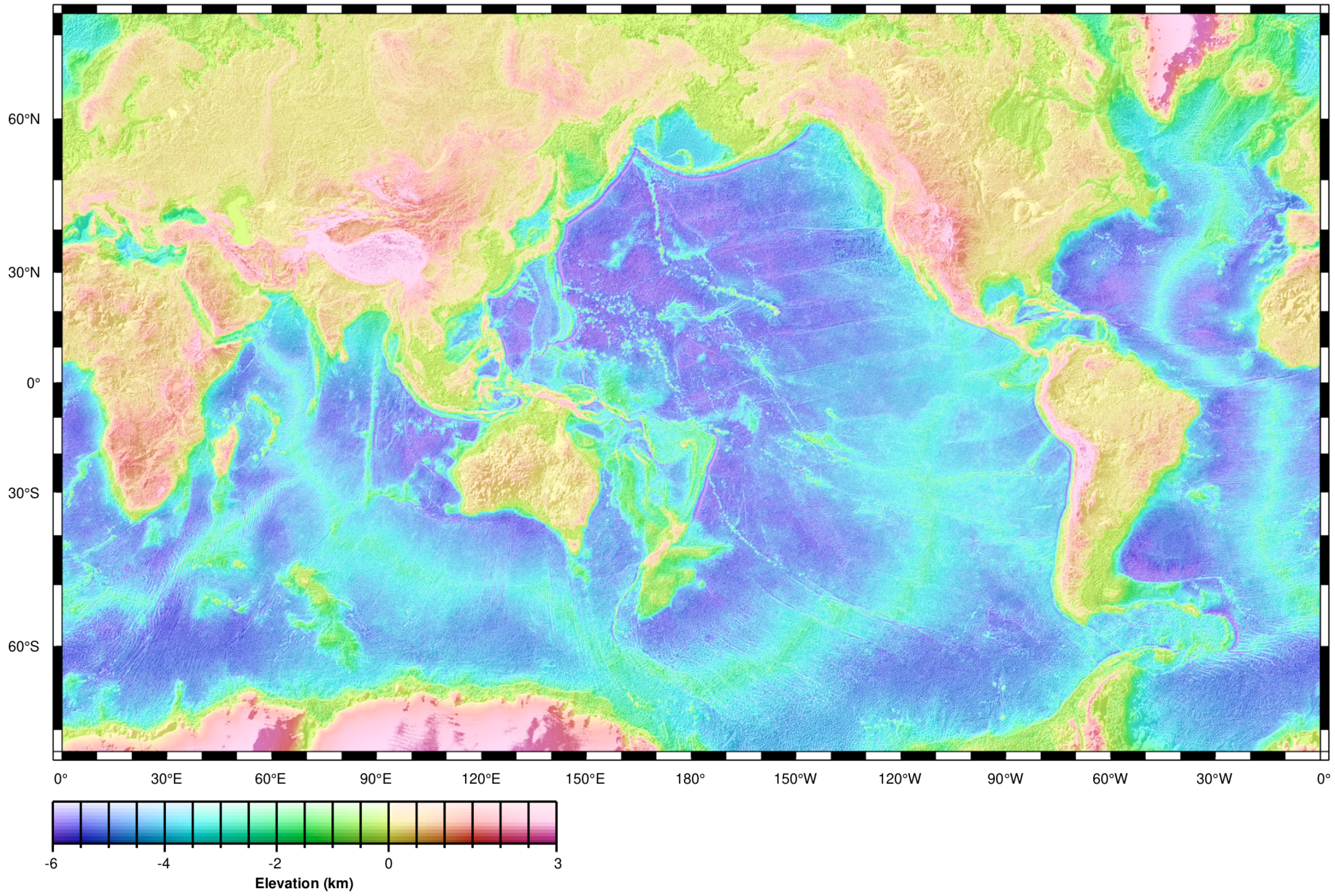
Lecture 6: Hot spots, seamounts, and ridges

The topography and geology of the seafloor offers some of the only clues we have to understanding the hidden workings of the mantle below. We have discussed some of the largest features of ocean basins, and today we consider the small seamounts and their critical role in this story.

- Plumes, stationary or not?
- Axial depth vs melt chemistry
- Trace elements and isotopes in MORB vs OIB

We acknowledge and respect the lək̓ʷəŋən peoples on whose traditional territory the university stands and the Songhees, Esquimalt and W̱SÁNEĆ peoples whose historical relationships with the land continue to this day.

Features of the seafloor



The source of lavas must be deep

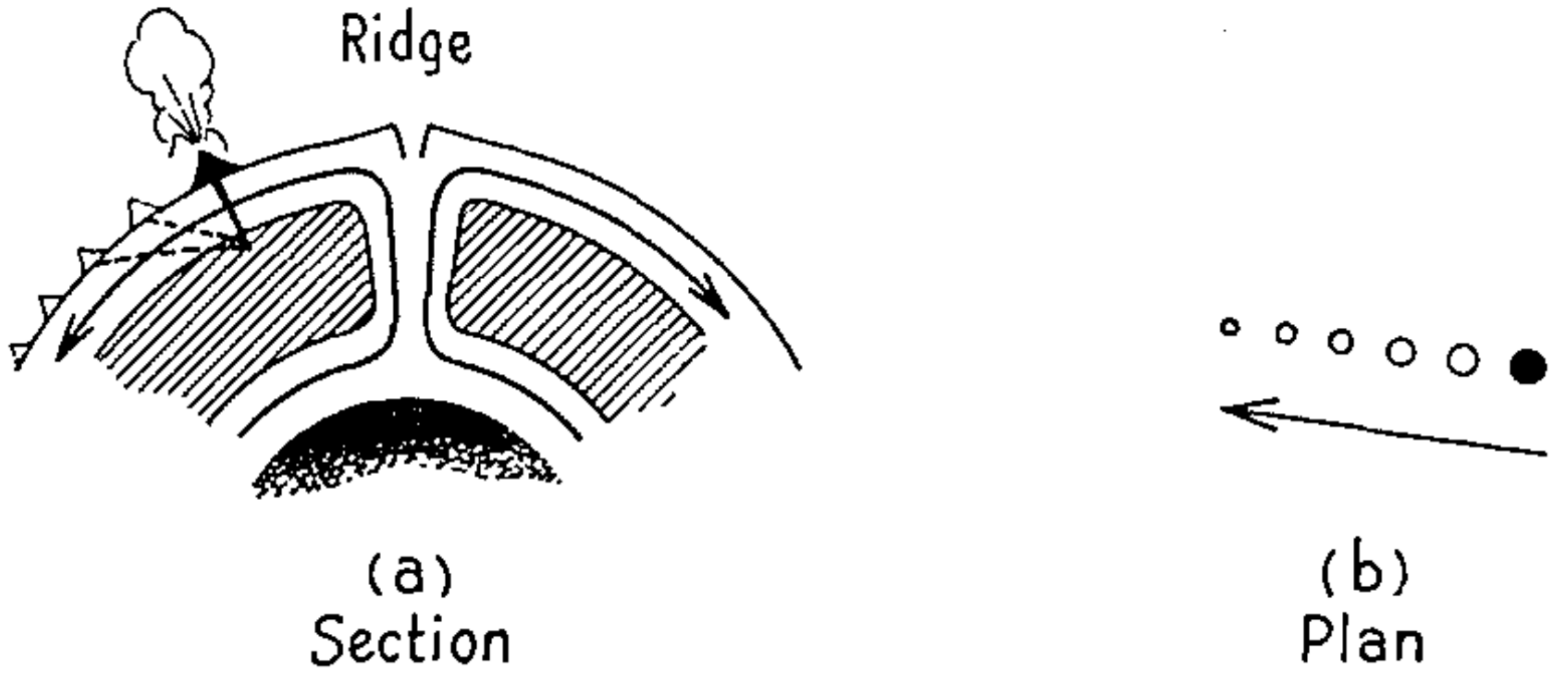
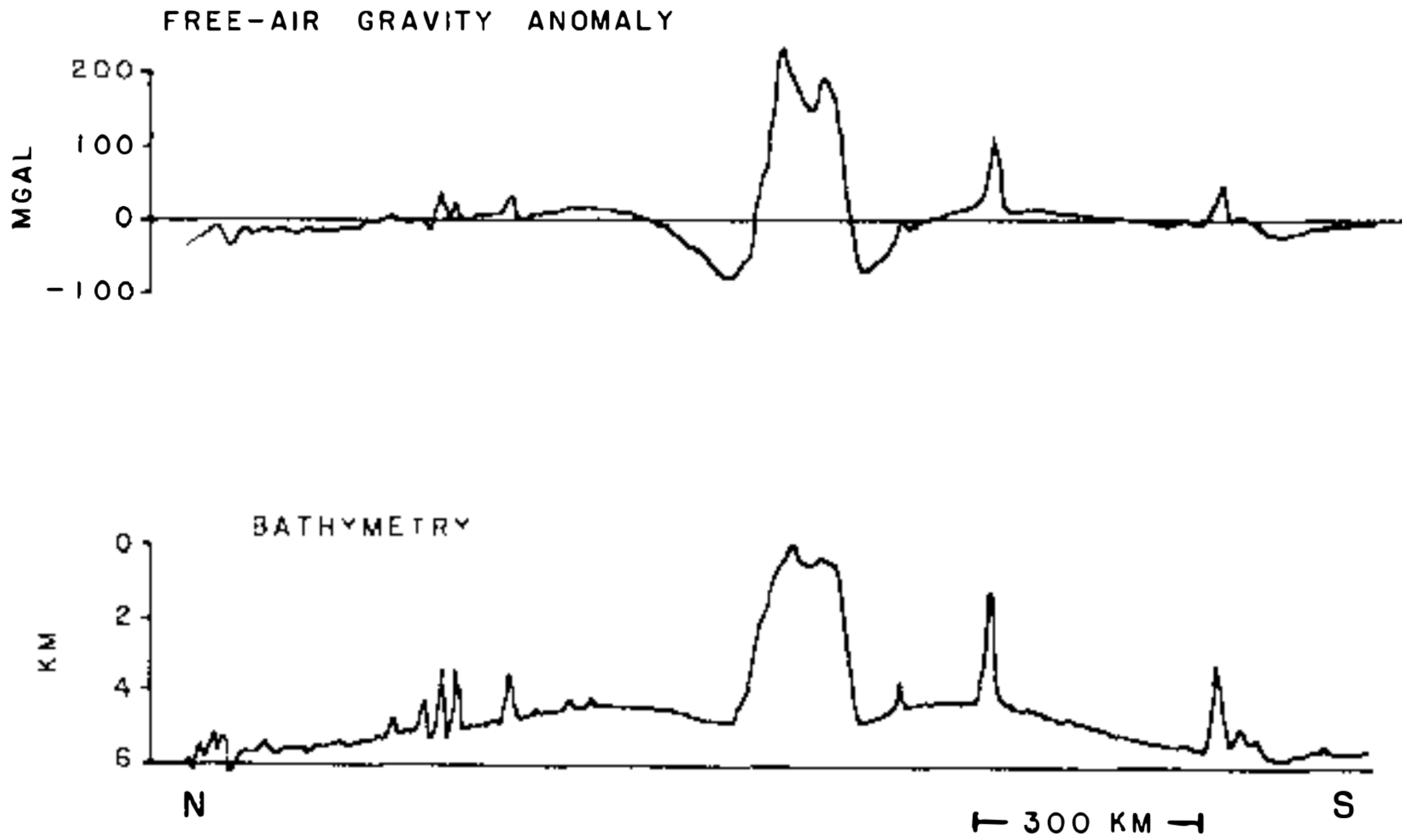


