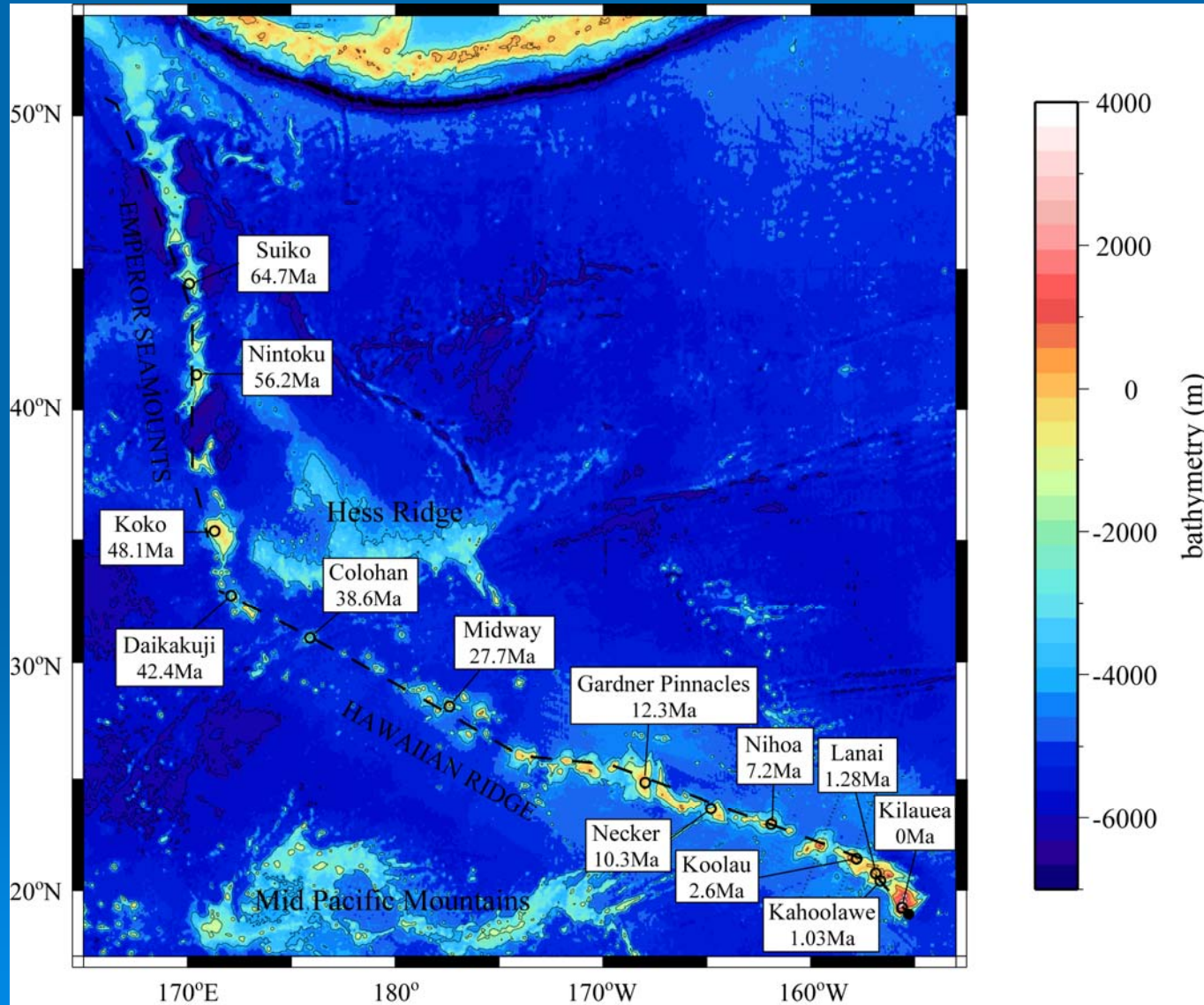
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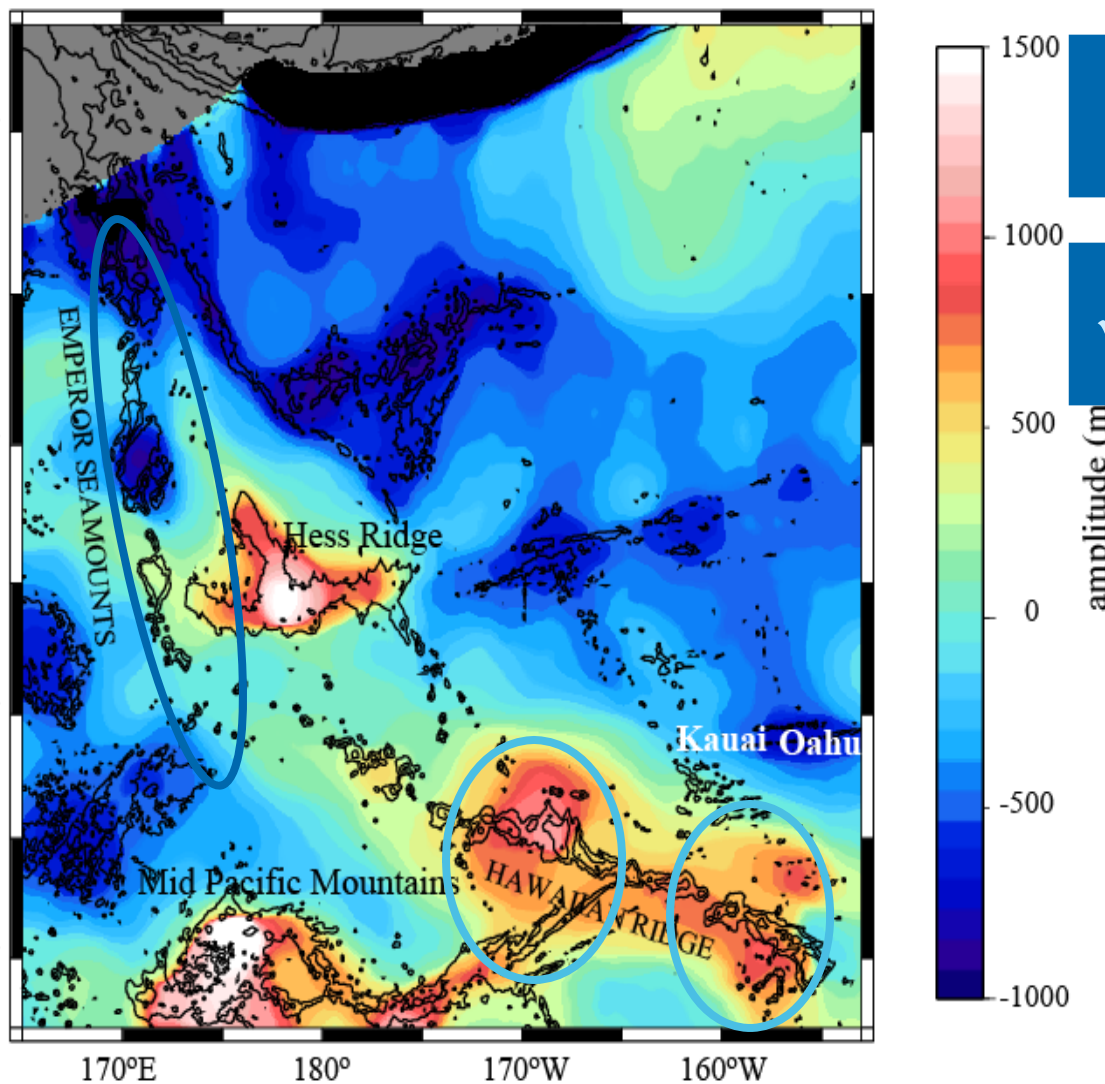
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Hawaii-Emperor



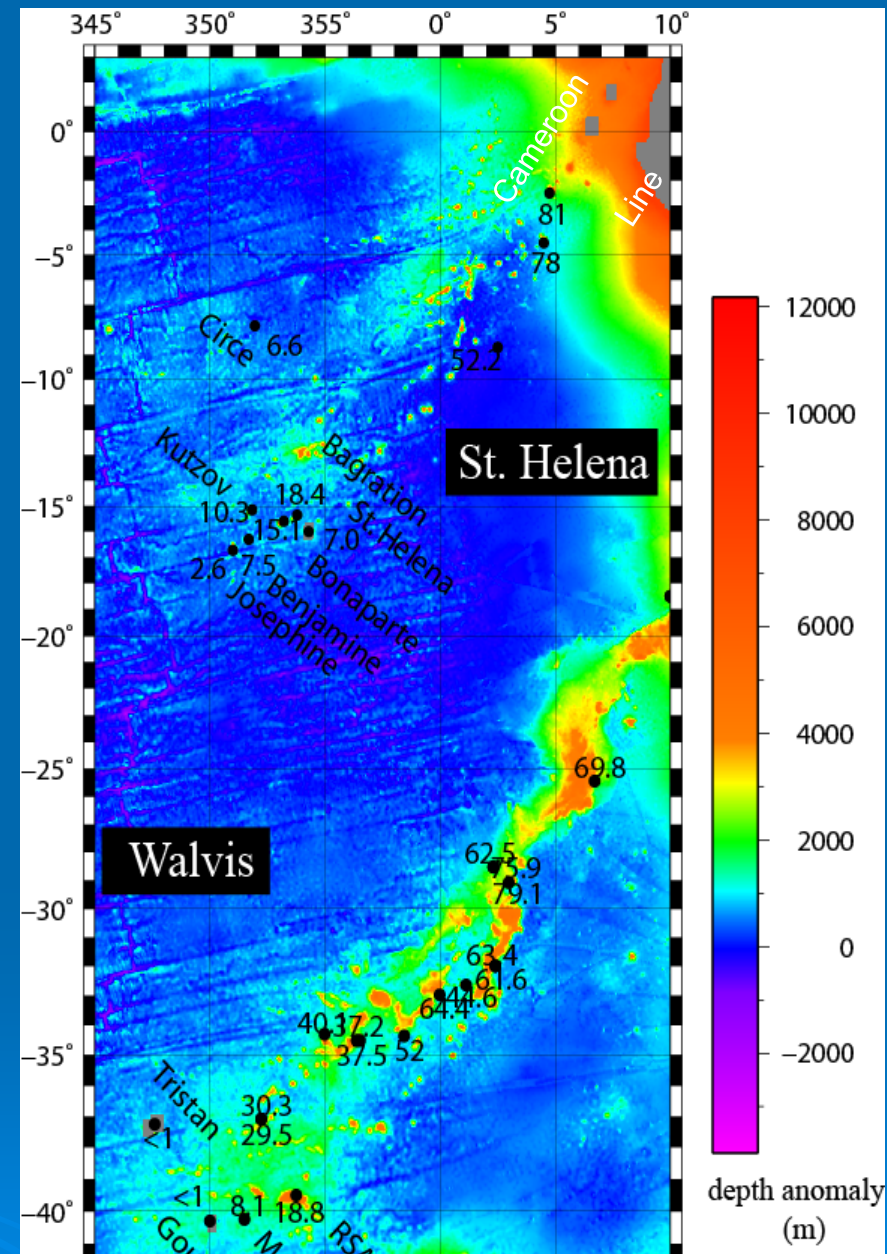
⇒ Hawaii-Emperor



- ✓ Swell has completely subsided along the oldest part of the chain
- ✓ Two maxima along the chain

