Response to the Reviewer#2's comments

Comments in *italic TNR*, and responses in Arial blue

Main comments

1. "*Have the authors tried running simulations with variable density walls in cases with deformable walls (i.e. channel density different from wall density)? How will that affect the pressure field?*"

The density is assumed constant throughout. Its variations would affect lithostatic pressure by a negligible amount (e.g. choosing ρ = 2700 kg m^{-3} would decrease lithostatic pressure at a depth of 100 km by about 3%), and change by a small amount the dynamic pressure through the body force term in the Stokes equation. Both effects are negligible in a first-order model such as ours. In the case of deformable walls, we parameterize their behaviour purely in terms of dynamic viscosity, and therefore a minor variation of density (through the change in lithostatic pressure) would be negligible.

2. "*What are the boundary conditions at the top of the channel (i.e. free surface/outflux)?I could not find this mentioned anywhere in the text*."

The condition at the top of the channel is given in the Appendix, but we have now added it to the main text. We also added the condition at the bottom boundary.

New text added: *slip condition on (parallel to) the bottom boundary (Nábělek et al., 2009), and outlet condition with 1 atm pressure at the channel's mouth*.

Minor comments

Paragraph 124-130: the magnitude of the effective viscosity. What are the limitations of choosing an effective viscosity approach vs an Arrhenius approach? i.e. non-linear effect.

The choice of the linear viscous rheology removes the effects of strain rate on the viscosity, which might affect the TOP. We can anticipate that at high velocities the viscosity would be lower, and so also the TOP.

Line 152-153: 1-2 sentences with the main conclusion from Marques et al 2018 could help the readers here.

The new paragraph reads: *This study builds on the conceptual work by Marques et al. (2018) on tectonic overpressure, in which the main conclusions are that TOP depends critically on boundary conditions (e.g. upward tapering channel can produce* *large TOP, whereas an outlet condition at the bottom prevents TOP from developing) and on critical parameters like strain rate and viscosity*.

Line 164: Reference for "has been accepted as a simple but effective approximation"

We have clarified the statement as follows: *We have modelled the subduction channel … with an incompressible linearly viscous fluid. The assumptions of incompressibility and linearity considerably simplify the model, and constitute standard procedure in many geophysical and geodynamic problems (cf, e.g. Ranalli, 1995; Turcotte and Schubert, 2014)*.

Line 168: References for COMSOL

Reference added: https://www.comsol.com/

Line 239: The authors can extend this section further by comparing the effect on TOP of all these factors (see Fig 3,4). Which one has the strongest effect? This can open a discussion on how these factors evolved/change in time in the Himalayan region. Viscosity?

The new paragraph reads: *Given that the code is based on the Stokes' equation, viscosity and velocity play a fundamental role on the development of TOP. However, the the flow configuration is also critical, because velocity depends on the divergent of the velocity gradient in Stokes' equation. Furthermore, the flow configuration also depends critically on the boundary conditions, therefore some conditions favour the development of TOP (e.g. narrow channel mouth in an upward tapering channel) and others prevent it (e.g. an outlet condition at the bottom boundary).*

Line 261: Yes, alpha affects the flow pattern, but not so much the TOP. Why is it that?

We still do not have a sound explanation for this model result

Line 279: Is it not clear how the transpression was calculated/set. A schematic/clearer sentence is needed.

The new paragraph reads: *Transpression was set by adding an extra horizontal velocity component that made the velocity vector less steep than the moving subduction footwall*

Line 311: The hanging-wall-channel interface is no-slip (i.e. u=0). Because the footwall-channel interface has a prescribed U0. Or is that not the case?

The conditions at the hanging and foot walls are independent.

Line 323: The TOP/pressure can be plotted in Figure 8B for evidence.

Now plotted. Sentence replaced with this new one: "*The viscosity ratio (viscosity walls/viscosity channel) is therefore in the order of 102 to 105. In our modelling we chose a conservative value of the viscosity ratio equal to 102, where the walls and channel viscosities are 10E23 and 10E21 Pa s, respectively*."

Section 3.5: Yes, an important condition, but the authors show no results. A figure with these simulations results can be added to the Appendix.

