Solid Earth Discuss., 4, C120–C125, 2012
www.solid-earth-discuss.net/4/C120/2012/

Solid Earth Discussions

Interactive comment on "Numerical models of trench migration in continental collision zones" *by* V. Magni et al.

C.P. Conrad (Referee)

clintc@hawaii.edu

Received and published: 10 April 2012

This paper uses a series of well-designed numerical models to determine how and why trenches migrate in continental collision zones. The authors discover that slabs tend to steepen after continental collision, and that this steepening generates a flow patterns in the mantle that drive trench advance. In fact, trench advance has been observed in continental collision zones, so the models presented in this paper present a good mechanism to explain this observation. Because the paper is well written and describes a simple process that may explain a fundamental observation of earth subduction, I think this paper should be published.

I also feel, however, that this paper could be improved both in terms of its presentation but also by improving the comparison between the model predictions and observations

of trench migration at continental collision zones. I describe my suggestions below. Although I suggest several and significant revisions, I am recommending publication after "minor revision" because the paper is already in a nearly publishable form. I do feel, however, that the authors should consider my suggestions below, because I think addressing them would improve the impact of their paper.

1. It is a little unclear to me what "trench migration" actually means when applied to collisional subduction. For oceanic subduction, the location of the trench is obvious – it is the point where the subducting plate begins to become covered by the overriding plate. However, for continental subduction, this location is covered over by compressional tectonics of the continental crust. It is perhaps possible to estimate the location of where the trench would be without this continental crust, but this requires seismological observations – and these are only available for the present day, not past times, which makes estimating migration rates difficult. Is there a volcanological expression of trench migration? If so, can it be de-convolved with changes in slab dip? (which ultimately drive the trench migration, as demonstrated in this paper). Is there some other geological expression of trench migration for continental collision? I recommend that the authors add some discussion about how trench migration is measured in continental environments. Additionally, I think the authors should be more specific about how they determine the specific location of the trench in their models.

2. One of the significant results of this paper is that the authors use their models to predict that trenches should tend to advance in continental collision zones. They then provide, in the discussion, a summary of trench migration observations for various collisional zones, many of which are advancing. However, the authors motivate the paper by explaining the modeling efforts that have been used to investigate the dynamics of trench migration and continental collision in previous studies. I think it would make for a stronger paper if the authors motivated their study instead by the observation that many/most of the continental collision zones feature trench advance. This is distinctly different from oceanic subduction, in which most trenches are observed to be in retreat

(both in laboratory models and for natural subduction, although the latter depends on the choice of reference frame). In general, I think it is better to motivate a study by pointing out the basic observation that the study seeks to explain – and it seems to me that this could easily be done in this case by moving some of the material from the discussion into the introduction.

3. The low-viscosity zone between the plates is constructed using tracers. Movement of these tracers defines the location and shape of this weak zone. Also, the weak zone "moves with the velocity of the overriding plate" (p. 434 line 18). It is a little unclear to me how this is accomplished: Are the tracers pinned to the edge of the overriding plate? In that case how do they move to change the shape of the plate boundary? Or, are the tracers allowed to move freely? In that case, then what prevents the tracers from migrating away from the plate boundary and generating a low-viscosity region elsewhere? This is particularly a question for the wedge above the slab, which I would expect to have vigorous flow that would move tracers into the underlying mantle.

4. The model is 2D (as are many subduction models). Thus, the mantle flow patterns that lead to trench advance are 2D patterns. However, in 3D, the slab steepening process that drives these mantle flow patterns could instead be accommodated by flow around the lateral edges of the slab, which (I think) would lead to lateral variations in trench migration following collision (much as it does for trench migration in oceanic subduction systems with a finite lateral extent). I think the authors should discuss the effects of their 2D assumption on the dynamics of the system, and discuss the changes they would expect in 3D. Do these changes match with any of the geological constraints on lateral variations in trench migration rate?

5. The mechanism for trench advance is described on page 439, lines 16-20. However, I think this mechanism could be explained a little more clearly. In particular, the authors state that steepening of the slab "triggers return flow around the slab" (line 18). The term "around the slab" seems to imply "around the edges of the slab" (at least to me) – which is a 3D process that cannot be treated here (see above comment). Instead, I

think the authors mean "one convection cell below the slab and a second one above the slab" – this seems to be what is shown in Fig. 9. But if there are two convection cells moving in an opposite sense, why does the trench migrate? The cell beneath the slab would tend to cause advance by pushing the entire system toward the right in the diagrams, but the one above the slab would tend to cause retreat by pushing the entire system toward the left. Is the cell beneath the slab more vigorous, so that it "wins", and causes advance? I think that the specifics of the trench advance mechanism should be explained more clearly and in more detail. Additionally, since this is a key aspect of the paper, I think a brief explanation of the mechanism should be included in the abstract.