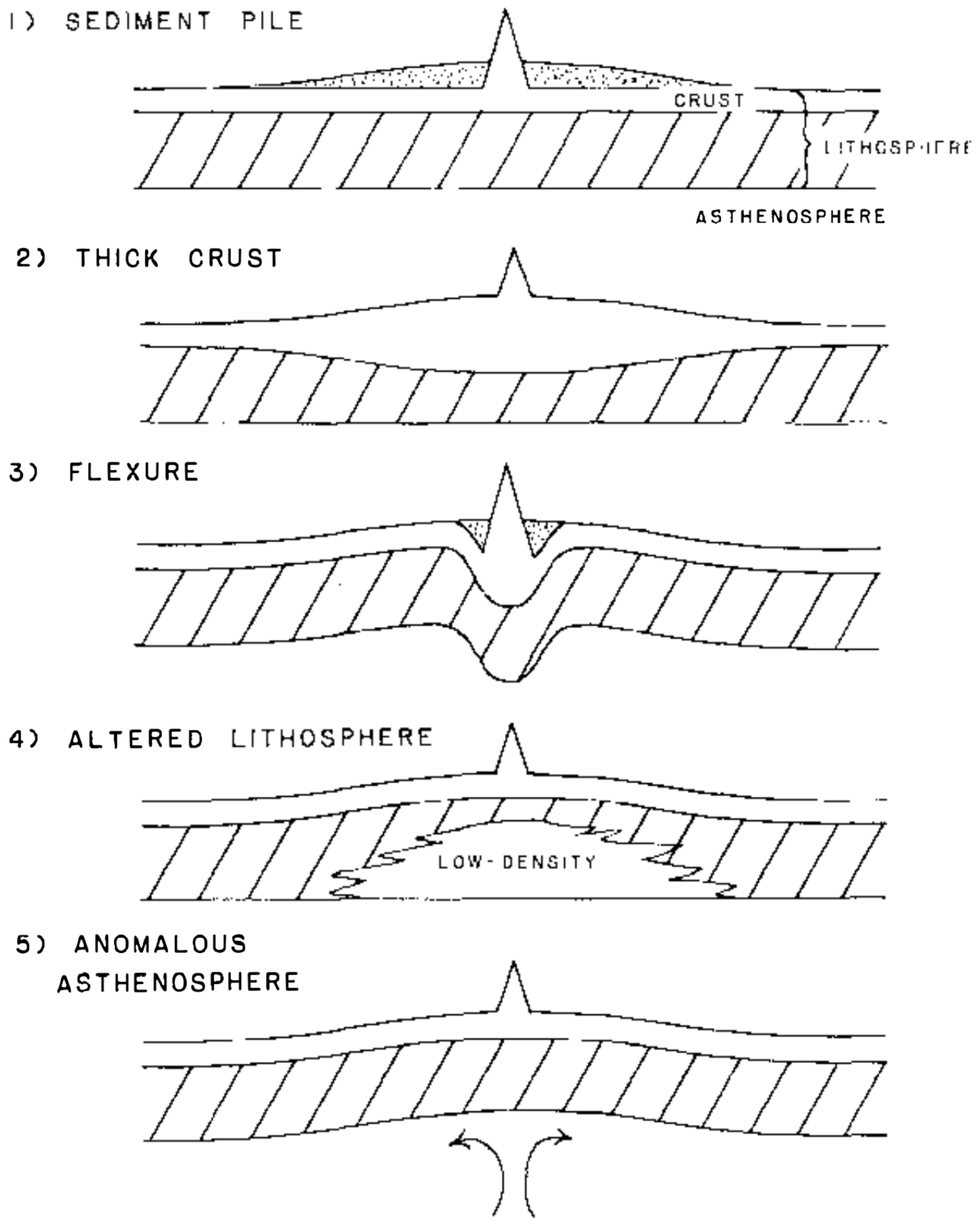
FIG. 5. Diagram to illustrate that if lava is generated in the stable core of a convection cell, and the surface is carried by the jet stream, then one source can give rise to a chain of extinct volcanoes even if the source is not over a rising current. This is proposed as a possible origin of the Hawaiian chain of islands.

Swells and depth anomalies

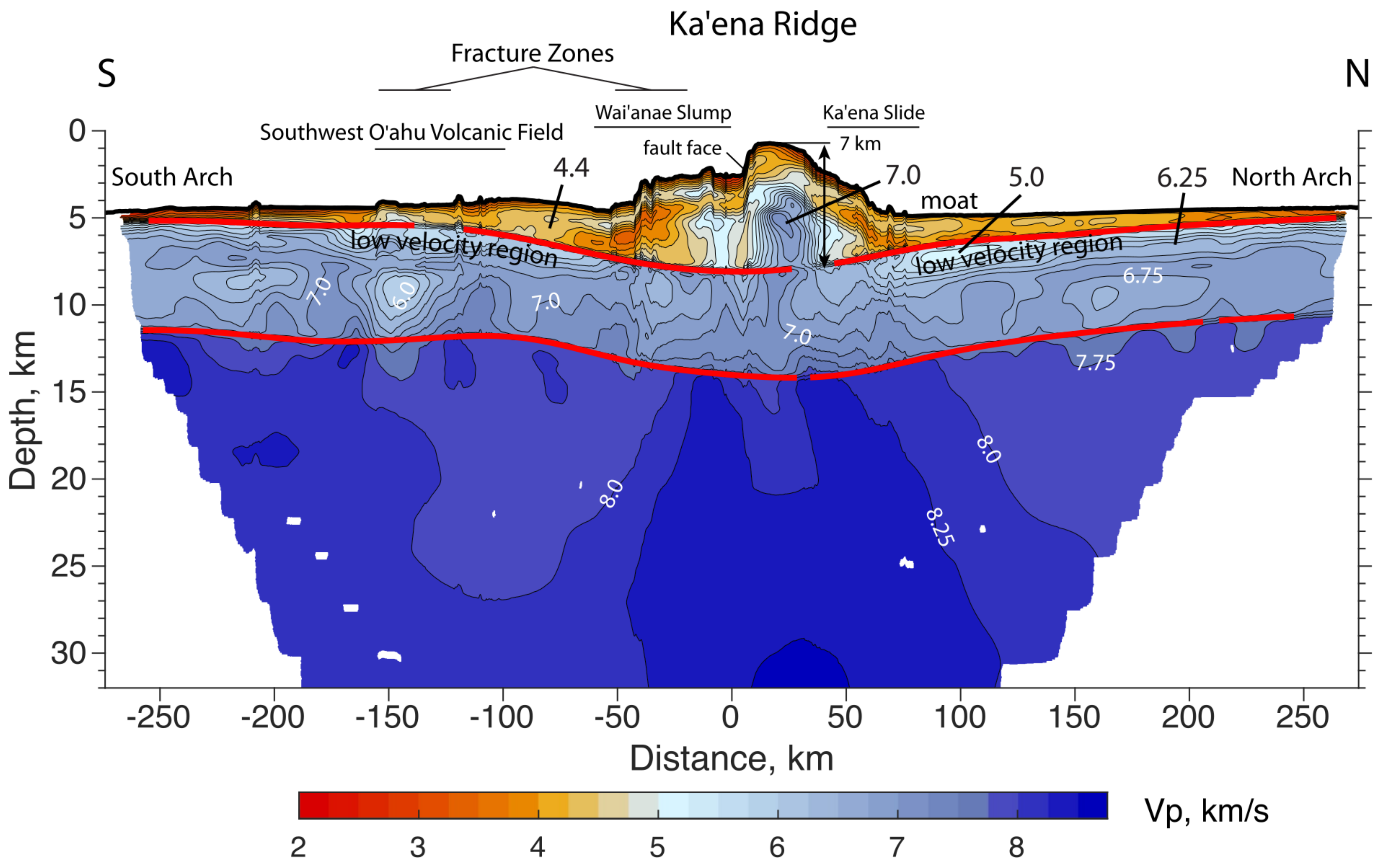


Transects across Hawaii (Crough 1983)

How are swells supported?

