The effect of oblique convergence on temperature in subduction zones: insights from 3D numerical modelling

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1. Introduction

In subduction zones the geotherm is thought to vary as a function of subduction rate and the age of the subducting lithosphere. Along a single subduction zone the rate of subduction can strongly vary due to changes in the angle between the trench and the plate convergence vector, namely the subduction obliquity. This phenomenon is observed all around the Pacific (Fig. 1; i.e. Mariana, Sunda-Sumatra, Aleutian . . .) and is supposed in the geological record of Turkey. However due to observed differences in subducting lithosphere age or lateral convergence rate in nature, the quantification of temperature variation due to obliquity is not obvious and need to be better constrained. In order to investigate this effect, 3D generic numerical models were carried out using the finite element code ELEFANT.

2. Setup and strategy

We use the finite element code ELEFANT[3] to solve the mass, momentum and energy equations in three-dimensions:

\[ \nabla \cdot \mathbf{v} = 0 \]  
\[ -\nabla P + \nabla \cdot (2\mu \varepsilon) = \rho g \]  
\[ \rho 
abla \cdot (\frac{\nabla T}{c_p}) + \nabla \cdot (k \nabla T) = \nabla \cdot (\lambda \nabla T) \]

Eqs.(1,2) are solved for a set of geometry and boundary condition. Then, the same \( \varepsilon \) is used to solve Eq. (3) until steady state is reached (Fig 3). The geometry is prescribe by the means of a simple sine or arctangent function to describe a convex, concave or S-shaped subduction zone. The temperature is measured along the interface using tracers.

Future work:

- Test with “real geometries” (i.e. slab dip and model domain; Mariana, South America)
- More complex material (i.e crust and mantle)
- Non-linear rheologies (ASPECT? Ptatin?)
- Link with mantle tomography and implication for segmented slabs

3. Results

4. Significance for subduction zones and future research

The thermal regime in the model can be very different (with geotherm from 5 to 12°C/km) according to the prescribed geometry, with \( \Delta T = 200°C \) from 50–70 km depth (Figs 4,5,6,7 & 8). Here the range of Temperature–Depth profile show that within the same subduction zone different PT regime can be encountered. This has implication for the general understanding of subduction zone mechanism (such as mechanical coupling and related seismicity that is linked to temperature via dehydration reactions). These important effect might also be linked to the differences of magmatism (and amount of partial melting in the mantle wedge) along trenches, for example in south America. The effect of obliquity is more important that admitted as showed by our first order models. Tests performed with different velocity and/or slab dip show similar effects.

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4. Link with mantle tomography and implication for segmented slabs

References

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Figure 3: Plate motion at trenches from the NNR-MORB model [1]. Baselayover with GeoMapApp (http://www.geomapapp.org) with topography and bathymetry from [2]

Figure 4: Compilation of plots for the reference model. (a) top view of the mantle flow and section of the velocity (both \( v \) and \( \omega \)) on the side of the model; (b) view of the model showing the mantle flow and the shape of the 450°C iso-therm; (c) temperature pattern in the model. Note the deflection of the 450°C isotherm; (d,e,f) Direction of the mantle flow at different depths and value of the \( v_y \), \( g \times c \) and \( v_y \) temperature pattern at different depth. Right panel: Depth–Temperature path along the plate interface, close-up and location of the tracers.

Figure 5: Mantle flow for different geometry and compilation of depth–temperature paths for the S-shaped models

Figure 6: Mantle flow for different geometry and compilation of depth–temperature paths for the -SIN-shaped models

Figure 7: Mantle flow and compilation of depth–temperature paths for the S-shaped models is different for model 40_05

Figure 8: PT path of the different models plotted on a phase diagram for a MORB composition after [5].

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