Figure added. Section now rewritten as follows:

"*3.5. Condition at the bottom boundary*

This is a critical boundary condition because it is directly related to the retention of overpressure. When we assign an outlet pressure (calculated lithostatic pressure at the depth of the bottom wall) to the bottom wall, TOP develops, but with lower magnitudes in the whole channel (supplementary figure)."

Line 351: Possible configurations: parallel-sided and downward tapering - what are the differences and the outcomes, limitations? Not all readers are familiar with the details of these models.

The differences and outcomes are given in Marques et al. (2018). Reference added to the revised ms.

Paragraph 383-393: There is previous work to suggest that pressure-depth conversion in subducted rocks is not necessarily correct (i.e. Yamato and Brun, 2016). Should add some references.

References added

Line 429: Experiments not shown.

Now shown in the Appendix

Line 462: How does this estimate of viscosity in the channel relate to previous published estimates?

New text added reads: … *viscosity in the subduction channel is probably in the range* $10^{20} \le \eta \le 10^{21}$ *Pa s, in agreement with the estimates for Himalayan subducted material (between* 10^{20} *and* 10^{21} *Pa s) by Liu and Yang (2003) and Copley and Mckenzie (2007).*

Paragraph 473-478: References for these hypotheses.

References added

Paragraph 479-494: The authors list the proposed models for exhumation of HP and UHP rocks across various tectonic settings/orogens (with different geometries, rheology, boundary conditions). The UTC model can be applied to the Himalayas, but it's not clear that it can be considered a unified model in other settings. The authors should make that clearer.

We rephrased the text as follows: *The UTC model presented here is a new potential model to explain the exhumation of HP and UHP rocks, …*

Figure 1: C) Numerical model setup. Since boundary conditions (moving/fixed walls, bottom boundary conditions) are important in this study, it would be useful if they could be represented graphically in Figure 1C.

They are now given in the main text to not overload the figure

Figure 2: D) the plots are confusing because they do not have the same vertical axis.

The curves would not be individually visible if the vertical axis had the same scale. Please note that the curves in Fig.2D, where the maximum values go up to 2.2 GPa (left most panel) would merge with one another if the vertical axes had a scale of 4 GPa, as in the right most panel. This is the reason why the three panels were prepared with their vertical axis at different values.

Figure 3, 4: Each simulation gave 3 values for TOP at different depths. What do these values represent? i.e. maximum/average TOP at the respective depth? same vertical axis would be desirable (currently apparent) and would allow comparison of factors on the overpressure. For example, which factor has the strongest effect on TOP? Green points are not distinct enough from blue markers.

The three values for TOP represent overpressure at three different depths at the middle of the channel, respectively 30, 60 and 90km for each experiment.

For appropriate visualisation of the curves, it was necessary to use vertical axes with different scales.

Previous light green colour is changed to deep green.

Figure 5: What are the other reference parameters for these simulations? viscosity, Wm* etc.

New caption now reads: "*Figure 5. Simulations showing the effects of channel dip (α) on flow pattern, keeping Wm=100 km, Wb=150 km, U = 4 cm/yr, and viscosity = 1021 Pa s.*"

Figure 6: missing panel B (possibly just a format/download issue)

Problem solved

Figure 7: How much transpression in this case? How was the transpression calculated from the velocity profile?

The figure shows a transient analysis of the velocity field, i.e. instantaneous flow in the channel under a given transpression rate, which is measured as the ratio between horizontal velocity and non-transpressional horizontal component (ca. 1.49E-9 m/s). Please note that this parameter is an alternative expression of the ratio between wall normal and wall parallel velocity components.

"Fig. 6 shows a plot of *TOP* as a function of transpression, represented as the ratio between horizontal velocity and non-transpressional horizontal component (ca. 1.49E-9 m/s)."

Figure 8B: TOP should also be plotted in this case, and the case with viscosity contrast 1e2.

To keep the clarity in the diagram, we plot only for the viscosity ratio 10^2.

Lisbon, 29th June 2018

Fernando Ornelas Marques on behalf of all co-authors