The Cooling Oceanic Lithosphere as Constrained by Surface Wave Dispersion Data

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A: Introduction

Why look at Data and not the Model?

The tremendous improvement in resolution capabilities of global surface wave phase velocity maps now encourage us to search for anomalies that are caused by mantle plumes. On the other hand, the implications of even large-scale anomalies in such maps are still not well understood. One such anomaly is caused by the cooling oceanic lithosphere. Some studies investigate the cooling effects by fitting thermal models to the 3-dimensional mantle models resulting from tomographic inversion. The inversion of surface wave data for structure at depth is non-unique and the model often depends on the technique applied. We prefer to compare the dispersion data directly with predictions from thermal models.

B: The SQRT(Age)-Signal in the Data

Summary: Simple cooling models produce a signal that is roughly proportional to the square root of age. This signal is typically much smaller than the one caused by lateral heterogeneity within the Earth’s crust and upper mantle. In a careful analysis we are able to extract clear, roughly linear trends, in all major oceans. Here we show the results for the Pacific Ocean.

C: Modelling

The Cooling Halfspace and the Cooling Plate Models

We explore the parameter space by fitting cooling half space as well as cooling plate models to the data. In the Pacific ocean, our data are inconsistent with standard parameters that are used to fit the observed bathymetry, and perhaps surface heat flux data. Instead of an initial temperature of 1350°C in the cooling half space model our data require a lower temperature (around 1200°C) to be well fit, especially the Love wave data. Regarding the cooling plate model, our data seem to require a thicker lithosphere to be well fit (135 km instead of the standard 100 km).

D: The Signal in the other Oceans

We observe similar trends for the other oceans investigated: the Indian Ocean, the South and North Atlantic Oceans. For the Indian Ocean in particular, a crust correction is crucial to obtain an internally consistent data set. After this correction, the sqrt(age) slopes are very similar to the Pacific ones suggesting a similar cooling history. For the Atlantic ocean, a large signal remains unexplained. The Rayleigh data in the South Atlantic Ocean exhibit quite small slopes that contradict this implication. It is also true that the sqrt(age) resolution of our Love wave maps is somewhat poor in the Atlantic (due to lower data density as well as lower spreading rates) perhaps hampering an analysis.

Observations:

- large lateral heterogeneity mutes a possible age-dependent signal in the phase velocity maps
- we therefore average the data into age bins (sqrt(age) = 0.5)
- we bin the data as function of sqrt(age) rather than age because the distribution over sqrt(age) is more uniform (i.e. statistically more robust)
- the data level off after a certain age, this is inconsistent with a cooling halfspace that would cause a linear trend, a similar observation was made by Scilker and others in the bathymetry
- for this includes that the halfspace model is too simple, e.g. two-stage heating could be present
- the halfspace model to examine the parameter space of a cooling plate model that indeed predicts the overall behavior in our data (see modeling section)
- variations in crustal structure may bias observations (we use our crustal model CRUST2.0)
- the uppermost age of the tectonic age signal (there is no such constraint in the CRUST2.0) also caused a leveling off as function of age and therefore enhances the signal in the raw data for unbiased models
- the signal from later cooling ages is not observable in our age map
- after crustal cooling, much of the leveling out is removed making our data less linear, but some signal remains

E: An Intriguing Anomaly in the North-East Pacific

The surface wave dispersion maps contain an intriguing oscillating signal (the “blue streak”) in Figure 1: that is particularly strong for Rayleigh waves in the Pacific Ocean. This signal is parallel to the EPR and is present at all periods but most pronounced at 17 Hz. A preliminary inversion for 3D structure does NOT restrict this anomaly to the upper lithosphere. In this case our observation may be caused by current convection processes. On the other hand, our inversion might map lithospheric structure in greater depth. In this case we would have to assume a shallow source for our observation and presence at the time the plates were formed (e.g. changes in spreading rates—still need to be checked) could be responsible ...

G: Is this Signal Real?

The data collected for this experiment were originally for a study in North America. Therefore the global data coverage is highly uneven. In fact, coverage in the Pacific Ocean is dominated by data in the Fiji-Californian domain. A concern therefore is that we map azimuthal anisotropy into our phase velocity anomalies. We have extensively tested this by including anisotropy. The anomaly diminishes but does not disappear. The reduction in magnitude may well be due to the fact that we introduce new trade-offs in the inversion.

We observe a real phenomenon. Of course, a local OBS study in the area would reliably strengthen (or refute) our case.

H: Summary

- on large scale, we don’t need anything spectacular other than a cooling plate to fit our data
- small scale, the Pacific Ocean is a fascinating object and has yet many secrets
- fun place to do OBS experiments!