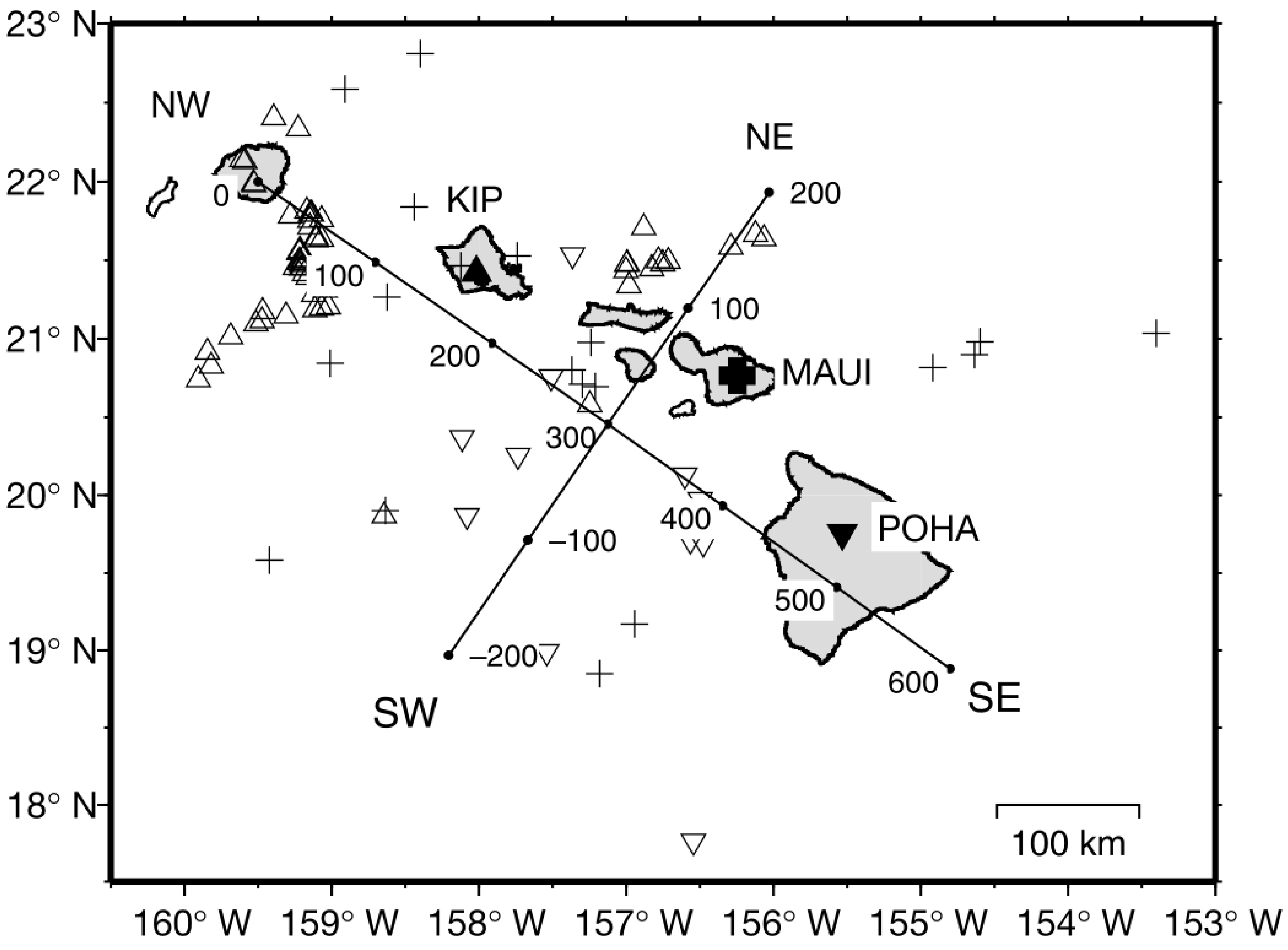


Constant crustal thickness



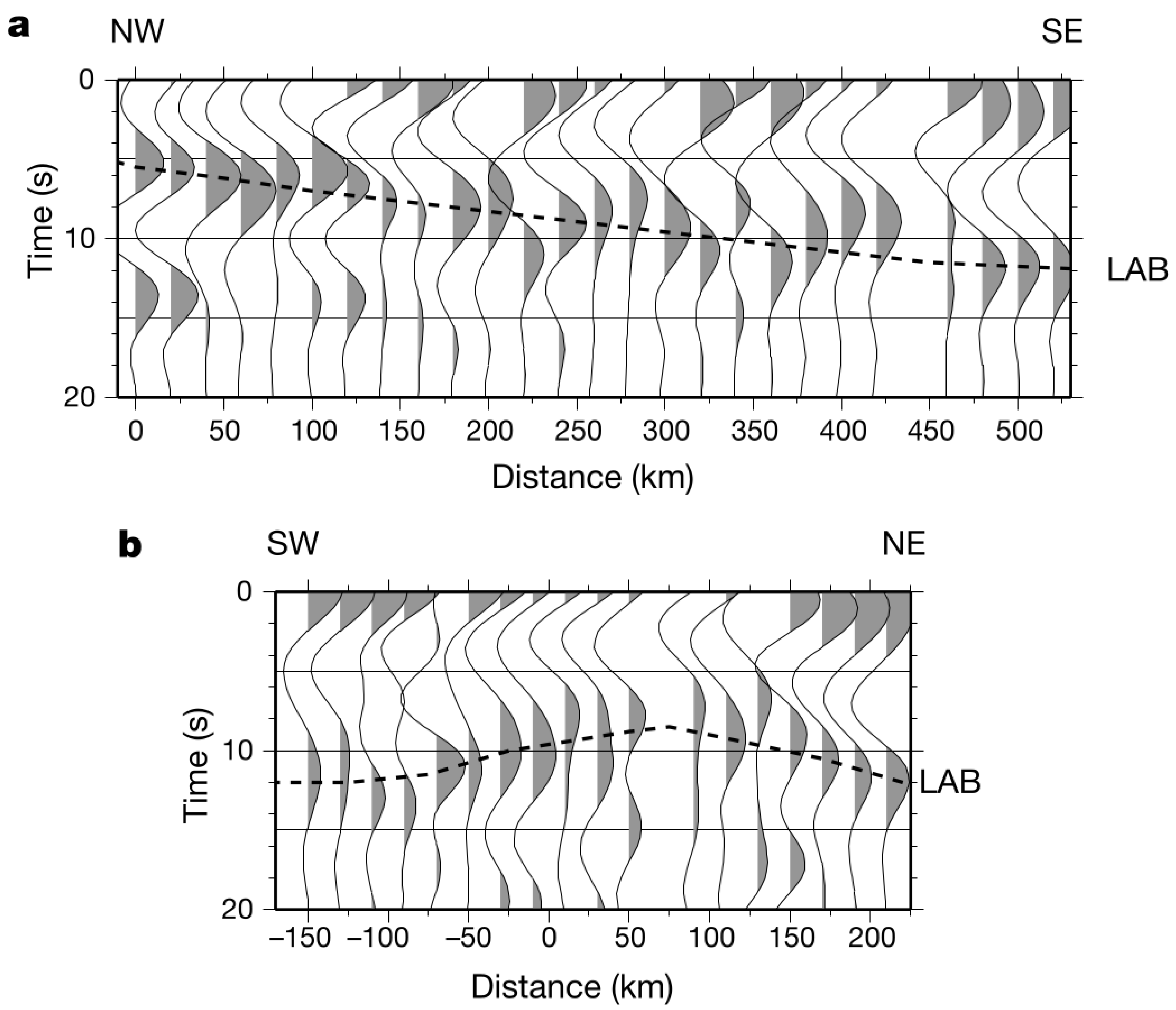
Dunn et. al. 2024

Are swells actually supported by thinner lithosphere?



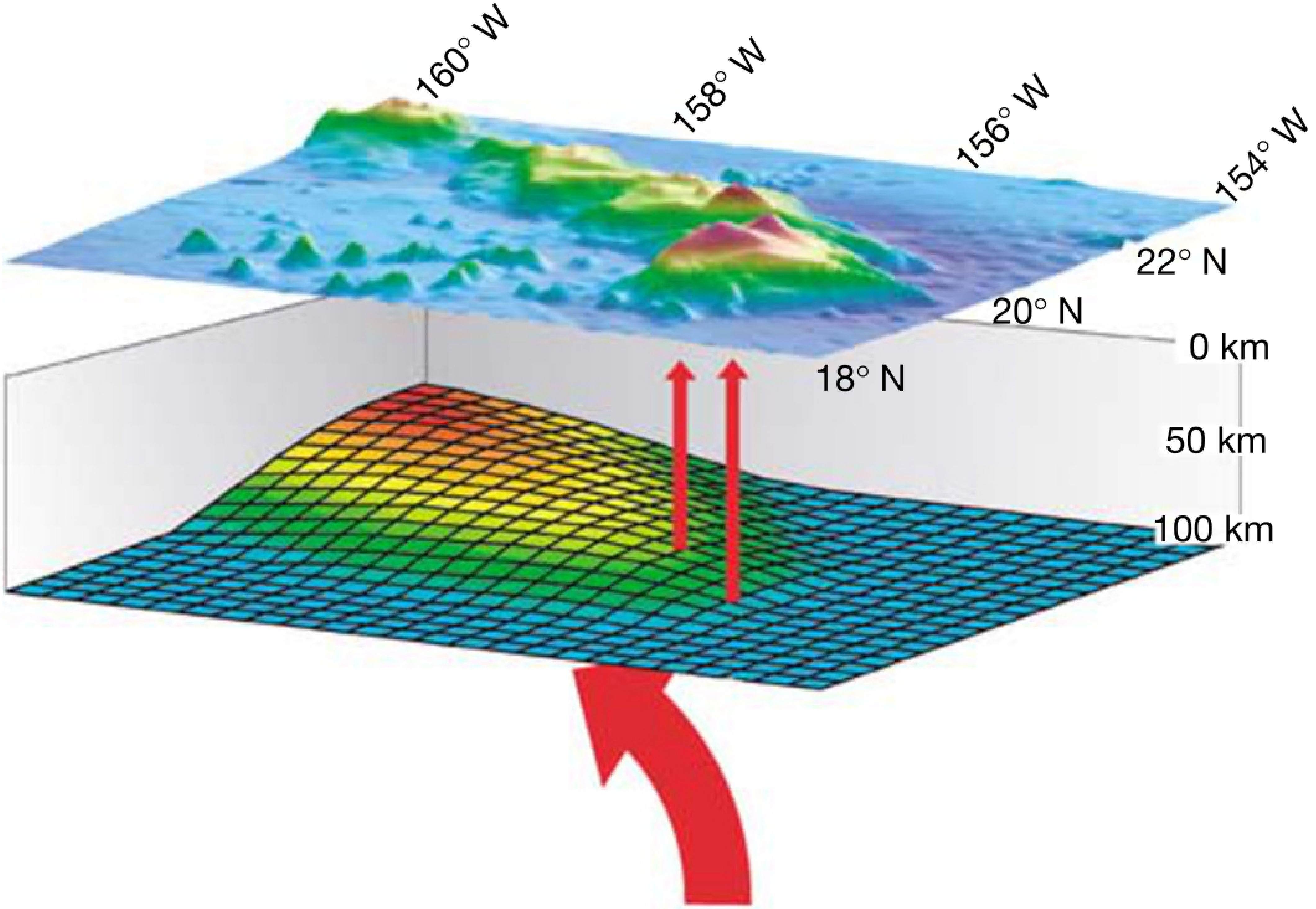
Lee et. al. 2004

Are swells actually supported by thinner lithosphere?



