Oblique trenches and temperature in subduction zones

Luuk Schuurmans, **Alexis Plunder**, Cédric Thieulot, Wim Spakman and Douwe van Hinsbergen

Utrecht University, Dept. of Earth sciences. Heidelberglaan 2, 3584CS Utrecht, The Netherlands. a.v.plunder@uu.nl

Universiteit Utrecht

Introduction

Subduction zones represent today 55 00 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 convergence 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].

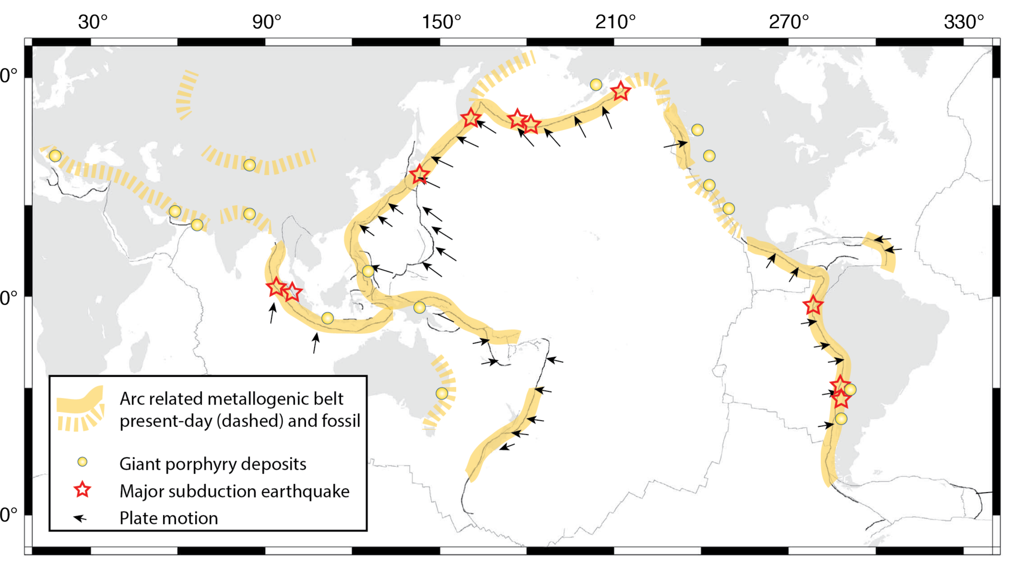

Figure 1: Plate motion at trenches. Modified from [8, 9]

Setup and strategy

1. Finite element model (with Q1P1 elements) computed with the thermo-mechanically coupled code ELEFANT [10]
2. 2.8 x 9 x 2.2 km spatial resolution (57^3 elements)
3. Geometry of the box varies to describe different type of curves subduction
4. Velocity (4 cm/yr) prescribed in the downgoing plate
5. Temperature profile of a *ca.* 5 My old oceanic lithosphere computed with a semi-infinite half space cooling for both the downgoing and upper plate.
6. Computed to steady state (*i.e* 10 My)