⇒ Walvis and St. Helena chains

- ✓ *Hotspot origin*
- ✓ *Volcanism ages scattering*
 - ⇒ *plume clusters?*
 - ⇒ *a single wide plume?*
 - ⇒ *irregular motion of the plume respectively to the lithosphere?*
- ✓ *Chains formed in different tectonic settings*
- ✓ *Circe: another hotspot?*

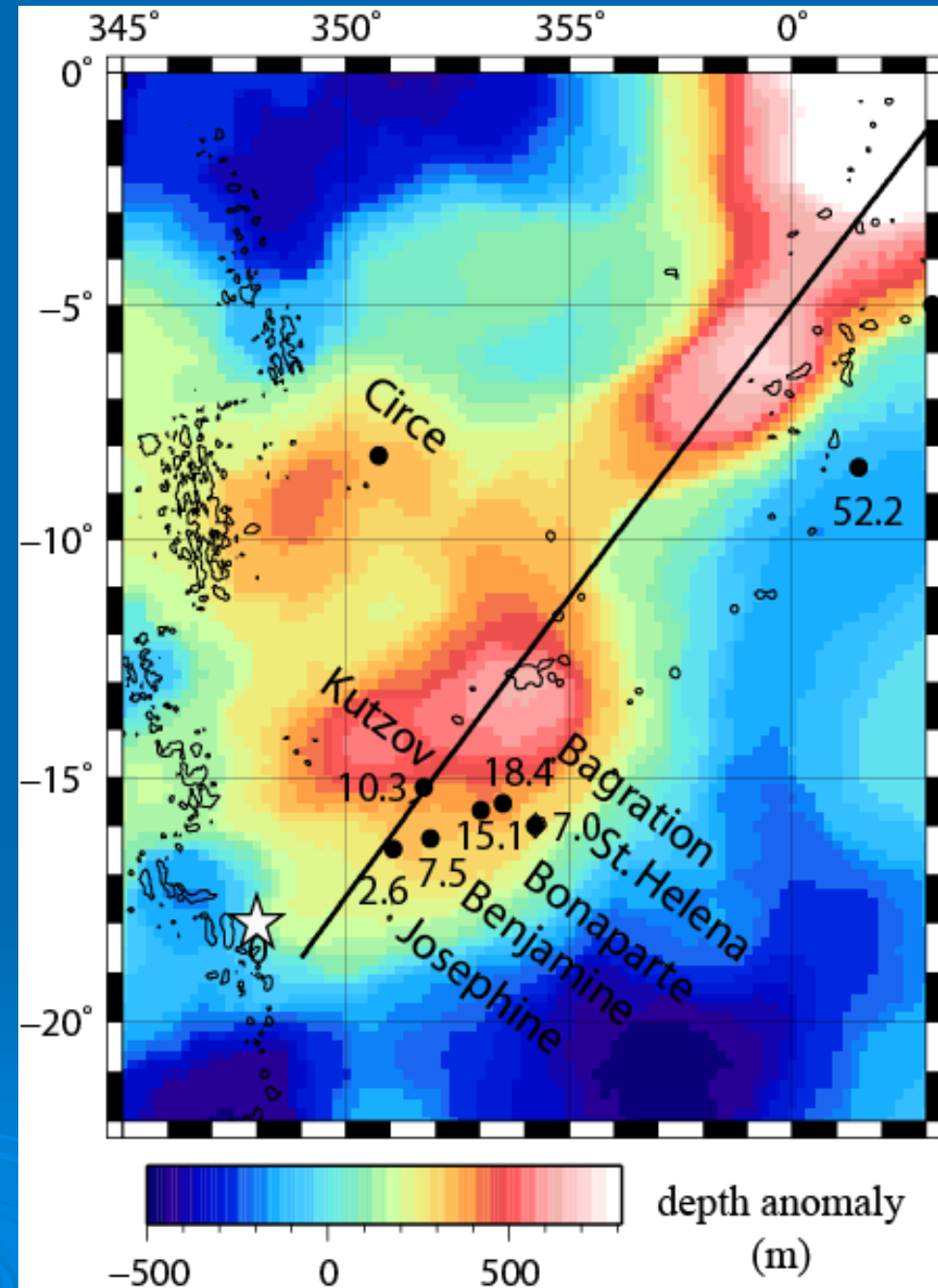


⇒ *new information about the loading history of these chains*

⇒ St. Helena swell

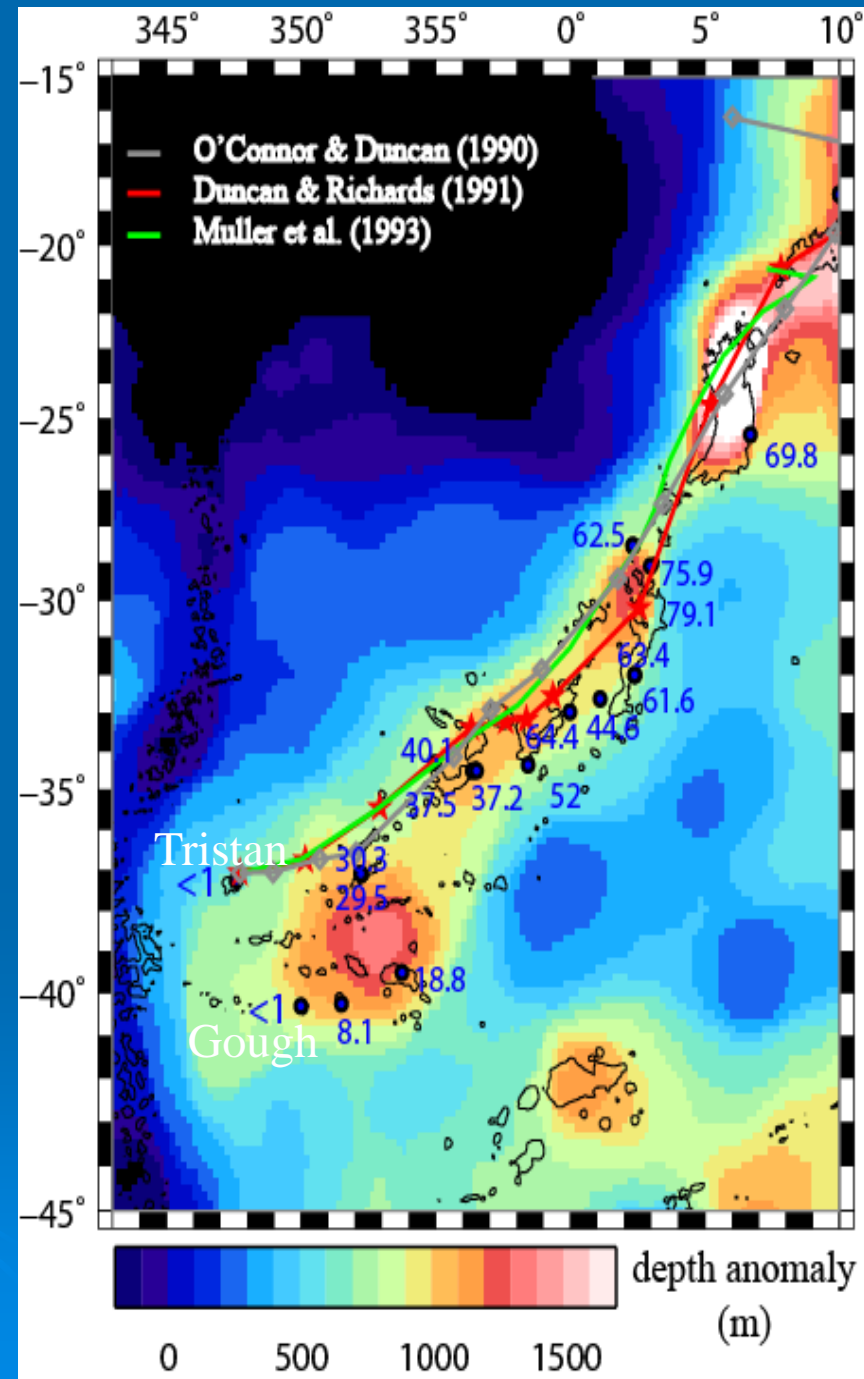
✓ *Two circular swells associated with the youngest part of the chain*
⇒ *two plumes?*

✓ *Another plume at the origin of the Circe volcano*



⇒ Walvis swell

- ✓ *One circular swells associated with the youngest part of the chain*
⇒ *present-day buoyant effect of the plume*
- ✓ *Two other bumps*



⇒ Walvis swell

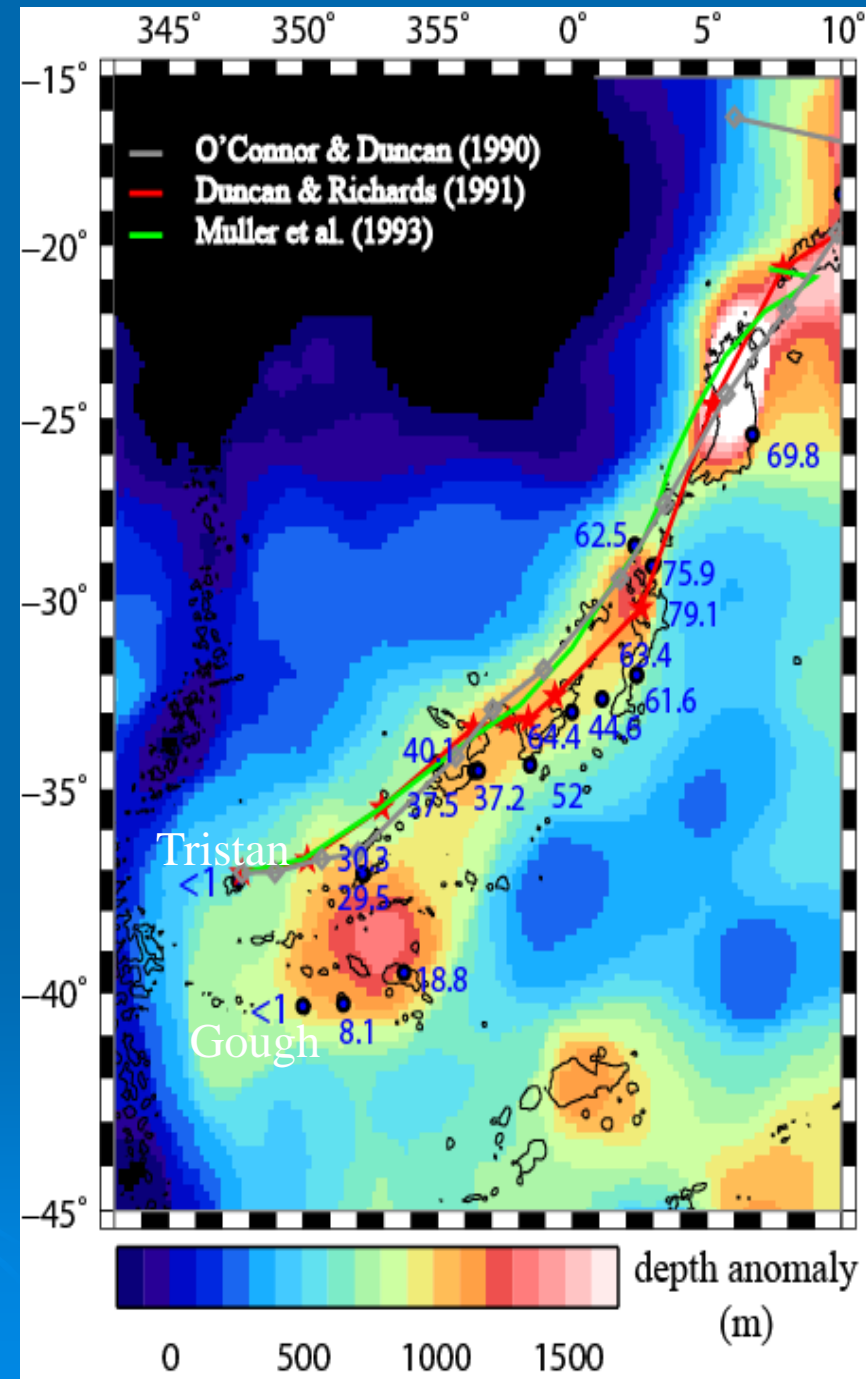
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⇒ *present-day buoyant effect of the plume*