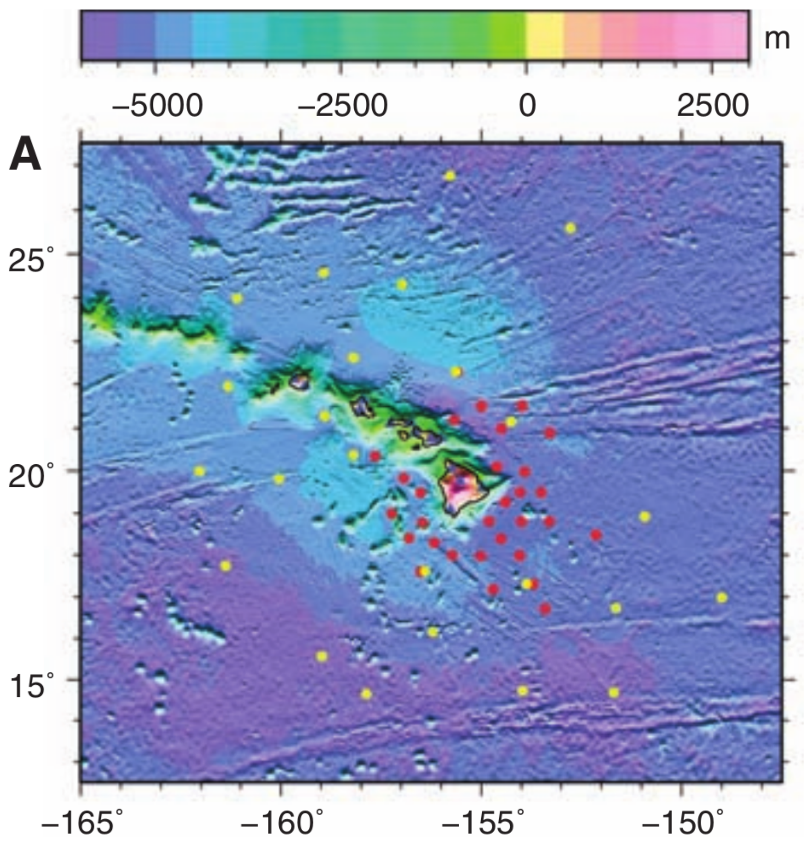
Lee et. al. 2004

Are swells actually supported by thinner lithosphere?



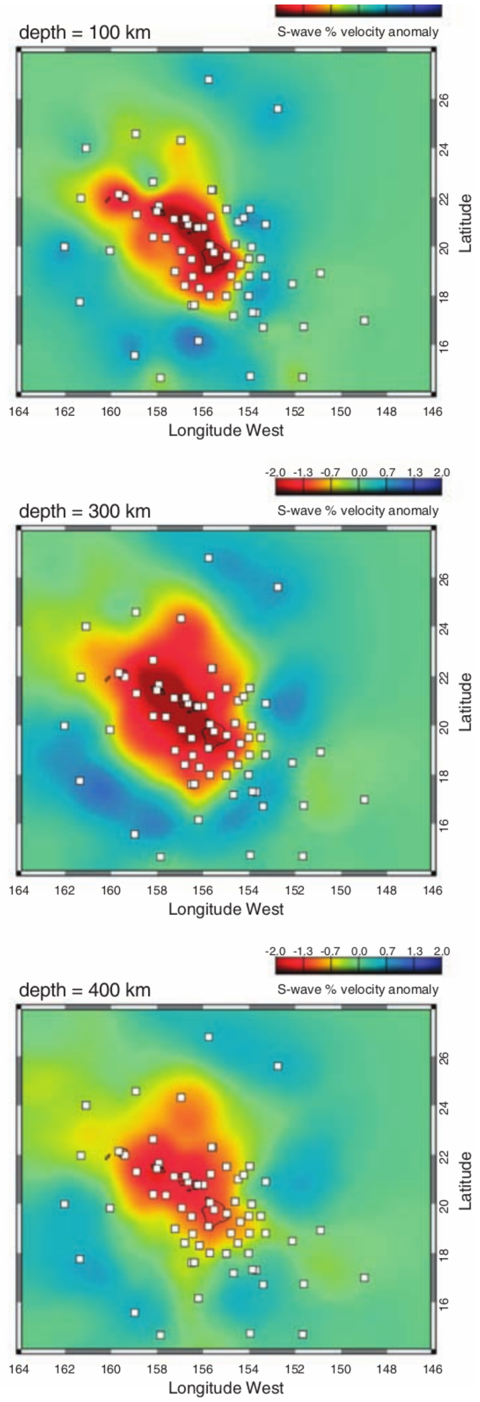
Lee et. al. 2004

The PLUME experiment



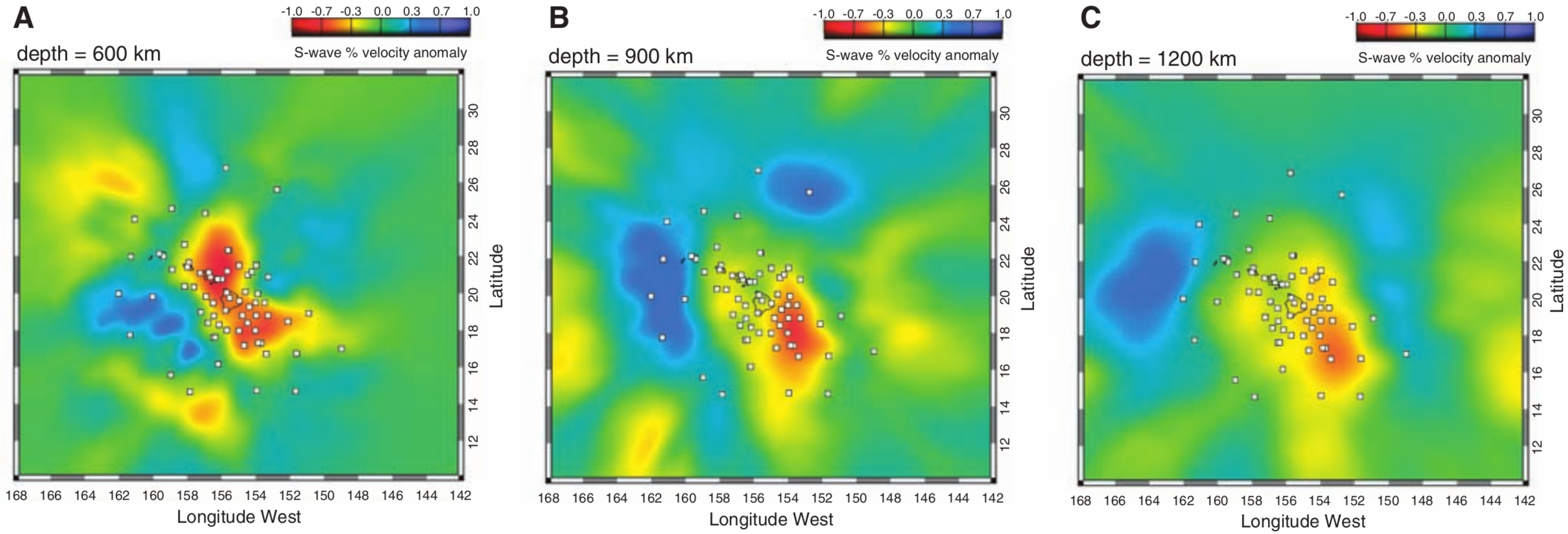
Seismic station network locations (Wolfe et. al. 2009)

The PLUME experiment



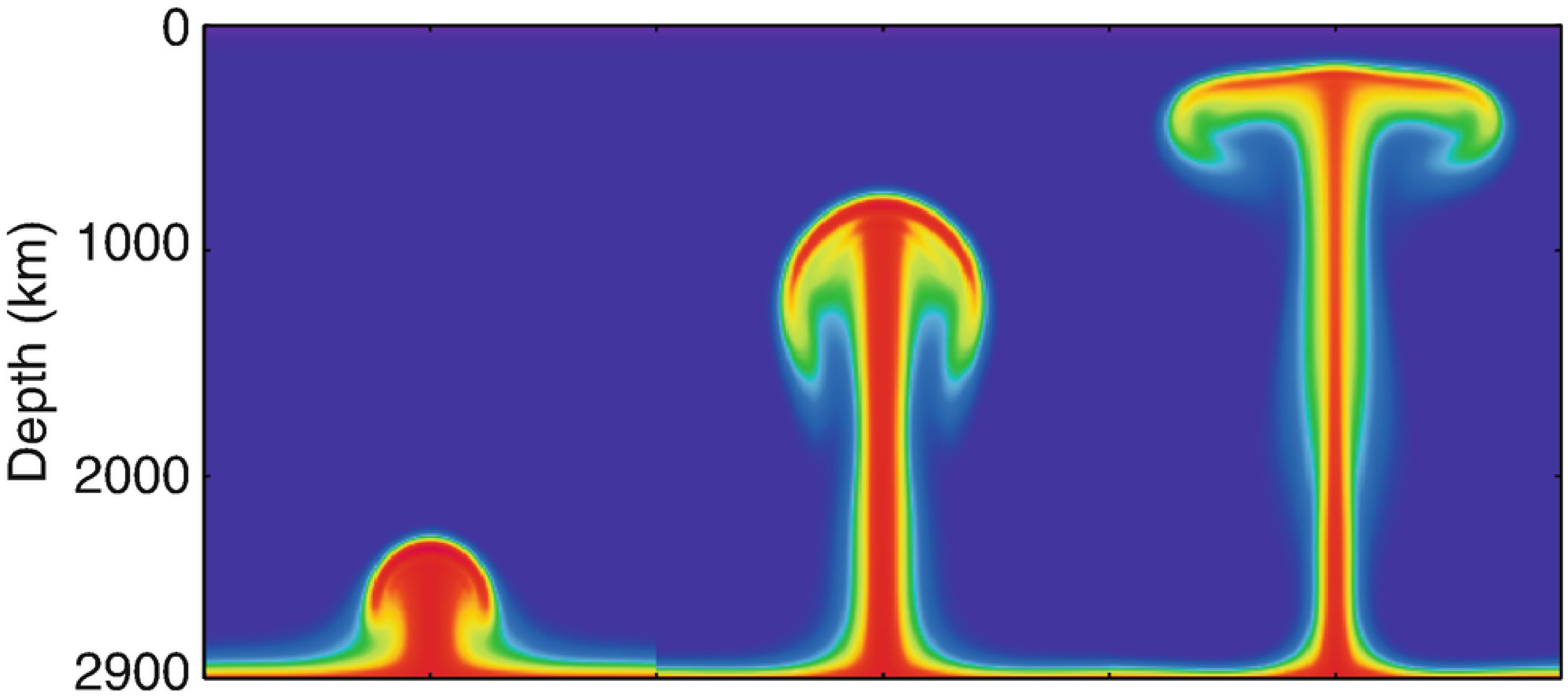
S-wave anomalies (Wolfe et. al. 2009)

