Oblique trenches and temperature in subduction zones

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Introduction

Subduction zones represent today 55 000 km of converging plate boundary on Earth. They are associated with arc magmatism and seismic activity in response to their thermal structures. The geotherm of a subduction zone is thought to vary as a function of subduction rate and the age of the subducting lithosphere [1]. Along a single subduction the rate of burial can strongly vary due to changes in the angle between the trench and the plate convergent vector, i.e. the subduction obliquity.

Numerous studies have been conducted on the effect of temperature and its link with seismicity, fluid release, coupling of the interface, and melting using 2D high resolution models [2, 3, 4]. In contrast, almost no studies [5, 6] investigated the effect of obliquity on the geotherm of subduction zone despite the preponderance of oblique subduction trenches on Earth (Fig 1) and their possible expression in the geological records of Turkey [7].

Setup and strategy

1. Finite element model (with Q1P1 elements) computed with the thermomechanically coupled code ELEKANT [10]
2. 2.8 x 9 x 2.2 km spatial resolution (Fig 3)
3. Geometry of the box varies to describe different type of curves subduction
4. Test with different dip along the subduction zone
5. Computed to steady state (i.e. after 10 My)
6. Computed to steady state (i.e. 10 My)

For the mantle wedge we solve the Stokes equations, which represent the conservation of mass and momentum:

\[ \nabla \cdot v = 0 \] (1)

and

\[ -\nabla P + \nabla \cdot (2\eta \nabla v) = 0 \] (2)

The time-dependent energy equation is solved in the entire domain and expressed as:

\[ \rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (k \nabla T) = \nabla \cdot (\lambda \nabla T) \] (3)

The variation of obliquity (i.e. the shape of the cartesian box) is computed with classical function such as:

\[ x \rightarrow x + A \arctan \left( \frac{B}{x^2 + 1} \right) \] (4)

or

\[ x \rightarrow x + a \cos \left( \frac{B}{x^2 + 1} \right) \] (5)

where A, B, a and \(\beta\) are some coefficient to define the amplitude and the degree of variation of the obliquity.

Significance for subduction zones

The temperature in the model can be very different (with geotherm from 5 to 20°C/km) according to the prescribed geometry. The temperature at 60 km depth \(\Delta T = 170^\circ\)C for the reference model \(\theta_{\text{nom}} = 0^\circ\). Obliquity is critical for segmented settings. Such configurations might represent the nascent period of subduction zone. These important effect might also be linked to the differences of magma (and amount of partial melting in the mantle wedge) along trenches, for example in south America. The effect of obliquity is more important than previously appreciated as showed by our first order models. Tests performed with different velocity and/or slab dip show similar effects.

Results: temperature depths path

Figure 4: Depth-temperature path computed at the plate interface for different geometry. See figures 3 or equations 4,5 for the significance of the parameters.

Results: 450°C isotherm & flow pattern in the wedge

Figure 3: Summary of some of the results with the arctangent geometry. Location of each PT path is indicated on Fig. 2. Lateral flow are indicated in orange, and the magnitude is of about few mm yr\(^{-1}\) (i.e \(C = 2\) cm/yr).

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[8] van Kemenade, Hacker, Syvitski, and others. JGR, 2014

Conclusions and perspectives

Geometry is a very important parameter for the thermal regime of subduction zone. Variation of few hundred degrees (up to 400°C) at 60 km depth are described here (Fig 5). Obliquity is critical for segmented settings. Such configurations might represent the nascent period of subduction zone. These important effect might also be linked to the differences of magma (and amount of partial melting in the mantle wedge) along trenches, for example in south America. The effect of obliquity is more important than previously appreciated as showed by our first order models. Tests performed with different velocity and/or slab dip show similar effects.

1. Test with different dip along the subduction zone
2. Real geometry (South America or Mariana)
3. Non-linear rheologies
4. Continental subduction