✓ *Two other bumps*

✓ *Swell morphology inconsistent with the rotation poles tracks*

⇒ *wrong rotation poles tracks*

⇒ *plume motion*



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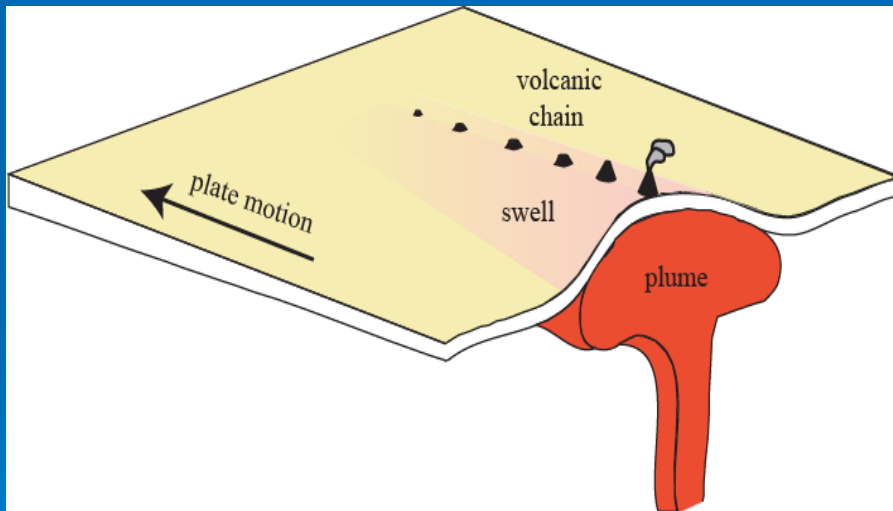
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⇒ hotspot concept

Two main surface manifestations:

- ✓ *volcanic chains*
- ✓ *swell*



Atlantic ocean ⇒

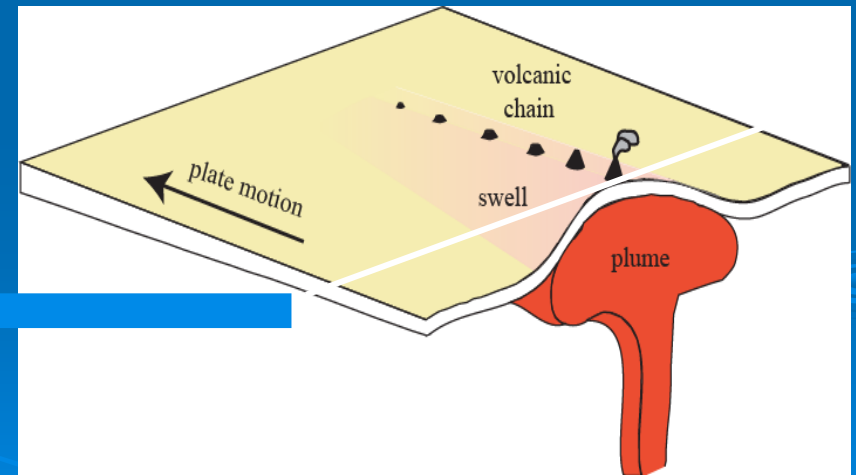
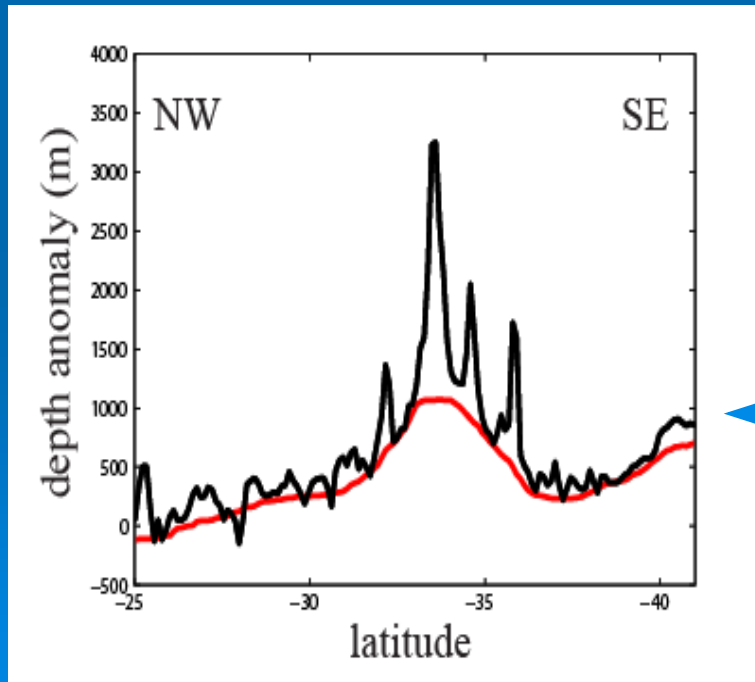
Walvis and St. Helena chains

Pacific ocean ⇒ Hawaii

These observations are used to study the plume temporal variability

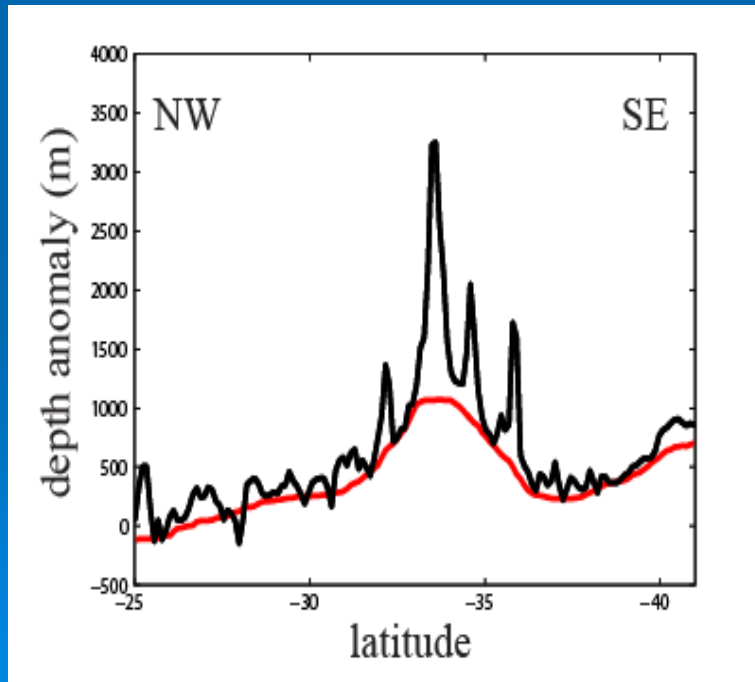
⇒ Methodology

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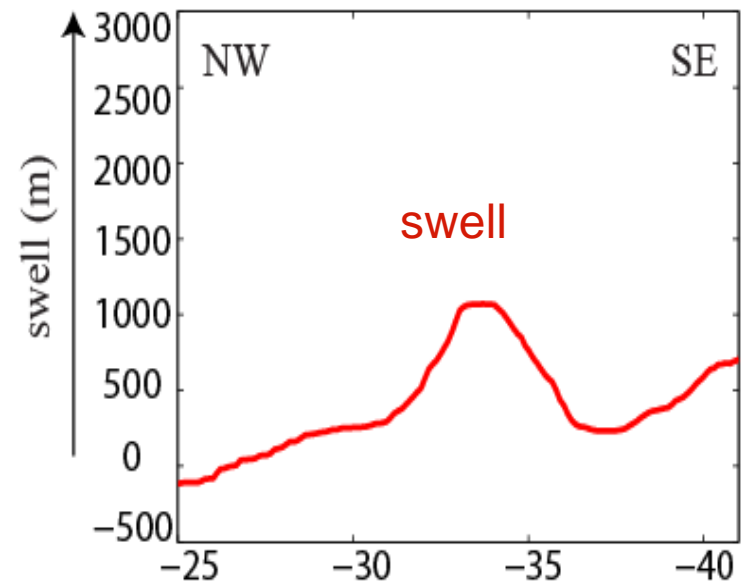