The PLUME experiment



S-wave anomalies (Wolfe et. al. 2009)

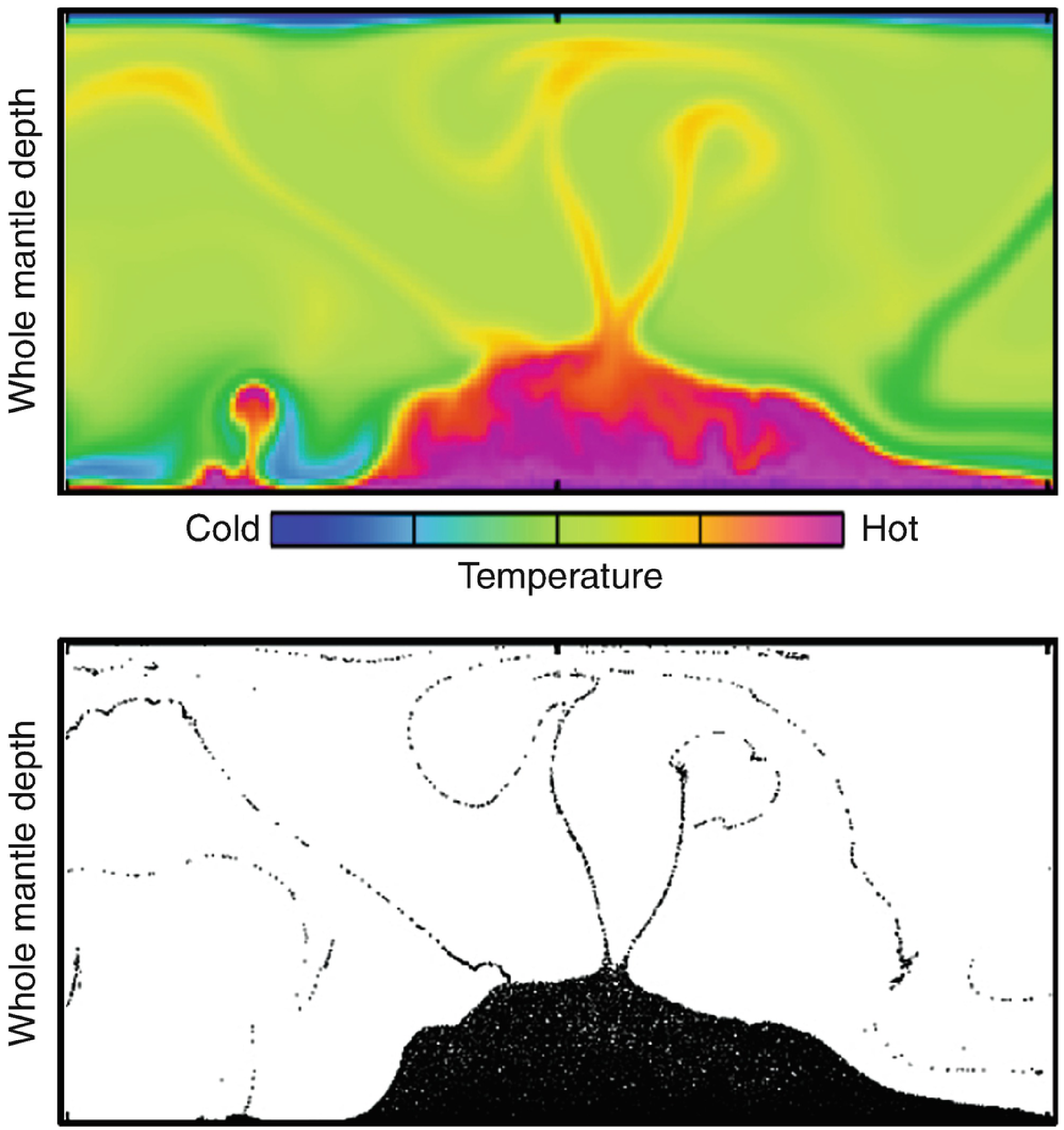
Thermal Plume simulations



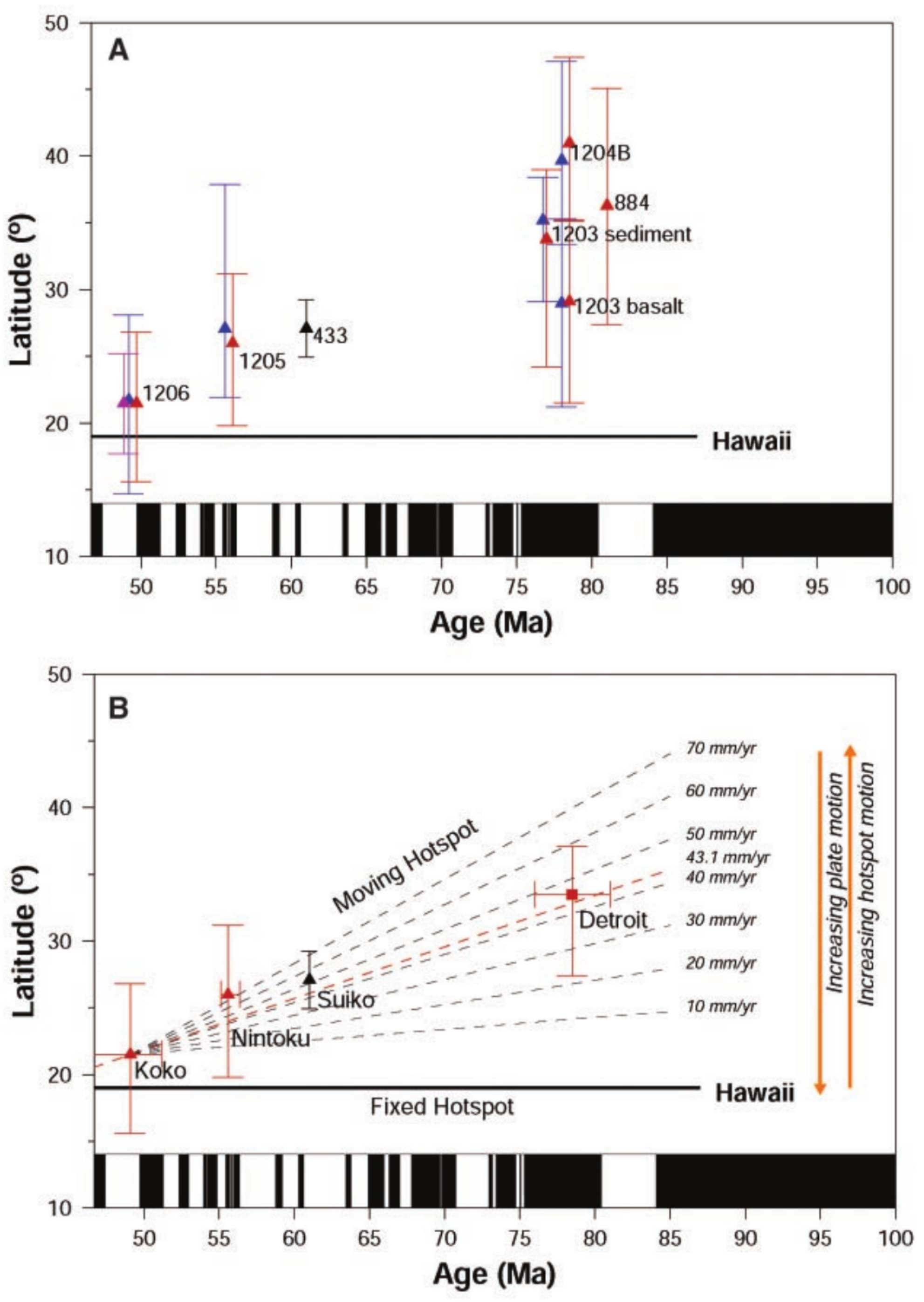
Breaking the mold

- Ages:
  - Bioko: active
  - Pricipe: ~6 Ma
  - Sao Tome: ~1-3 Ma
  - Continental volcanos: ~1-3 Ma