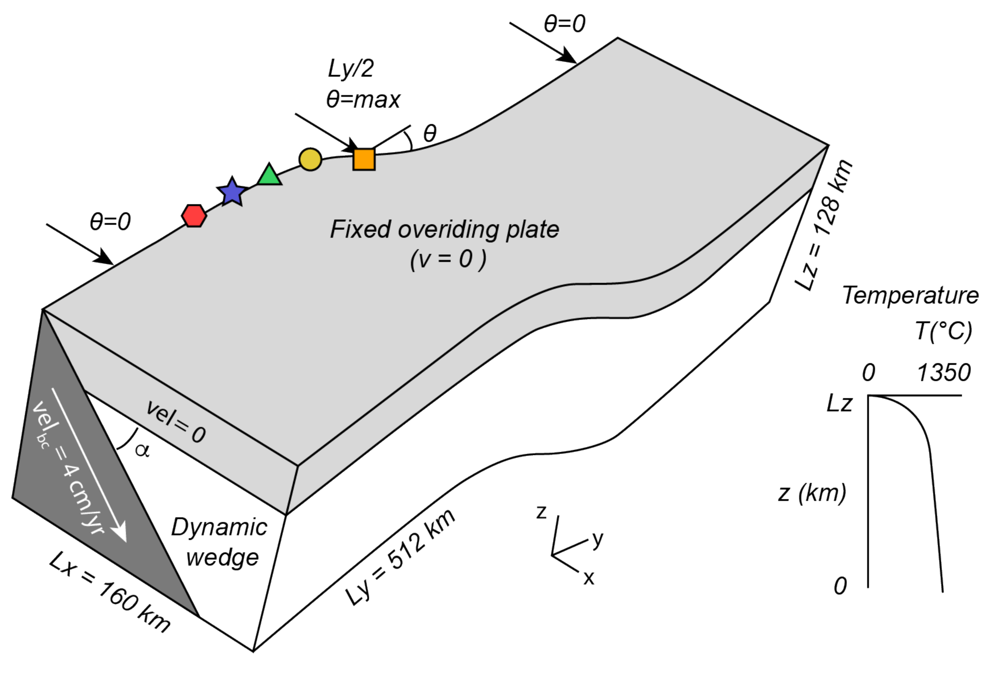

Figure 2: Setup of the numerical model with location of PT path (Fig. 3)

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

$$\nabla \cdot \vec{v} = 0 \tag{1}$$

and

$$-\nabla P + \nabla \cdot (2\eta\dot{\varepsilon}) = 0 \tag{2}$$

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

$$\rho C_p \left(\frac{\partial T}{\partial t} + \vec{v}.\nabla T \right) = \nabla.(k \nabla T) \tag{3}$$

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

$$x \to x + A \arctan \left[B \left(\frac{y}{L_y} - \frac{1}{2} \right) \right] \tag{4}$$

or

$$x \to x + \alpha \left(\sin \left[\left(\frac{y}{L_y} - \frac{1}{2} \right) \pi \right] \right)^{2\beta} \tag{5}$$

where A, B, α and β are some coefficient to define the amplitude and the degree of variation of the obliquity.

Significance for subduction zones

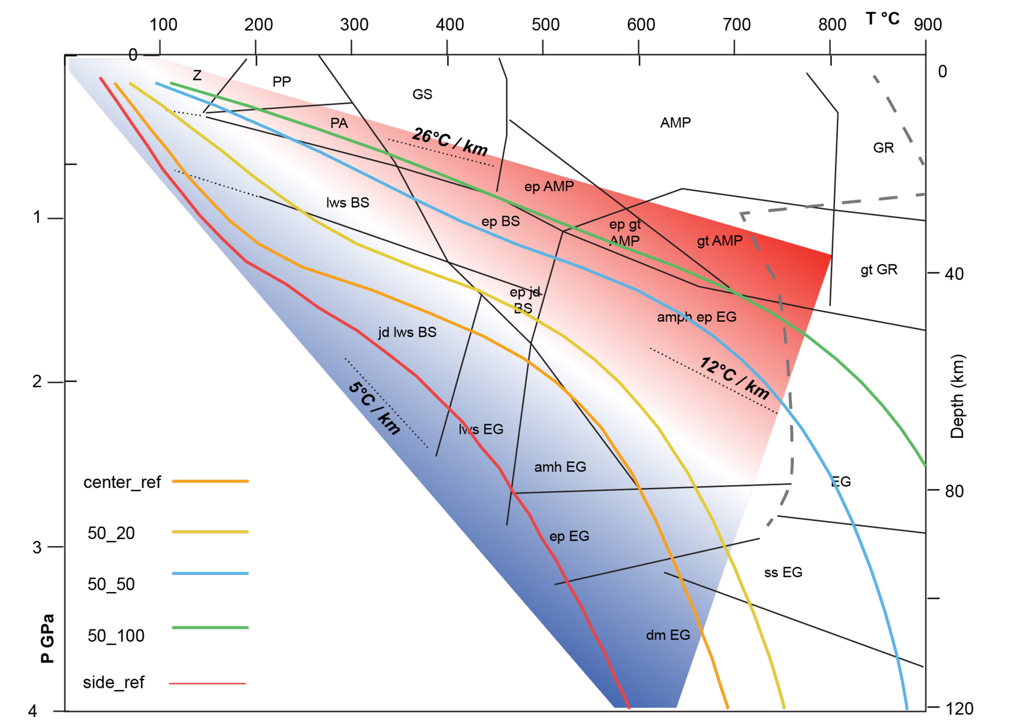

Figure 5: PT path of some models plotted on a phase diagram for a MORB composition after [11].

The temperature in the model can be very different (with geotherm from 5 to 26°C/km) according to the prescribed geometry.