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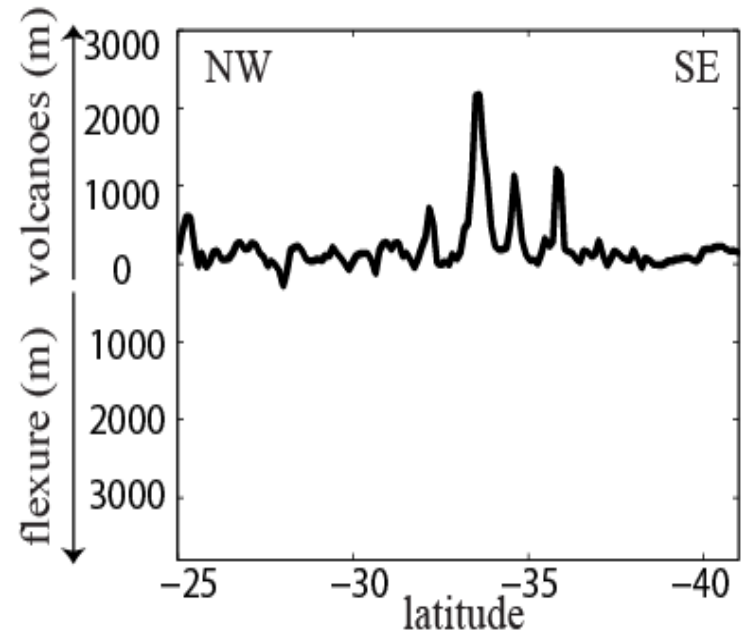
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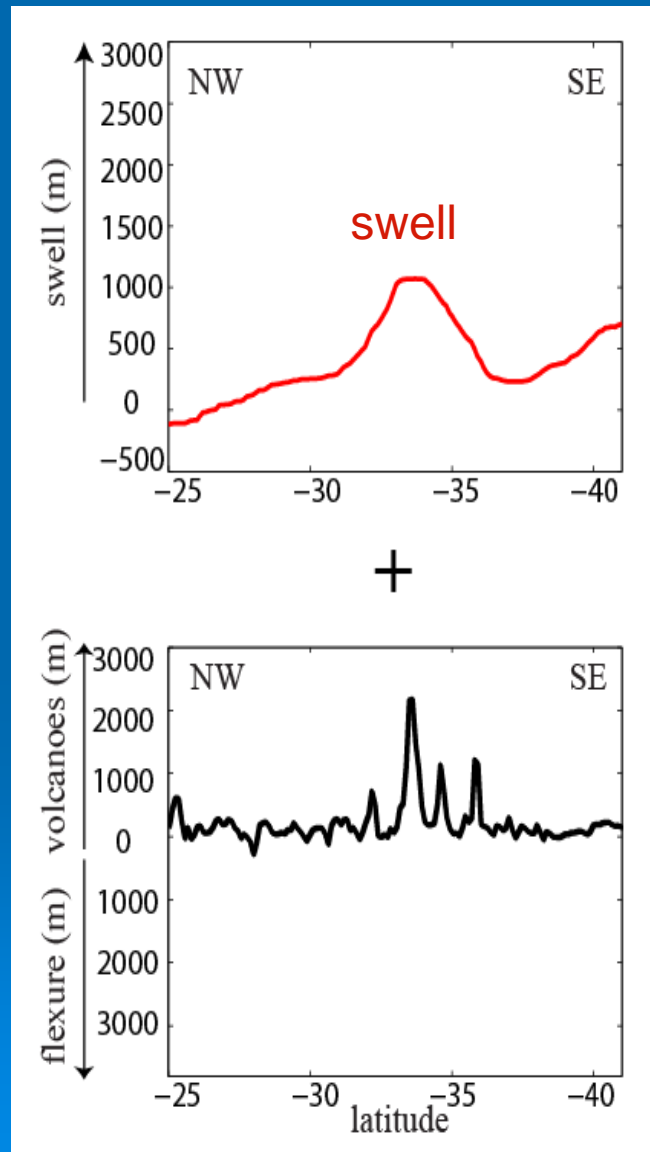
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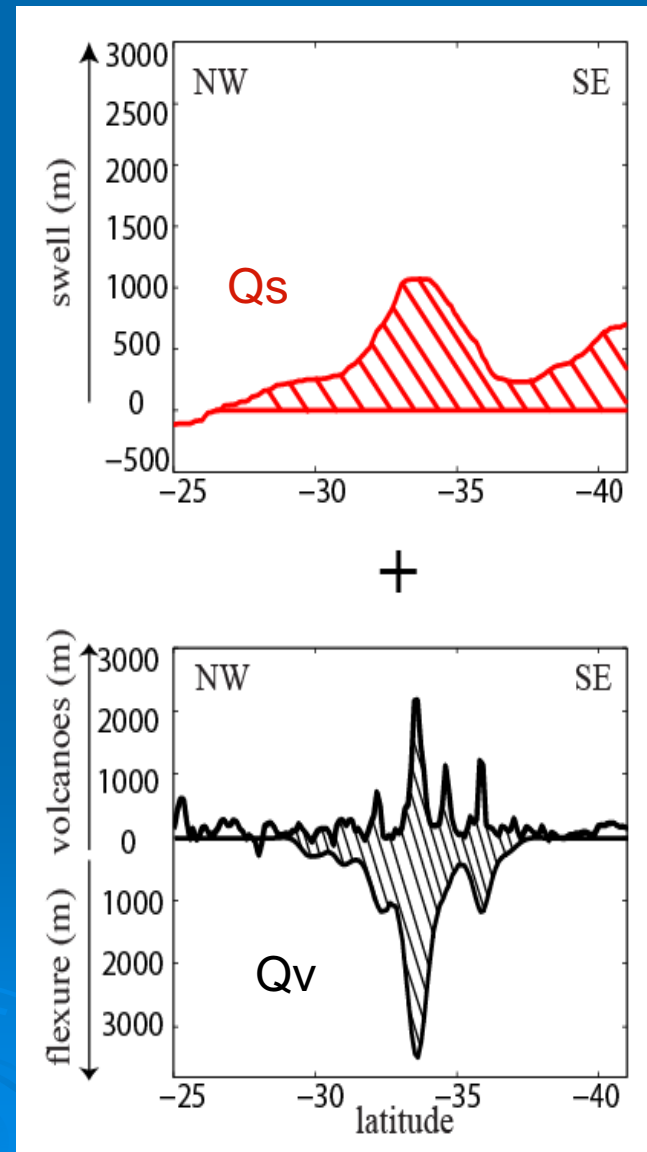
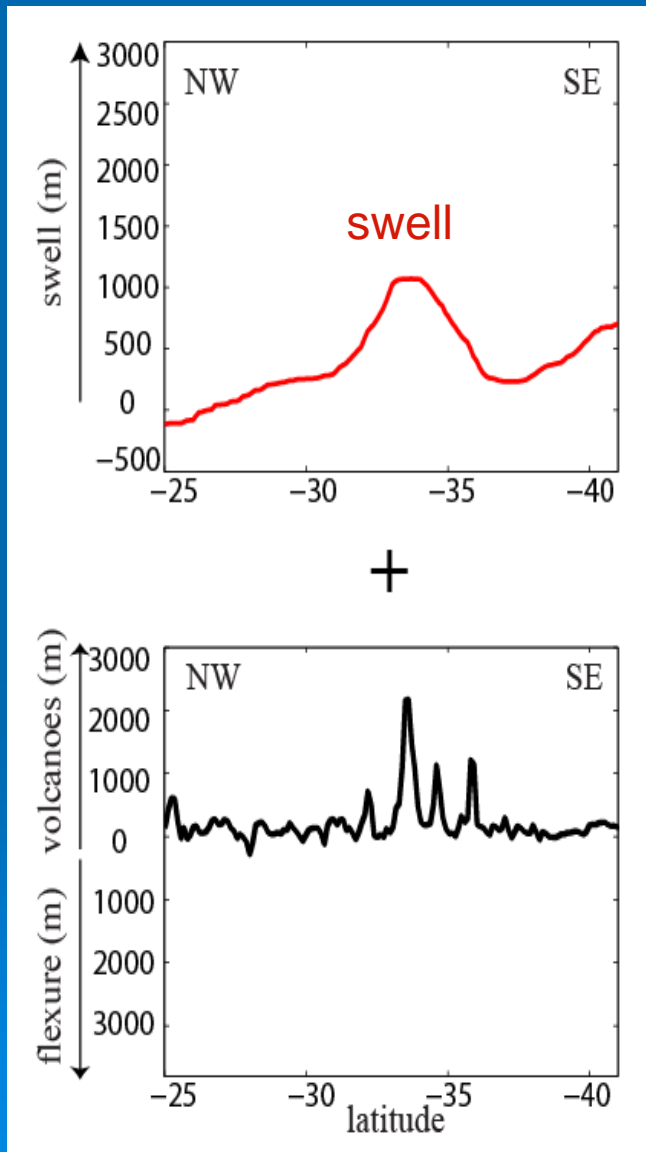
⇒ Fluxes temporal evolution