Thermochemical plumes

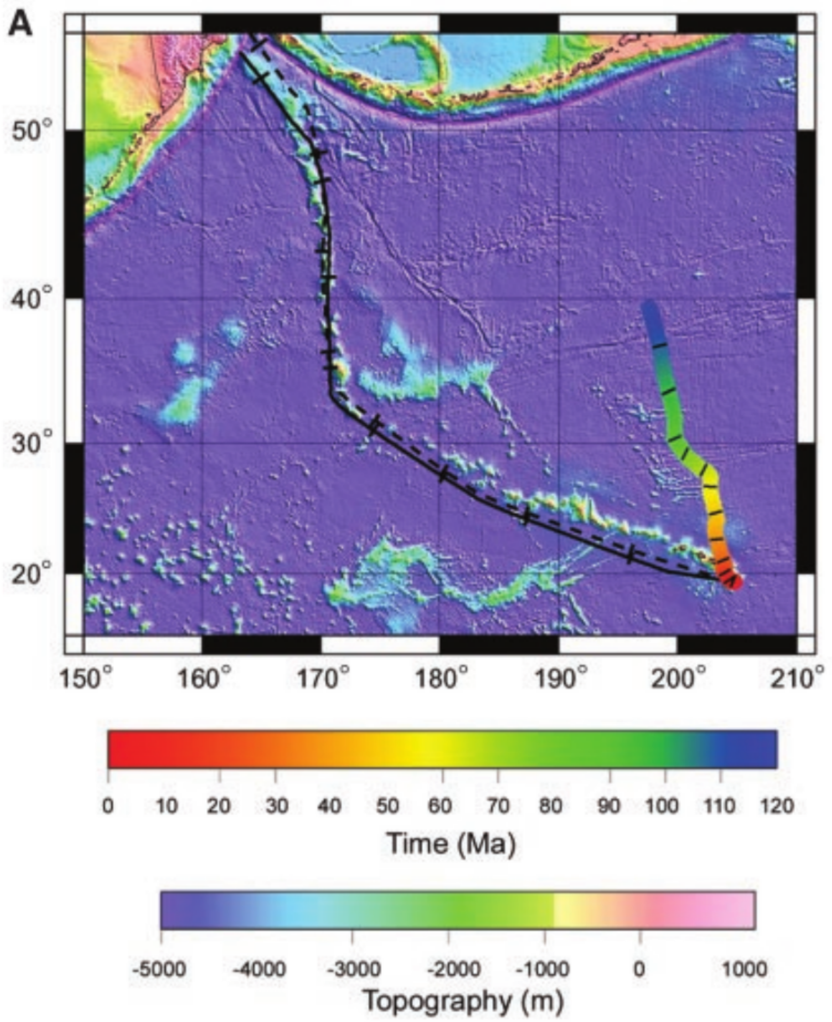


Are plumes stationary?



Tarduno et. al. 2003

Are plumes stationary?



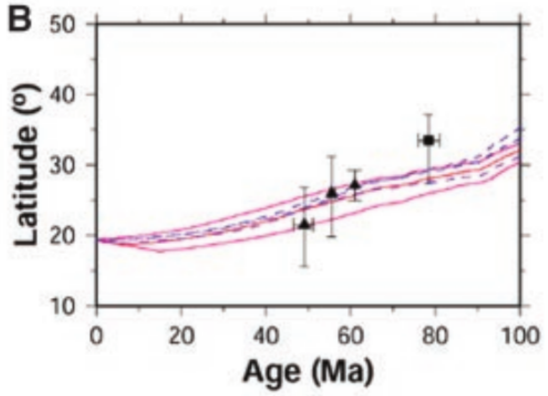
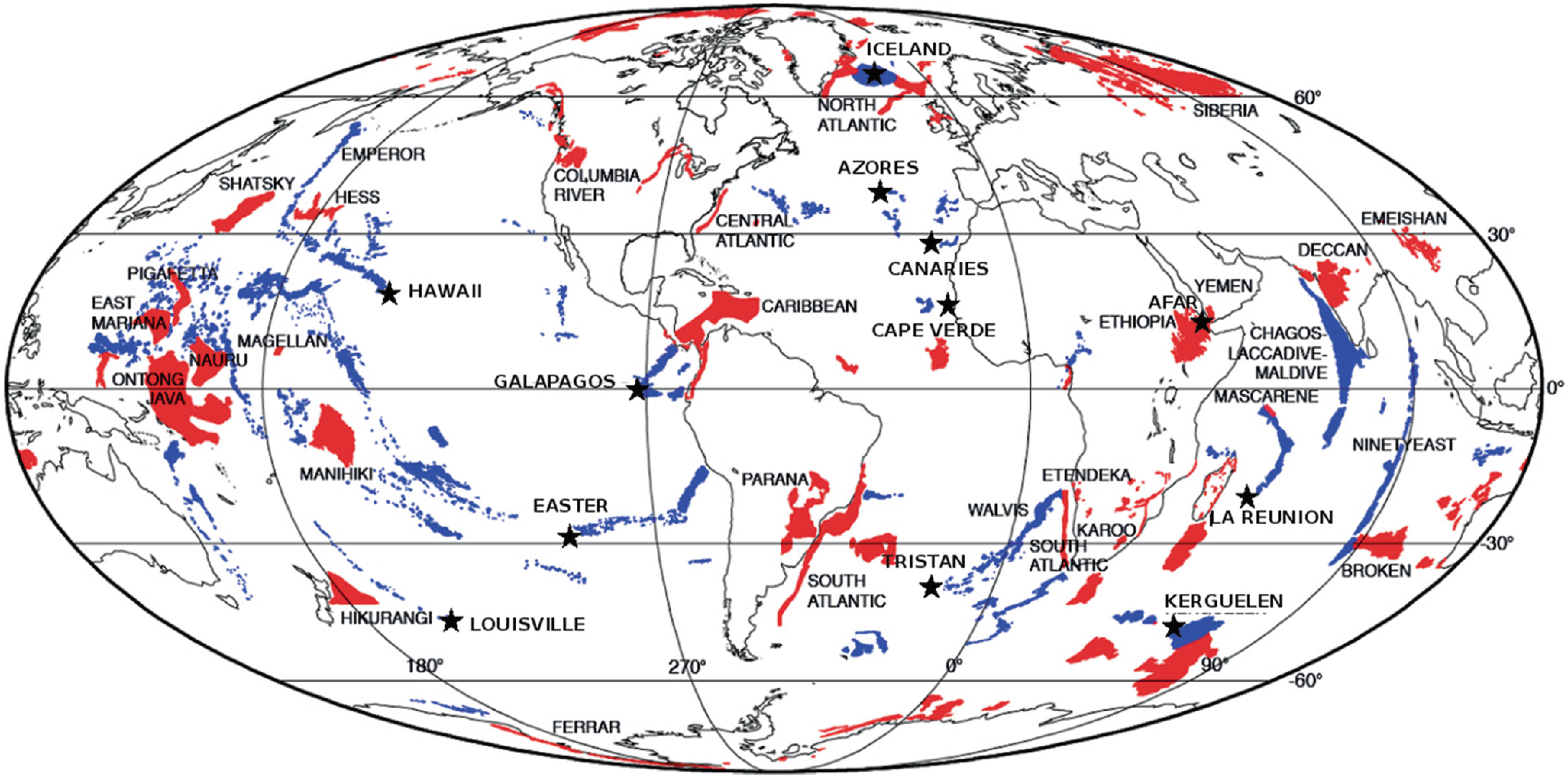


Fig. 4. (**A**) Computed Hawaiian hotspot motion for fixed-source model (colored line), and tracks for fixed-source models (continuous line; plume initiation at 160 Ma) and moving-source models (dashed line; plume initiation at 170 Ma). Tickmark interval is 10 Ma for both. (**B**) Computed changes of hotspot latitude for fixed-source plume model (*13*) (continuous red lines) for plume-initiation ages of 150, 160, and 170 Ma (upper to lower). Moving-source model (*13*) results (dashed purple lines) are shown for plume initiation at 180, 170, and 160 Ma (upper to lower). Paleolatitude means for Koko, Nintoku, Suiko, and Detroit Seamounts (Fig. 3) are also shown.

Tarduno et. al. 2003

Large igneous provinces and flood basalts



What can hotspots tell us about the mantle?