- At 60 km depth $\Delta T = 170°C$ for the reference model ($\theta_{max} =$)
- At 60 km depth $\Delta T = 250°C$ between the side and the center (for maximum amplitude difference ; $\theta_{max} =$) the reference model ($\theta_{max} =$)
- Up to $\Delta T > 400°C$ in the most extreme cases
- Sine geometry shows similar effect with ΔT up to $200°C$

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

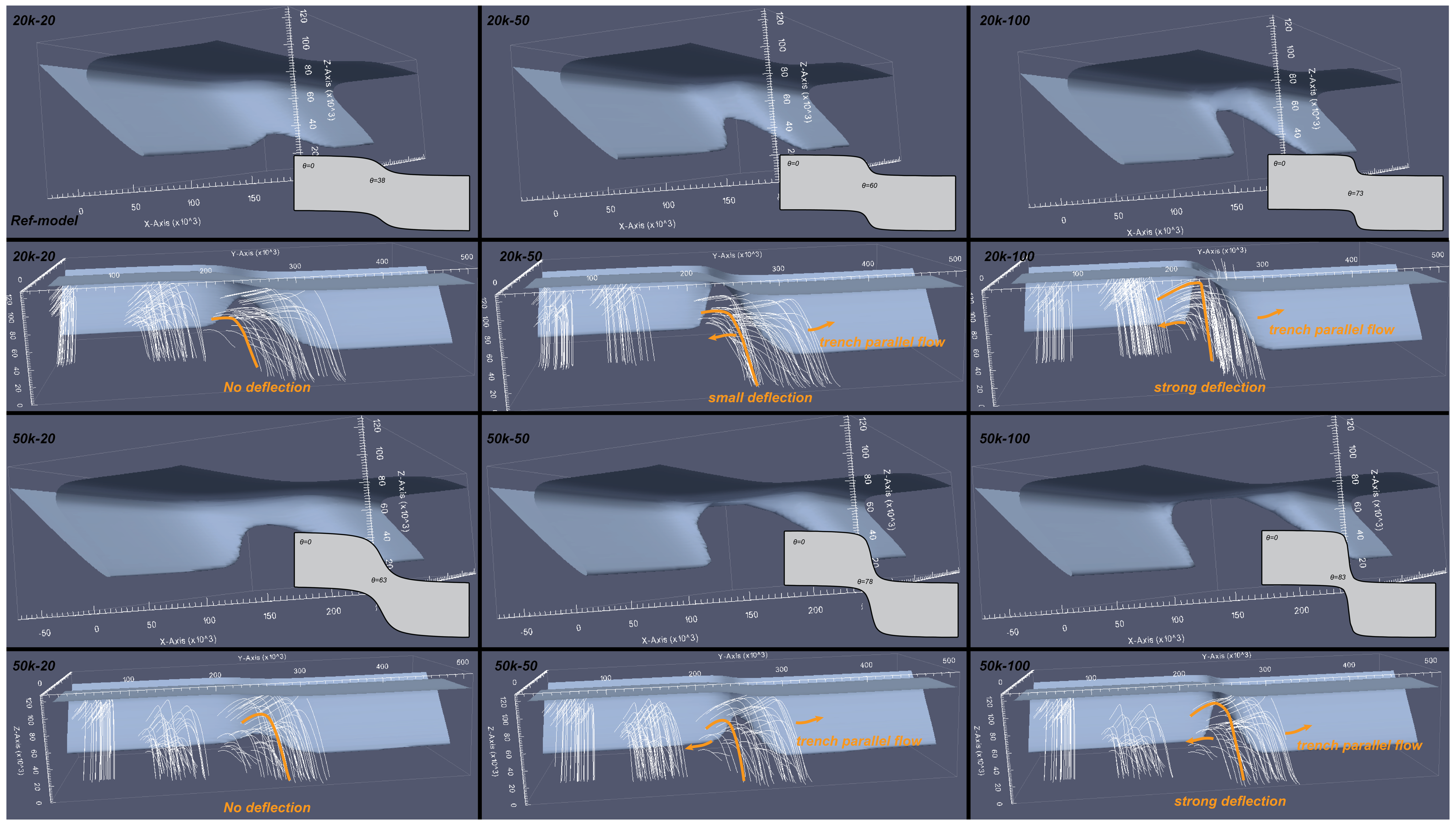

Figure 3: Summary of some of the results with the arctangent geometry. Location of each PT path is indicated on Fig. 2. Lateral flow are indicated in orange, and the magnitude is of about few mm/yr ($\vec{v_x}$ and $\vec{v_z} \approx 2cm/yr$).