Buoyant uplift of the plume

Volcanic output to the seafloor

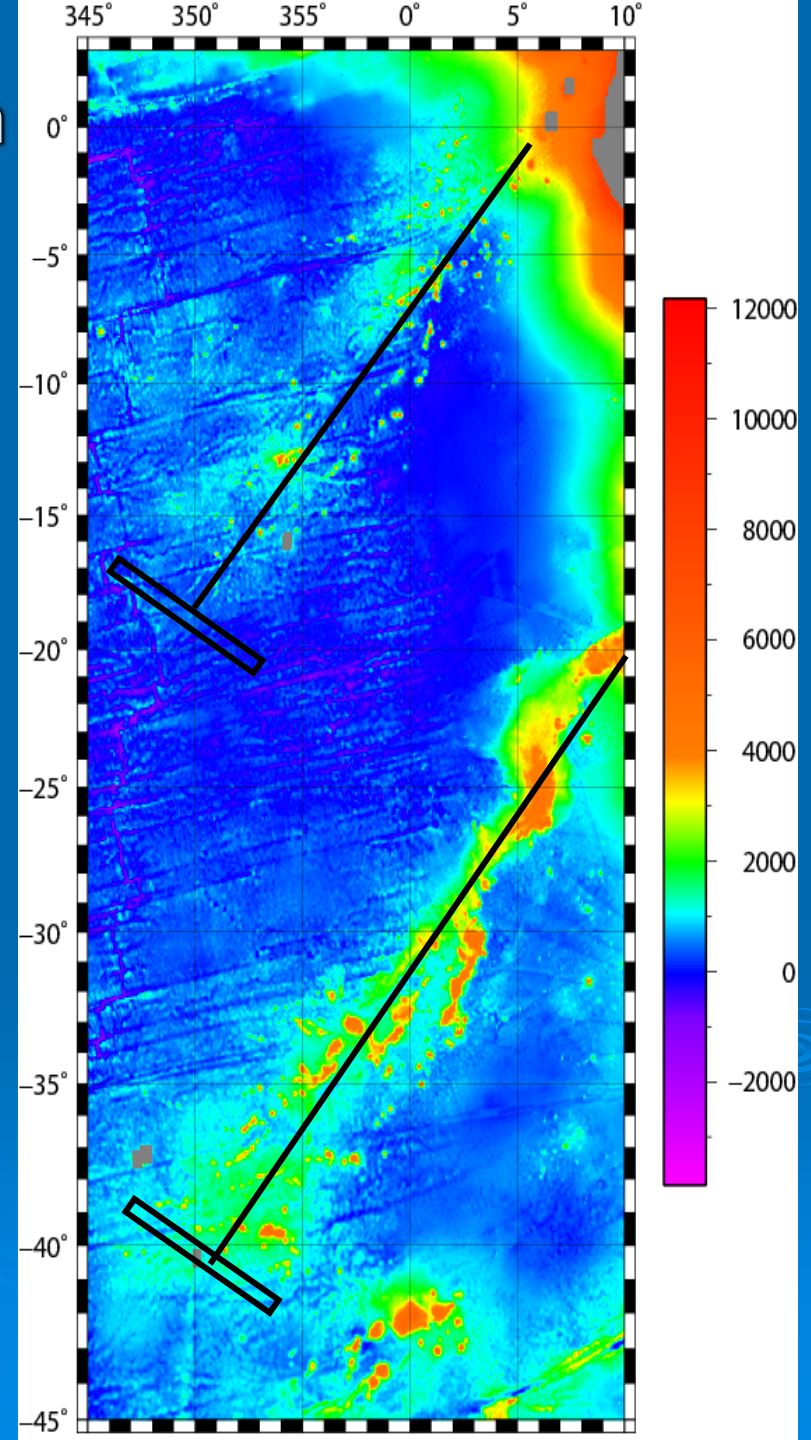
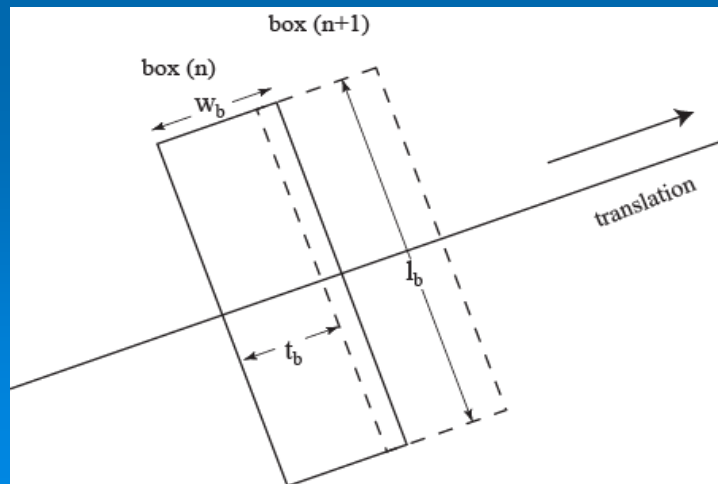
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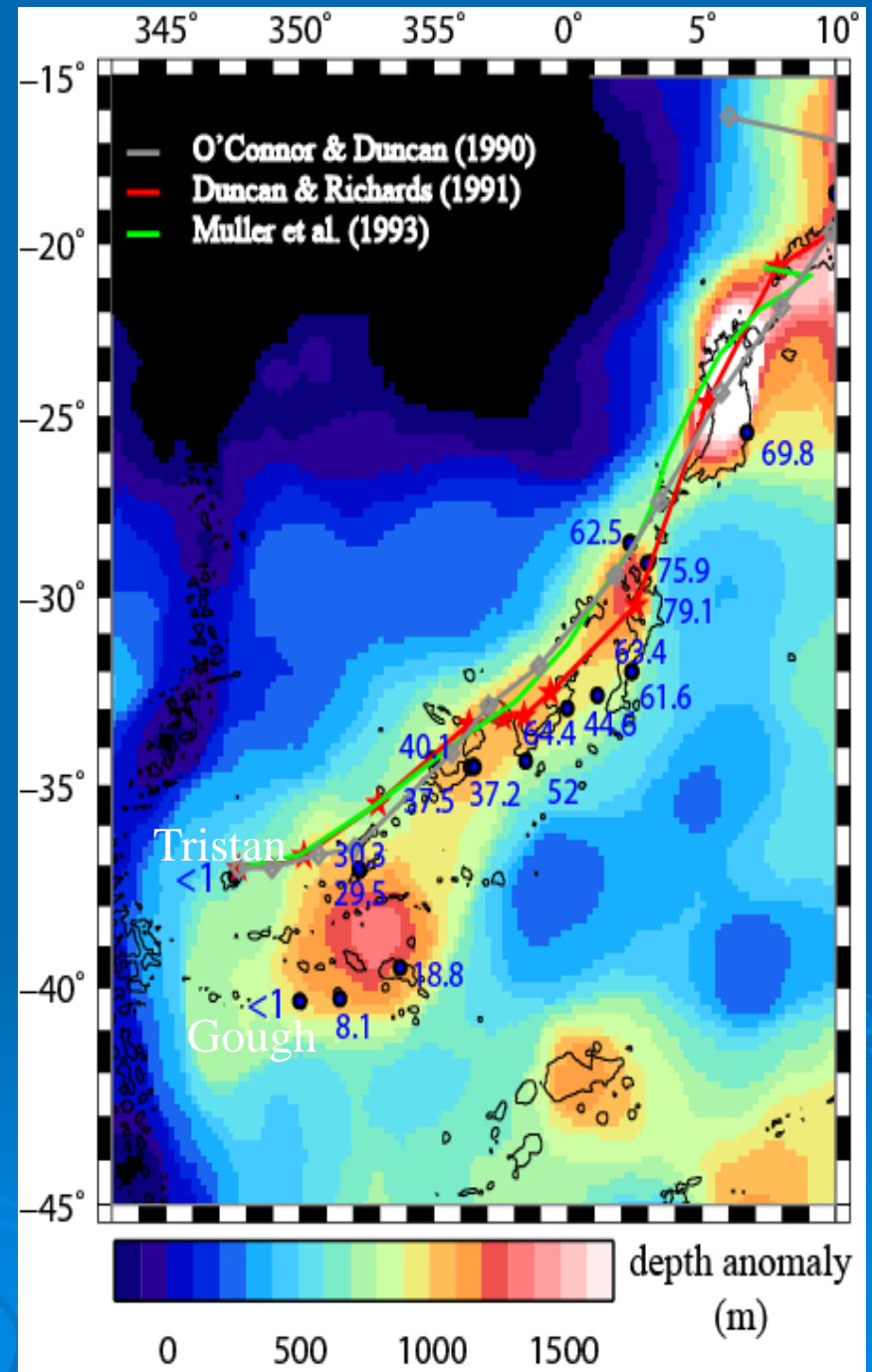
✓ *variations of the buoyancy and volcanic flows through time*

⇒ *translating boxes*
(Vidal & Bonneville, 2004)





Main axis?



✓ *Swell morphology inconsistent with the rotation poles tracks*

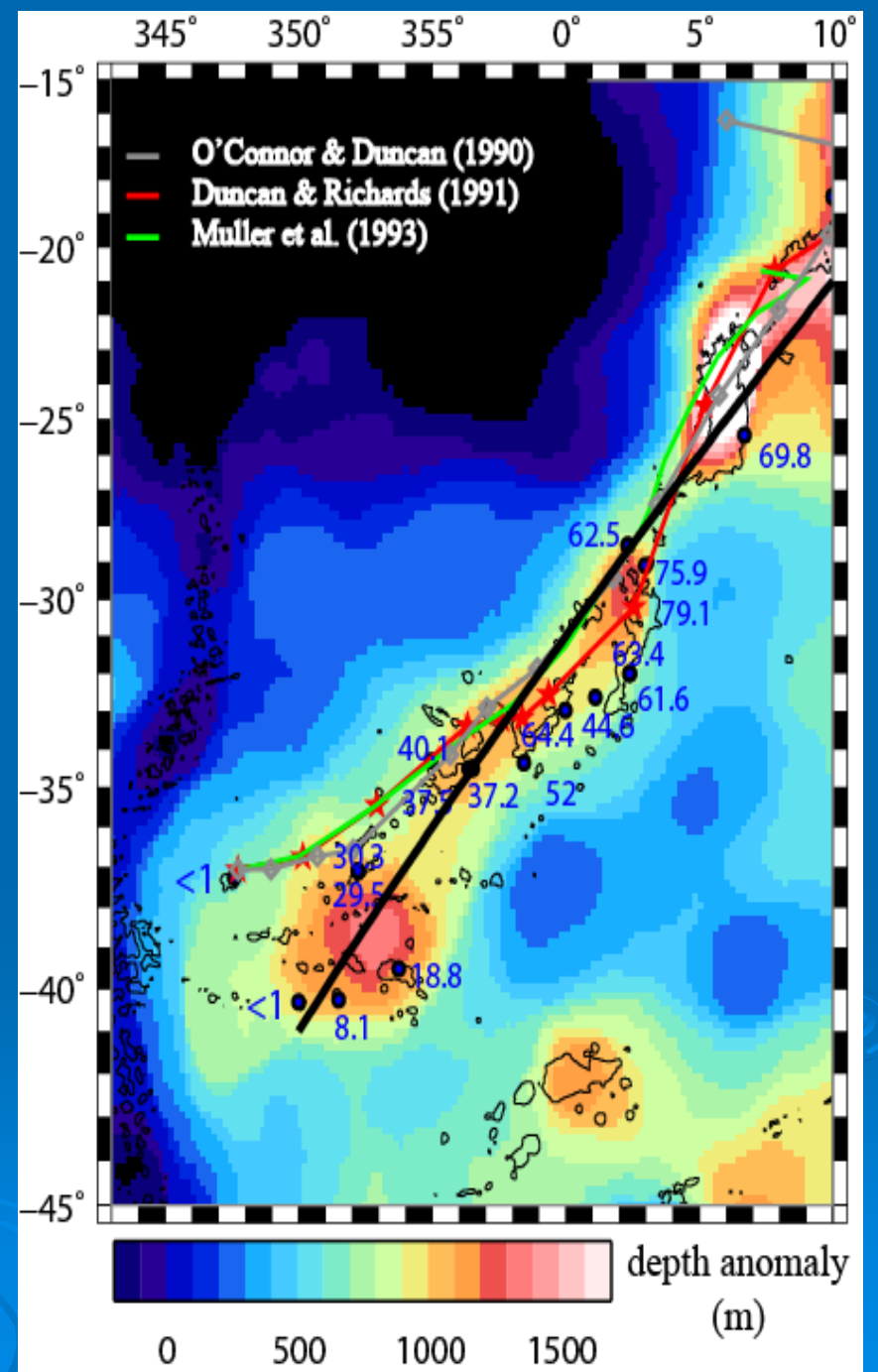


Main axis?