6. The authors describe a process in which subduction of an oceanic plate generates a slab of limited length in the mantle prior to continental collision. Does the trench migration behavior that is observed depend on the length of the already-subducted slab in the mantle? For example, if there were only a very short slab in the mantle prior to continental collision, then presumably the observed trench advance following collision would not occur because it is driven by descent of the already-subducted slab. At the other extreme, if a very long slab were already subducted, then it might become anchored in the lower mantle, and steepening of the slab would become more difficult – its continued descent into the lower mantle would then perhaps draw the trench toward the anchoring point (which would also cause trench advance but for a different reason). I think it would help to mention that the dynamics may depend on how much slab material is already in the mantle, and also to discuss how the results may be different if a longer or shorter mantle slab were present.

7. The models predict trench advance following continental collision – this is something that can be compared against observations (as is done in this paper). However, it seems to me that the models make other predictions that could be tested against observations. For example, slabs beneath continental collision zones should be steeper than other slabs, and they should be more often detached from the surface plates (because slab steepening and detachment are two processes described here as natural

events that follow continental collision and that cause trench advance). Is there any evidence from mantle tomography that slabs beneath continental collision zones are typically steeper or more detached? (besides Ontong Java, as mentioned) Such evidence would tend to support the conclusions of this paper. Also, the models predict two episodes of trench advance – one associated with steepening of the slab and another associated with the detachment. Are these episodes observed in the geological record of trench motion in continental collision zones?

8. I think that a few of the figures could be made smaller and clearer. In particular, Figures 2 and 4 show 3 panels for each of 6 different times, making 8 panels total. This makes the individual panels rather small, and the details of the flow patterns even smaller. I think it would be clearer if the middle column (temperature) was eliminated since it basically shows redundant information with the left column (viscosity). Also, I think the right column could be eliminated if the regions of continental crust were drawn in blue (or some unused color) over top of the viscosity in the left column. This would reduce the number of panels to 6, and they could be much larger. I also wonder if the trench position and trench velocity panels of Figs. 3 and 5 could be combined onto Figs 2 and 4 (similar to what is done for Fig. 6). Alternatively, it seems to me that the information in Figures 3 and 5 is redundant to the information in Figures 7 and 8, and thus could be simply eliminated. Finally, I think Figure 7 could be made clearer if the oceanic and continental cases were always given the same colors (e.g., blue shades for oceans and green shades for continents) – this would highlight the differences between the oceanic and continental cases more clearly.

More minor points:

– equation (6) – I think that the symbol for the density contrast is incorrect in this equation (it should be del rho_c).

– Page 434, lines 13-24 – it seems to me that these paragraphs should be part of section 2.2 (Model Setup), rather than section 2.1 (governing equations).

– The sense of trench motion (advancing or retreating) should be clearly defined somewhere, as readers can become confused about which direction is retreat and which is advance. I think that Figure 1 would be a good place to define retreat and advance.

– Page 435, line 20 – the authors mention that the model uses a no-slip condition on the bottom boundary, which may seem counter-intuitive to some. The authors should justify this (the high viscosity lower mantle acts as a rigid boundary).

– Page 437, line 3 – I think that {mu} should be {\mu}

– Page 441, line 18 – The authors describe how Ontong Java may be an example of behavior similar to continental collision. Is there evidence for trench advance here?

– Figure 1 caption. The “continental plateau” is highlighted in yellow. I think that the yellow region is actually “continental lithosphere” or “cratonic lithosphere”. A “plateau” is usually a crustal feature, not a lithospheric one as is drawn here.

– Figure 3 shows different symbols/colors for the different phases of system development (1-4). I think that the colors of these symbols should match those that are used to designate these states in Fig. 2. Also, the stages should be labeled somewhere, so that the reader doesn't have to dig through the text to figure out how these stages are defined. It is also difficult to distinguish the blue and purple colors in Fig. 2 – more distinct color choices for subduction phases 3 and 4 would help.

Interactive comment on Solid Earth Discuss., 4, 429, 2012.