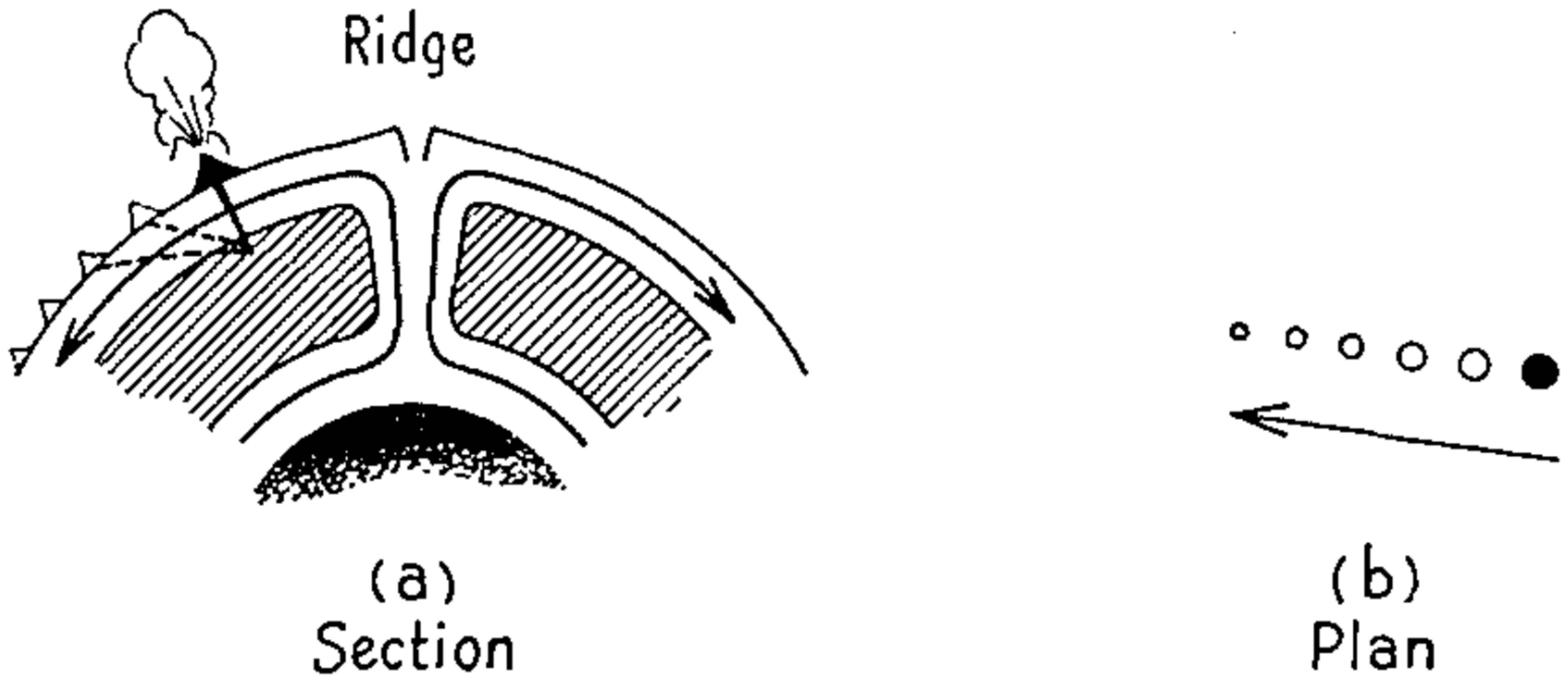
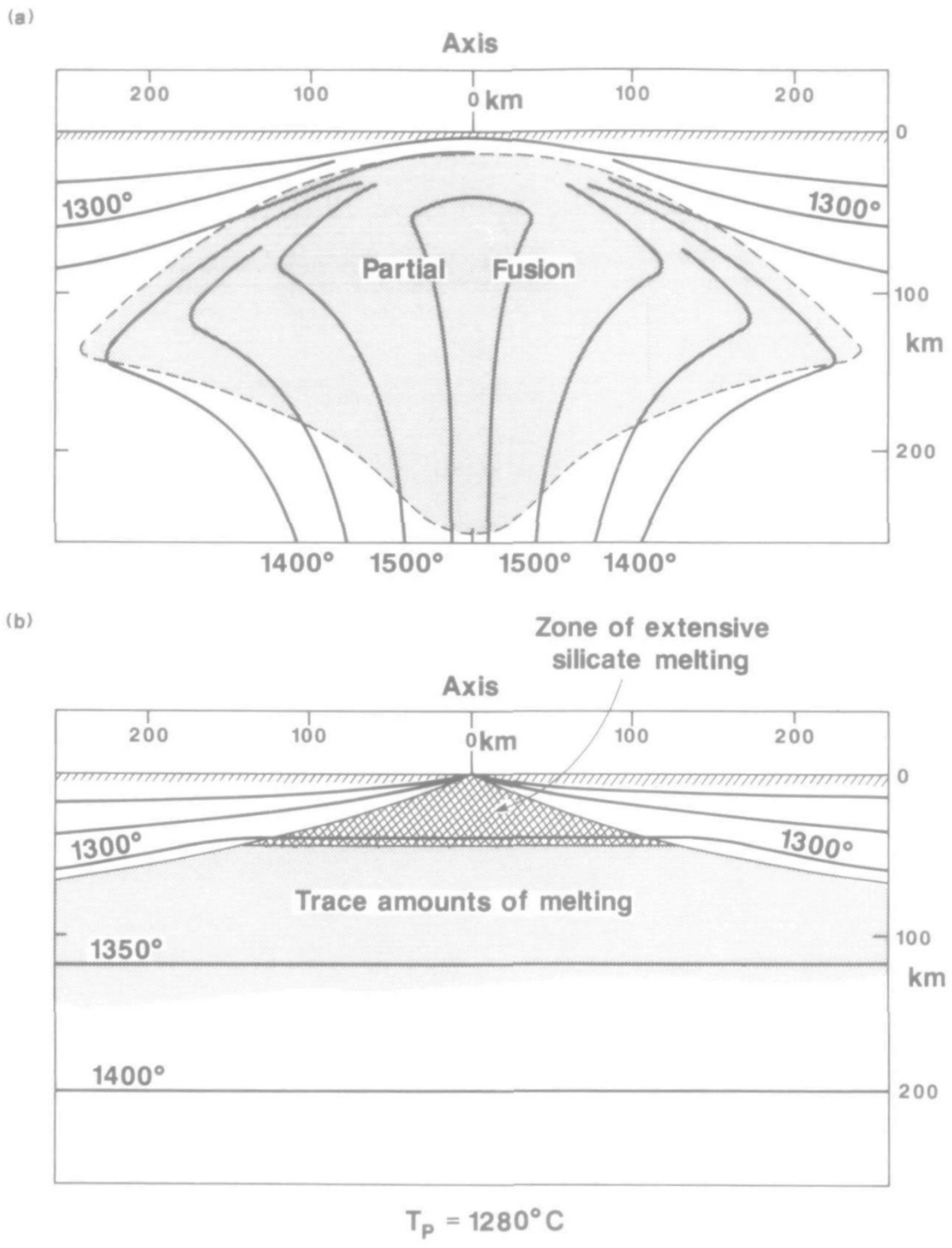


FIG. 5. Diagram to illustrate that if lava is generated in the stable core of a convection cell, and the surface is carried by the jet stream, then one source can give rise to a chain of extinct volcanoes even if the source is not over a rising current. This is proposed as a possible origin of the Hawaiian chain of islands.

Are ridges passive or active?



- Ridges move with respect to a reference frame (what reference frame??)
- What happens when a ridge is offset by a transform fault?
- Challenges posed by these questions are solved if the ridge system is the result of spreading plates
- Melting is a passive process driven by spreading, not driven by hot sheets of rising mantle

Basalt chemistry tells us about process at depth: example from MORB

"The temperature and flow regime of the mantle should, in part, control the extent of partial melting that the mantle undergoes as it ascends beneath ocean ridges. The extent of melting should, in turn, govern both the chemistry of ocean ridge basalts and the thickness of the oceanic crust. Crustal thickness, to first order, should be related through isostatic compensation to the zero-age depth of ocean ridges. Thus, variations in ocean ridge basalt chemistry, axial depth, and crustal thickness should correlate with each other and with mantle temperature variations."

Klein and Langmuir, *Global Correlations of Ocean Ridge Basalt Chemistry with Axial Depth and Crustal Thickness*, 1987

- Why would zero-age depth and chemistry correlate?
- Geochemistry review:
    - What trends in MgO content of melt do you expect with increasing melt fraction? (think about minerals in peridotite)
    - What trends in NaO content of melt do you expect with increasing melt fraction? (sodium behaves like an **incompatible** trace element)

Potential temperatures

In our daily lives we have an intuitive understanding that a hot object generally has more heat content (enthalpy) than the same object after it cools. This intuition is less useful when considering materials on Earth (rocks, air, water) that are moving quickly across pressure gradients.

The *first law of thermodynamics* can be stated as:

$$\begin{array}{ccccc} dQ & = & dU & + & PdV \\ change\ in\ heat & = & change\ in\ internal\ energy & + & work\ done\ on\ the\ environm \end{array}$$

where dV is the change in volume, and P is the pressure. When considering **adiabatic** processes, where there is no change in *heat*, $dQ = 0$, we find that the temperature of a material changes due to work done by the system.

$$\begin{array}{ccccc} dQ & = & dU & + & PdV \\ 0 & = & C_v dT & + & PdV \\ & & C_v dT & = & -PdV \end{array}$$

C_v = heat capacity at constant volume

Potential temperatures

$$\begin{aligned} dQ &= dU + PdV \\ 0 &= C_v dT + PdV \\ C_v dT &= -PdV \end{aligned}$$

So when the volume change is positive (expansion), dT must be negative (cooling). Alternatively if we considered the case of constant volume, using $PdV = -\frac{VdP}{\gamma}$, then decreases in pressure lead to decreases in temperature (γ is a positive ratio of the specific heat for the material at constant pressure and constant volume).

The potential temperature, T_p, is the temperature defined at a reference pressure, and it allows us to use our **daily** intuition about temperature when considering the energy (heat content) in a parcel of rock, water, or air. Potential temperatures of the mantle control the starting point for melting during adiabatic decompression.