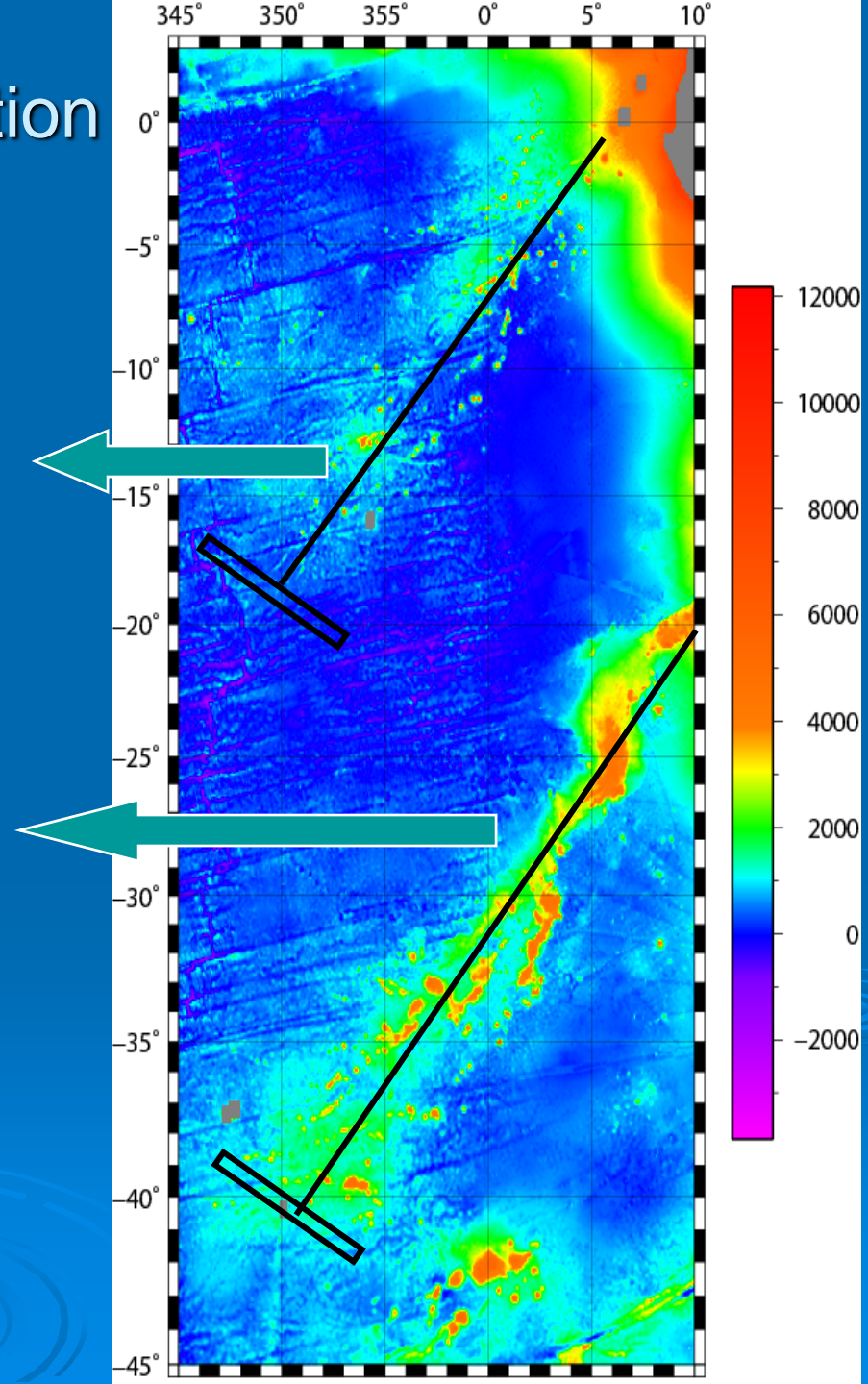
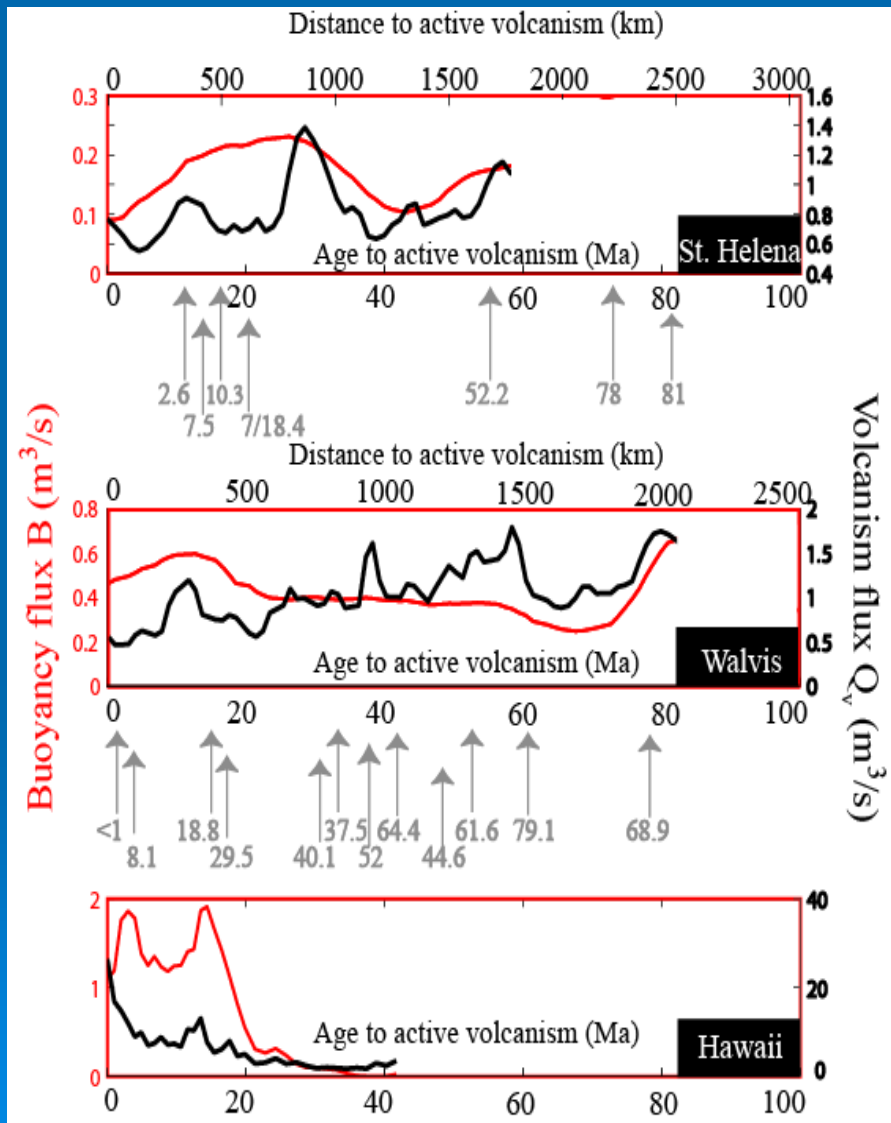
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Choice of a linear main axis



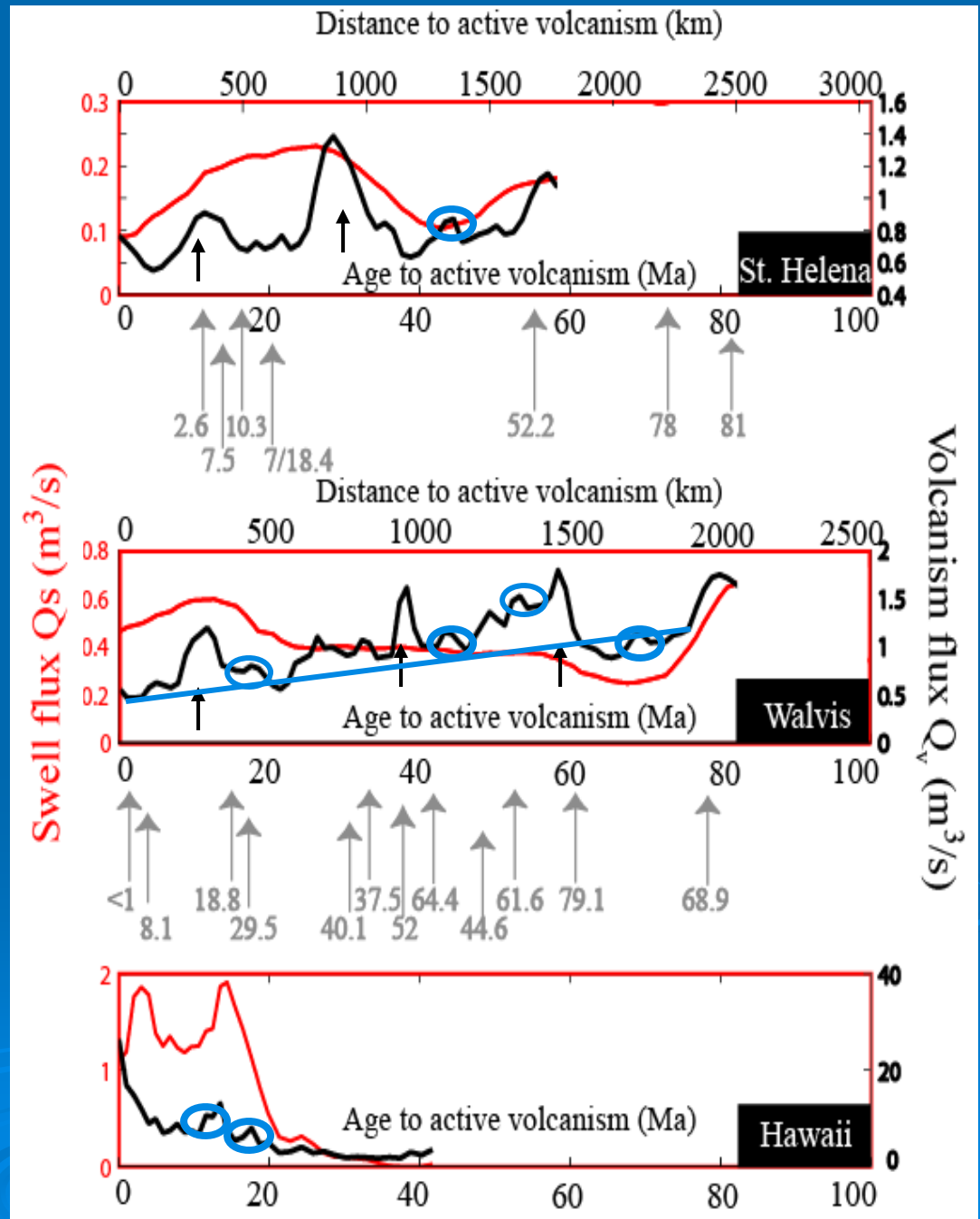
Fluxes temporal evolution



⇒ Fluxes temporal evolution

- Volcanism flux (Q_v)

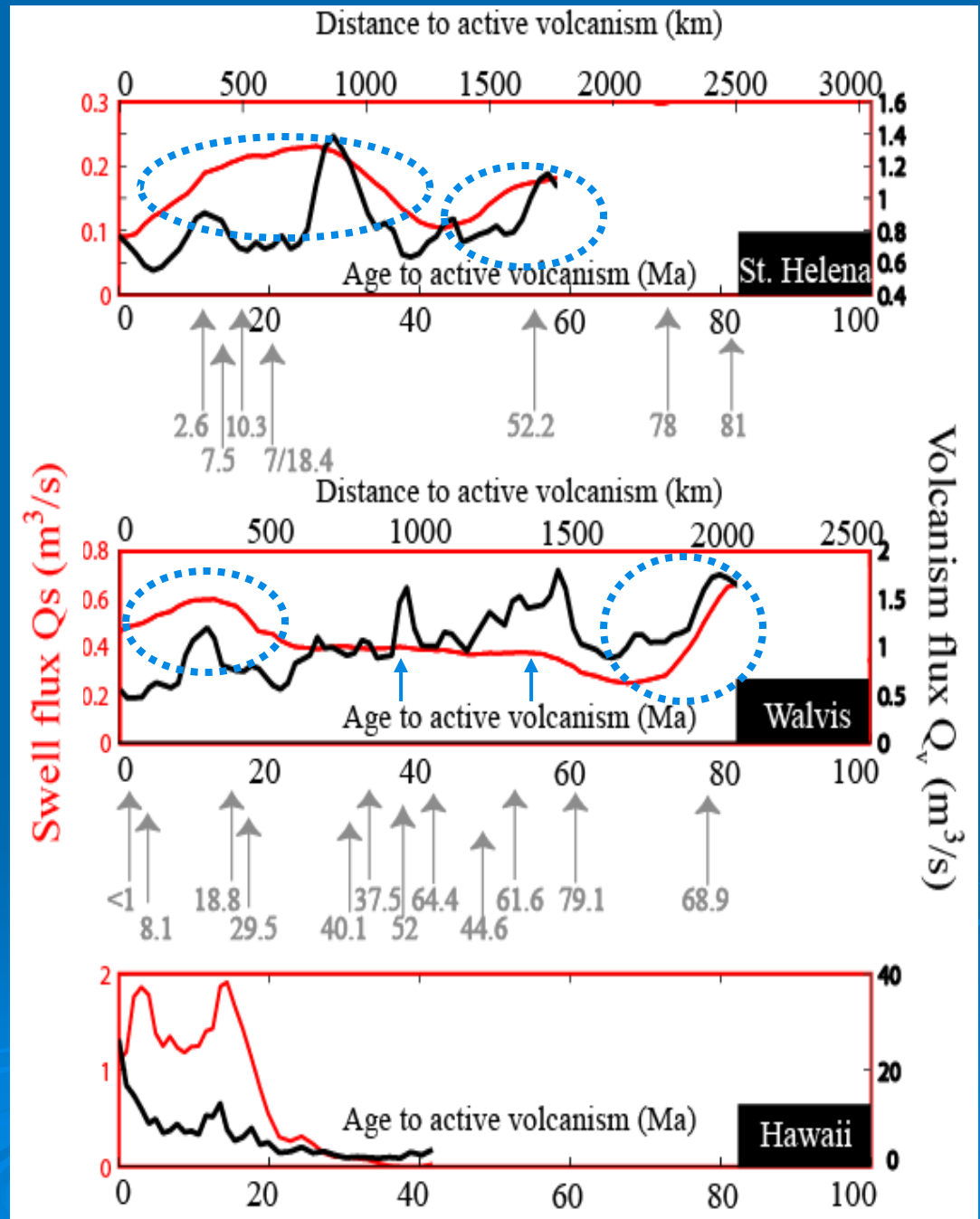
- ✓ peak at youngest ages well synchronized
- ✓ peak at 30 Ma (St. Helena) ⇒ other hotspot?
- ✓ Walvis: two peaks at 40 and 60 Ma ⇒ plume temporal variability?
- ✓ short-term variations (5 Ma)
- ✓ Walvis: general decrease