Results: temperature depths path

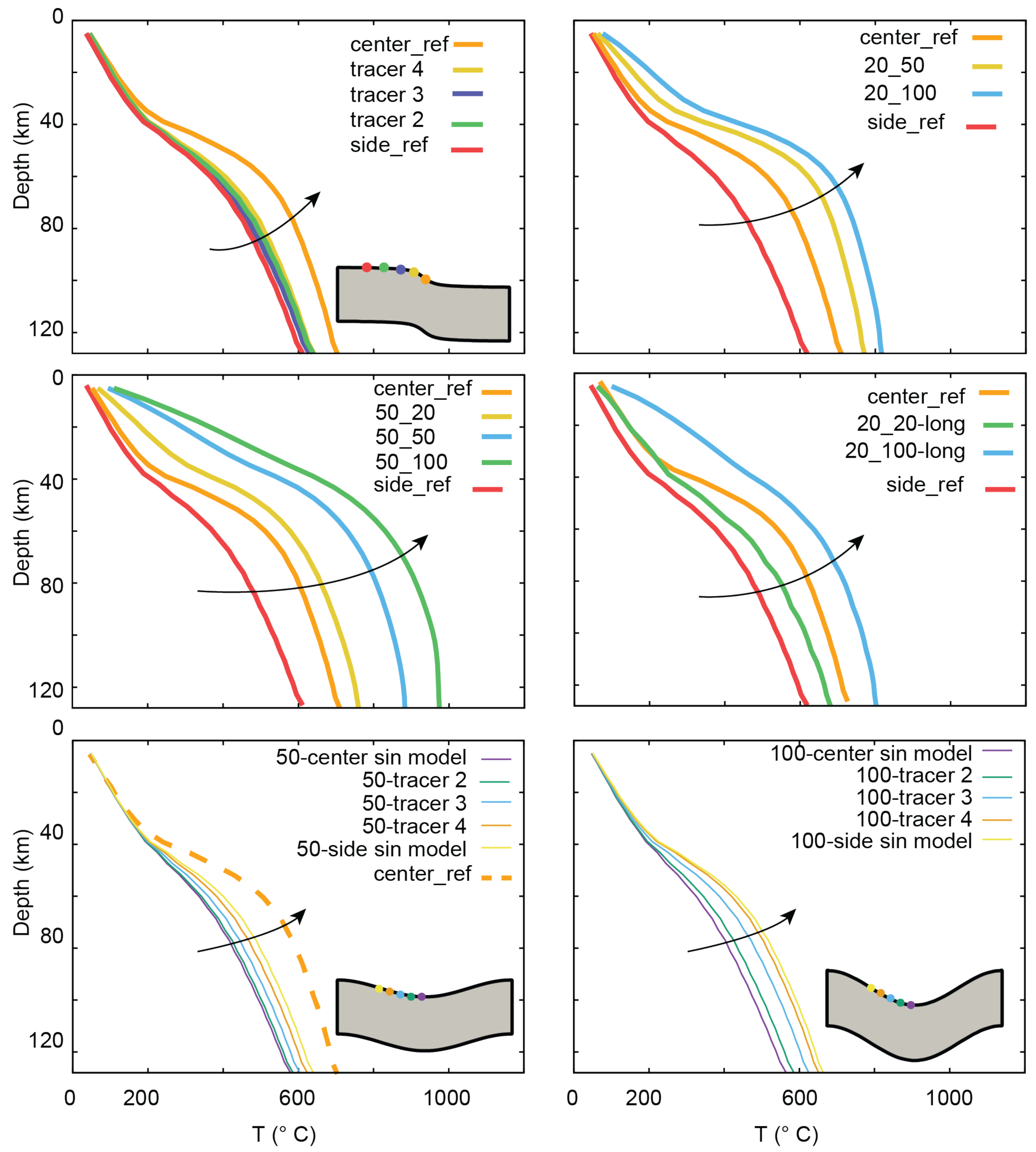

Figure 4: Depth-temperature path computed at the plate interface for different geometry. See figure 3 or equations 4,5 for the significance of the parameters.

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 magmatism (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 Marianna)
3. Non-linear rheologies
4. Continental subduction

Acknowledgements & references

A. P and D.J.J, v.H. are grateful to the ERC starting grant SINK (306810) awarded to D.J.J. v.H. A.P is indebted to Loes van Unnik Hoorn for her guidance

[1] Kirby, Durham, and Stern. *Science*, 1991.

[2] Wada and Wang. G^3, 2009

[3] Syracuse, van Keken, and Abers. *PEPI*. 2010

[4] van Keken, Hacker, Syracuse, and Abers. *JGR*, 2011

[5] Kneller and van Keken. G^3, 2008

[6] Bengtson and van Keken. *Solid Earth*, 2012

[7] van Hinsbergen, Marco Maffione (the amazing!!!), Plunder et al. *Tectonics*, 2016

[8] Bird. G^3, 2003

[9] Richards. *Nat. Geosc.*, 2013

[10] Thieulot. *Solid Earth*, 2014

[11] Hacker, Abers, and Peacock. *JGR*, 2003