Axial depth, crustal thickness, and melting

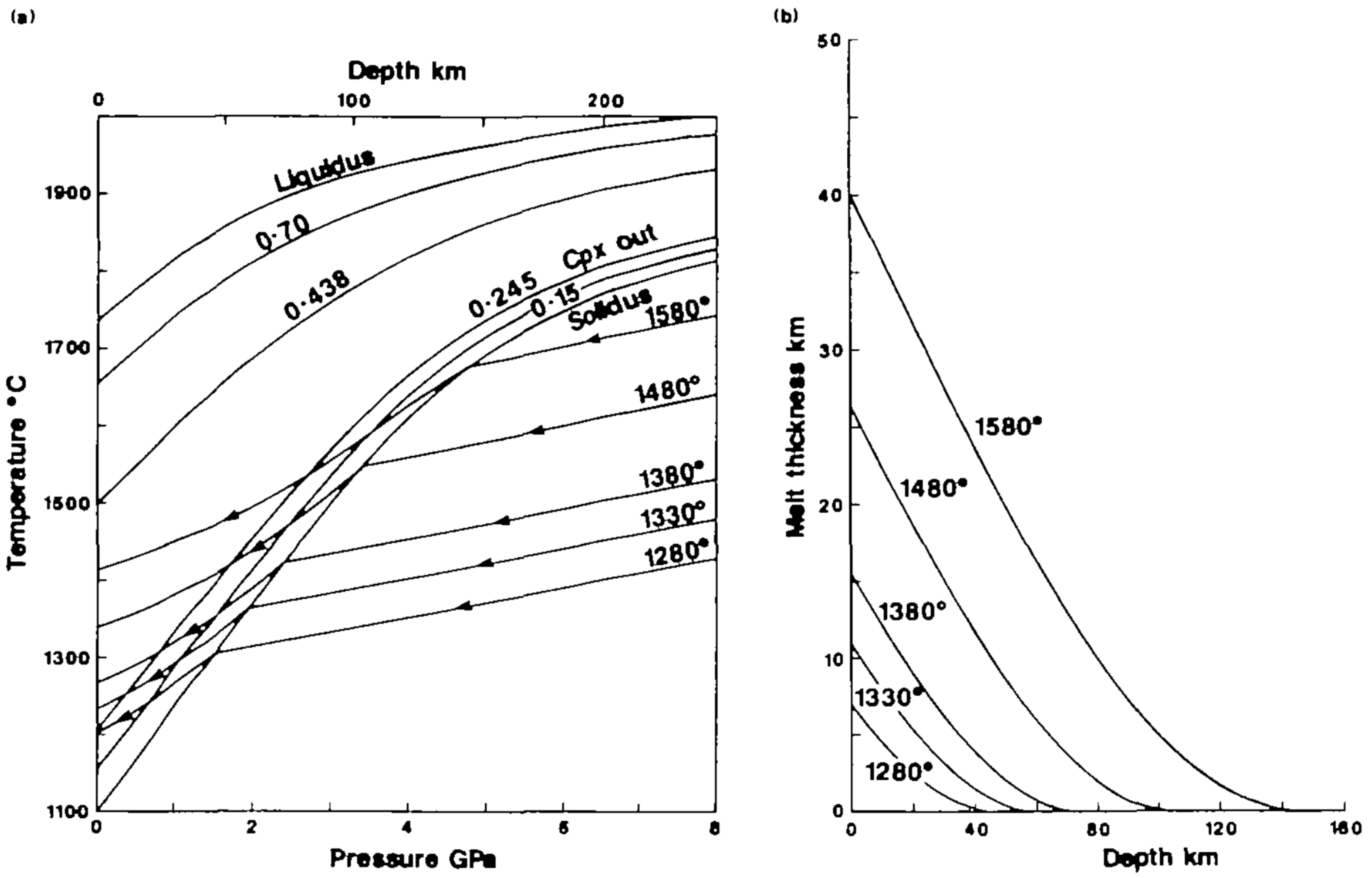
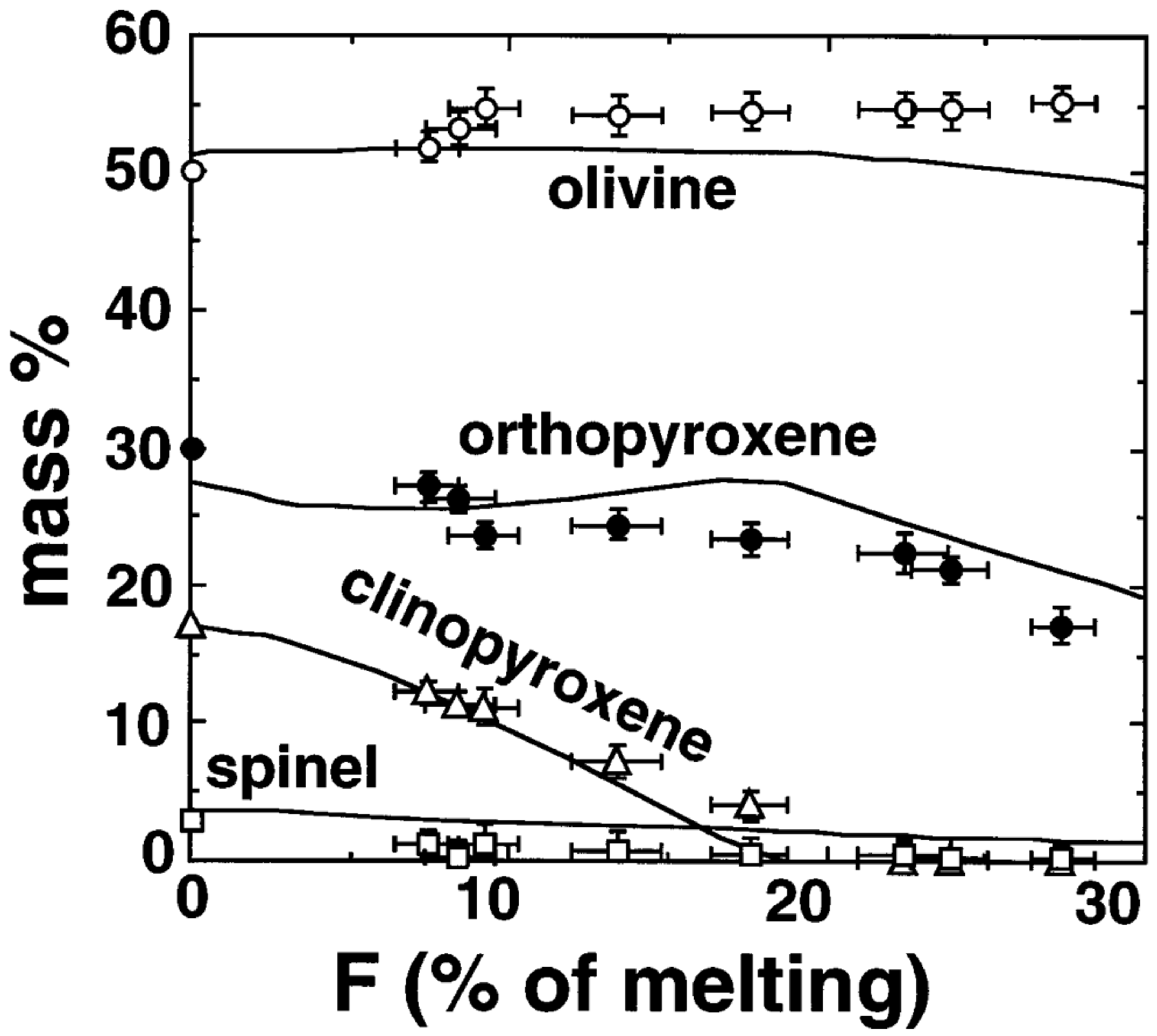


FIG 7 (a) Adiabatic decompression paths calculated using the equations given by McKenzie (1984*a*) Appendix D, a fourth order Runge–Kutta scheme and

$$\Delta S = 250\ \mathrm{J\ kg^{-1}\ {}^{\circ}C^{-1}}.$$

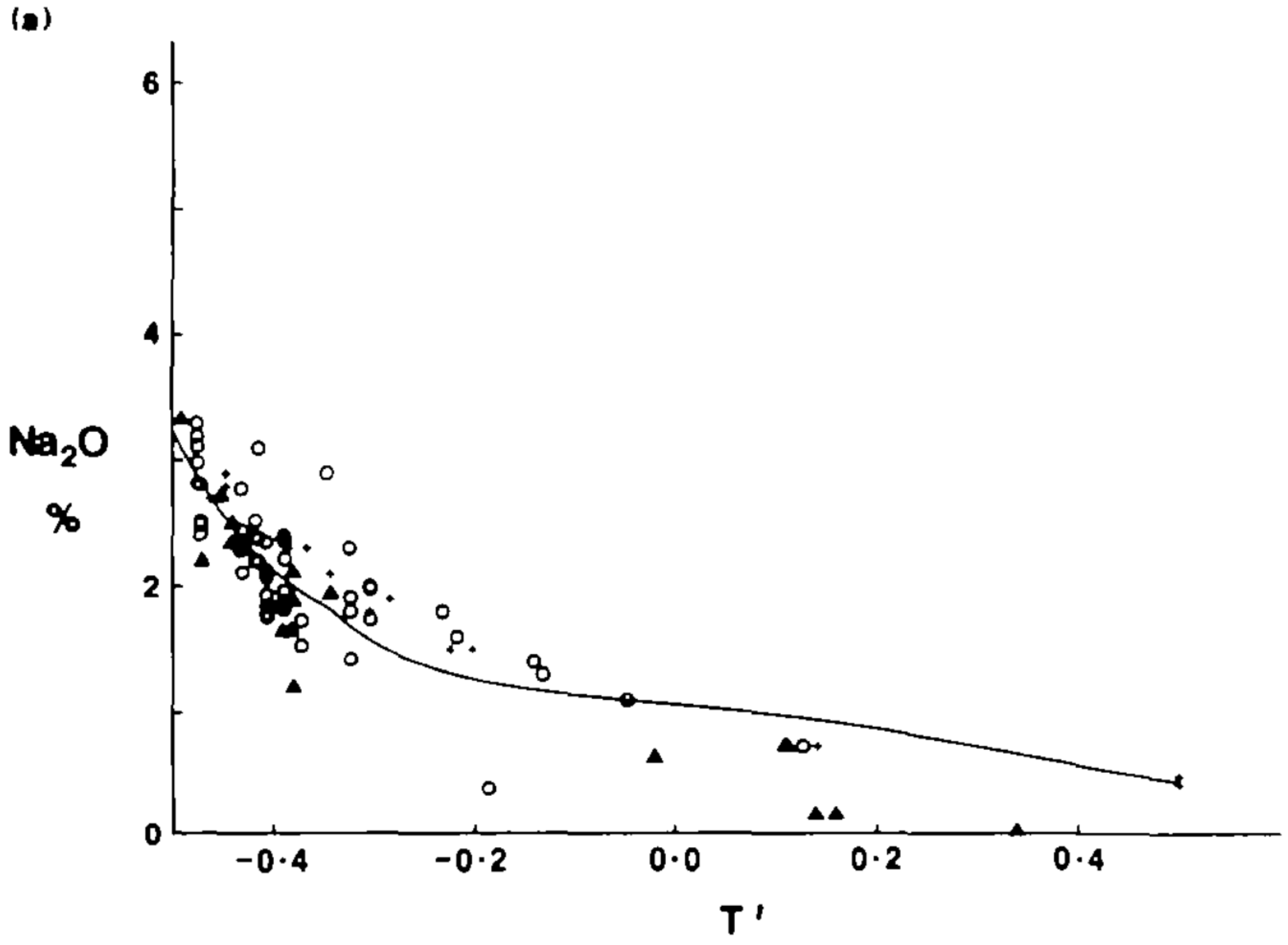
The curves are labelled with their potential temperatures, and entropy is conserved to 1 part in 10^4 during the numerical integration. The curves between the solidus and the liquidus are labelled with the melt fraction by weight. (b) The total thickness of melt present below a given depth plotted as a function of depth, calculated by integrating the volume of melt present in (a).

Melting peridotite



Peridotite melting experiments

(-0.5 is the solidus, 0.5 is the liquidus)



Peridotite melting experiments

(-0.5 is the solidus, 0.5 is the liquidus)