⇒ Fluxes temporal evolution

- Swell flux (Q_s)

- ✓ first peak wider for St. Helena
⇒ encompass the effects of two plumes?
- ✓ Walvis: first Q_s peak well correlated with the first Q_v peak
- ✓ Walvis: two other smaller Q_s peaks well correlated with the Q_v peaks (delay)
- ✓ older parts ⇒ continental origin!





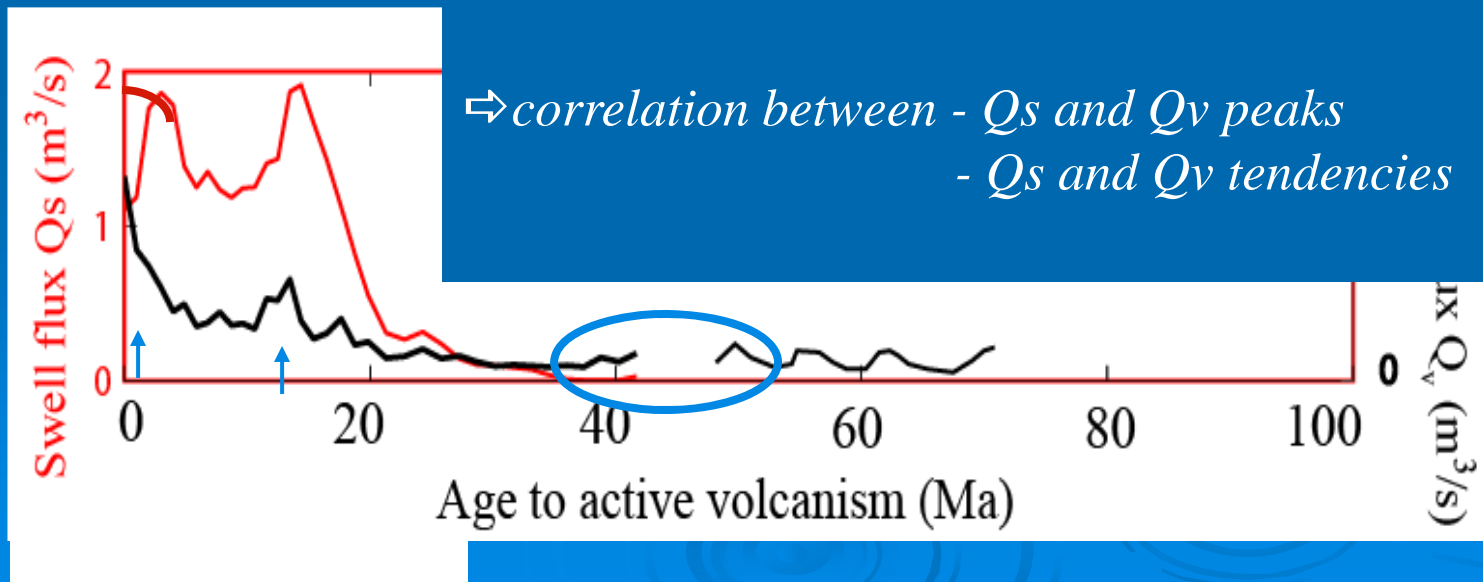
Fluxes temporal evolution: Hawaii

- Volcanism flux (Q_v)

- ✓ exponential increase in the last 30 Ma
- ✓ two peaks: 15-18 Ma and actual (?)
- ✓ gap: to avoid biased values

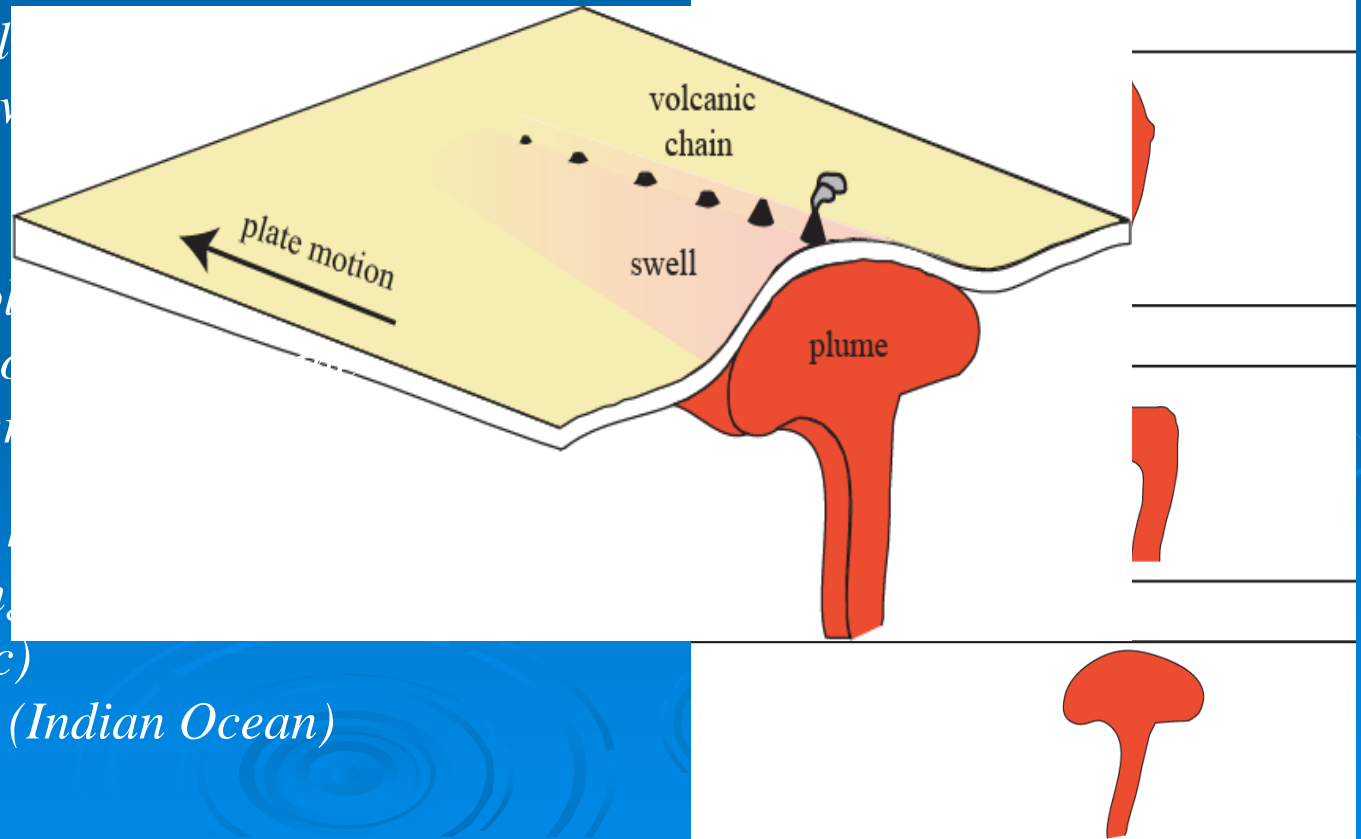
- Swell flux (Q_s)

- ✓ swell completely subsided for ages >40 Ma
- ✓ exponential increase of Q_s
- ✓ two peaks: 15-18 Ma and actual (?)



⇒ *Plumes pulsation*

- ✓ *correlated Q_v and Q_s peaks*
 - ⇒ *variation of the plume activity through time*
- ✓ *periodicity*
 - ⇒ *20-30 Ma for Wal*
 - ⇒ *> 15 Ma for Hav*
- ✓ *origin?*
 - ⇒ *pulsation of the plume*
 - ⇒ *tilt of the plume caused by drifting of the over*
- ✓ *other insights of this*
 - ⇒ *study of other long*
 - Louisville (Pacific)*
 - Ninety East ridge (Indian Ocean)*



⇒ Discussion

❖ Information provided by the temporal evolution of Q_v and Q_s :

- ✓ *common characteristics feature: “pulsation of the plumes”*
- ✓ *no “classical” plume behavior*
- ✓ *peak in Q_v at 10 Ma: the only correlation existing between St. Helena and Walvis*
- ✓ *Q_v trend ⇒ variation of the plume activity through time*
 - ⇒ *decrease of the Walvis plume activity*
 - ⇒ *increase of the Hawaii plume activity*

❖ Information provided by swells morphology:

- ✓ *two plumes at the origin of the St. Helena chain*
- ✓ *confirmation of the existence of the Circe hotspot*
- ✓ *problem with the chain tracks deduced from rotation poles*

