Why does the convergence rate between Nazca and South America decrease since the Neogene?

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Introduction

The classic example of the not-well-understood rapid change of tectonic plate motion is the increase and then decrease of the convergence rate between the Nazca and South America plates during the past 25–20 m.y. that coincided with the growth of the Andes Mountains. Currently, the decrease in convergence rate is explained either by the increasing load of the Andes or by the appearance of flat slab segments beneath South America.

Here, we present an alternative view based on a thermomechanical self-consistent (gravity driven) model of Nazca plate subduction. We explain the changes in the convergence rate as a natural consequence of the Nazca plate penetration into the transition zone and lower mantle after long-term oblique subduction of the Farallon plate. The model is consistent with seismic tomographic images of the Nazca plate beneath South America. Our model also shows that the presence of the Andes does not significantly affect the convergence rate between the Nazca and South America plates.

Model setup

We used a version of SLIM-3D (Popov and Sobolev, 2008) with the following enhancements to simulate the evolution of a subducting slab up to shallower lower mantle (Quinteros et al., 2010):

- Elastic-visco-plastic rheology
- Diffusion, dissolution and Peierls creep mechanisms
- Real free surface
- Dive-in and spinel perovskite phase transitions (~4% and ~8% density increase)
- Gabbro-eclogite phase transition
- Dynamic, low-friction and low-velocity subduction channel

Facts

- Global reconstruction of plate velocities (after Müller et al., 2008). Subduction in central and northern Chile had a highly oblique (or parallel) component at least in the past ~95 m.y.
- The situation changed during the Oligocene, with the abrupt increment in convergence and the change in the direction of subduction, i.e., more perpendicular to the continent. At about the same time, the Cocos and Nazca plates formed from the splitting of the Farallon plate.

Two examples of evolution

Slab evolution in two experiments is shown below. The experiment in the left column best fits the convergence history (blue line in the left plot). Left (ref2–40S-500) is 40 m.y. old slab with +2.0 and +0.5 MPaK of Clapeyron slope at 410 and 660 km boundaries, respectively. Velocity is ~101.17 Pa in shallower lower mantle, and overiding velocity is 3 cm/My until 10 Ma, and 2 cm/My after that.

The setup for the right column experiment in right column includes a 40 m.y. old slab with +2.0 and +1.5 MPaK of Clapeyron slope at 410 and 660 km boundaries, respectively. Velocity is ~101.17Pa in shallower lower mantle, and overiding velocity is 3 cm/My. One can see that the combination of a young slab and a Clapeyron slope of +1.5 MPaK does not cause a strong reduction in subduction velocity. Our results are in full agreement with the seismic images of the Andes.

With or without Andes?

We also considered the effect of the thick crust and high topography of the Andes on the convergence rate between the plates. We repeated half of our models with an orogen similar to the Andes (20 km thick) and half without. The slab is then allowed to pull into the mantle transition zone and the lower mantle below this part of the South America plate.

Our experiments show that the increase and later decrease of the convergence velocity between the Farallon-Nazca and South America plates might be explained by the natural evolution of a slab, a large part of which has reached the mantle transition zone for the first time into the mantle transition zone and the lower mantle below this part of the South America plate. The slab first accelerates due to the increased slab pull in the mantle transition zone, and then slows down due to the resistance of the 670 km phase transition and highly viscous lower mantle. However, the presence of the Andes on the overriding plate does not explain the strong reduction in the subduction velocity. Our results are in full agreement with the seismic images of the Andes.

Conclusions

Our experiments show that the increase and later decrease of the convergence velocity between the Farallon-Nazca and South America plates might be explained by the natural evolution of a slab, a large part of which has reached the mantle transition zone for the first time into the mantle transition zone and the lower mantle below this part of the South America plate. The slab first accelerates due to the increased slab pull in the mantle transition zone, and then slows down due to the resistance of the 670 km phase transition and highly viscous lower mantle. However, the presence of the Andes on the overriding plate does not explain the strong reduction in the subduction velocity. Our results are in full agreement with the seismic images of the Andes.

References

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