⇒ Discussion

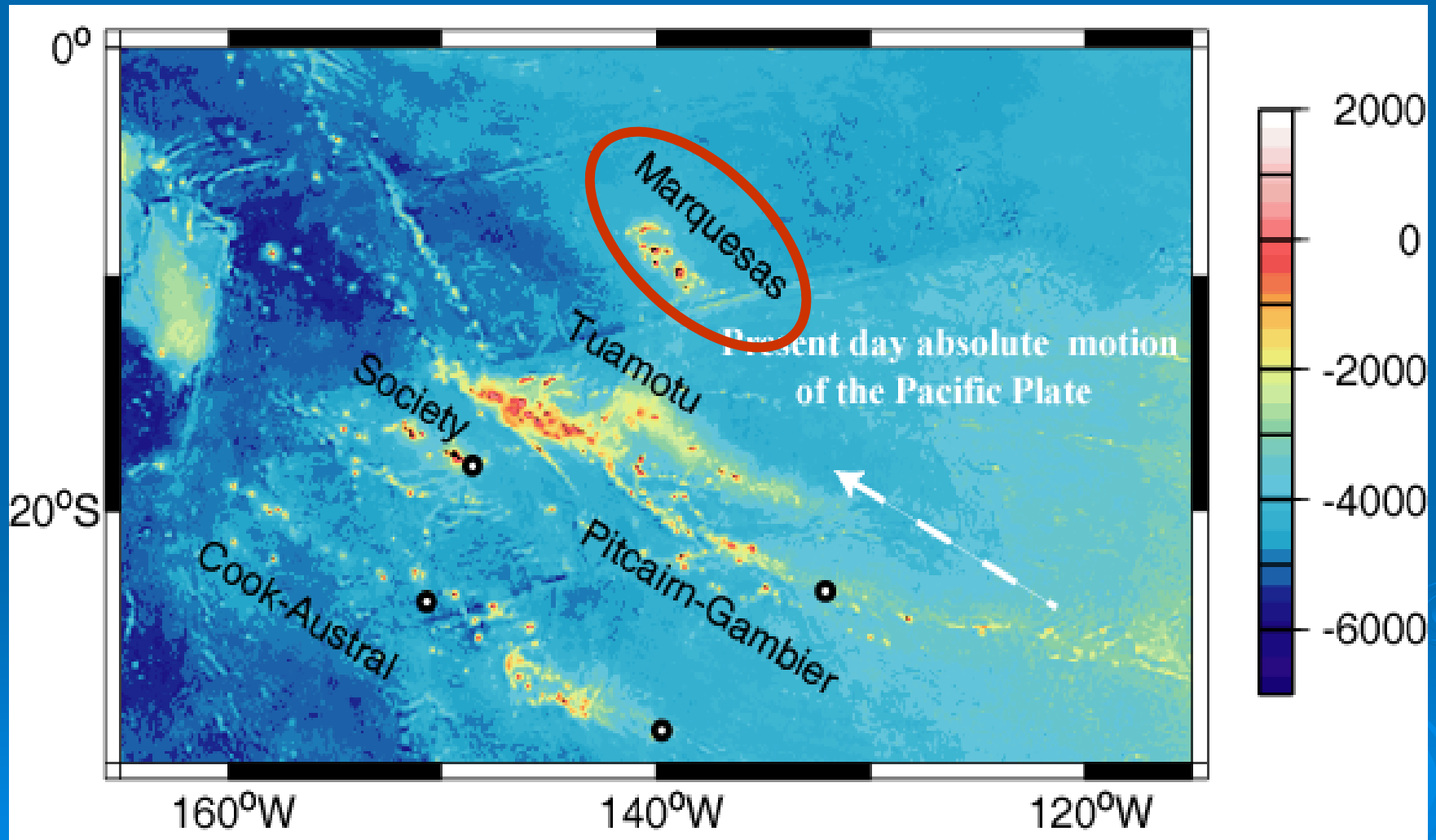
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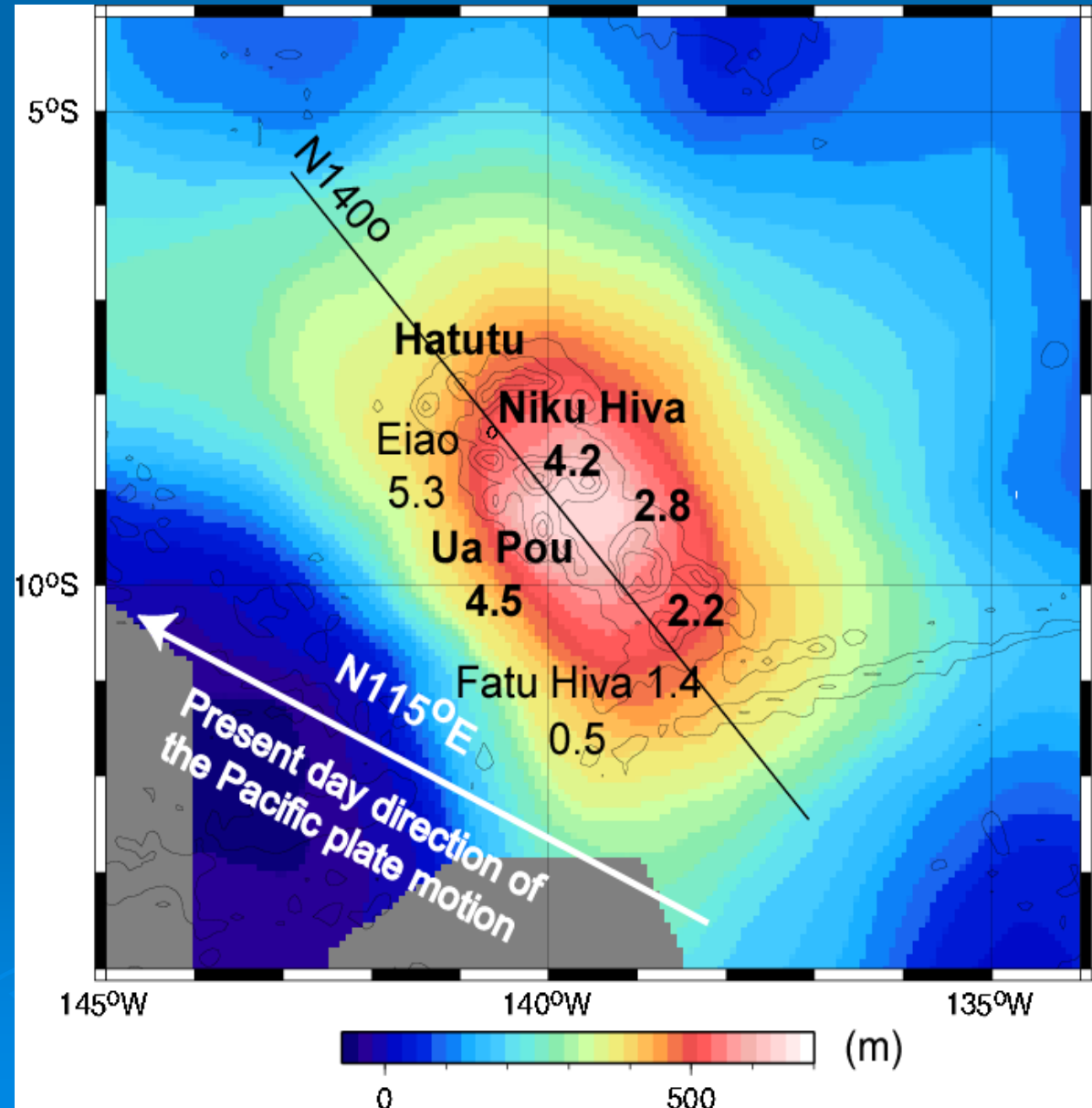
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⇒ Marquesas



The Marquesas swell

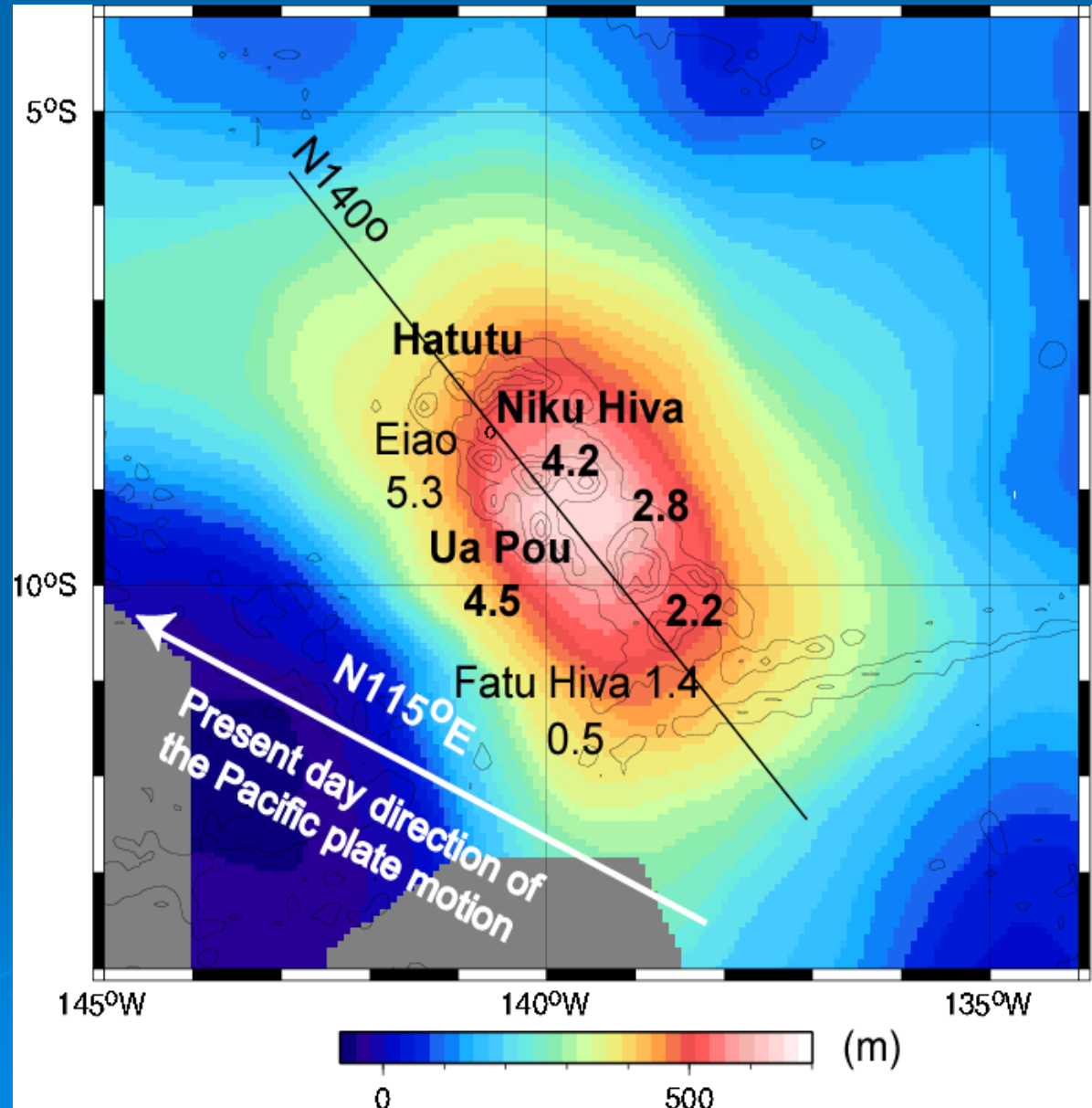
*chain direction \neq
direction of
plate motion*



The Marquesas swell

*chain direction \neq
direction of
plate motion*

underplating



Marquesas: the geoid anomaly

