**Solid Earth
Discussions**

Interactive comment on "Segmentation of the Izu-Bonin and Mariana plates based on the analysis of the Benioff seismicity distribution and regional tomography results" *by* K. Jaxybulatov et al.

K. Jaxybulatov et al.

jaxybulatov@gmail.com

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Dear W.P. Schellart

We are very grateful for your friendly and constructive comments. We took into consideration most of them which required considerable work to be done. We looked through a lot of paper and learned a lot of things about the topic of our paper. In particular, major revision of discussion section was done (we have added new figure (Figure 9) and included changes into figure 8).

The revised manuscript is given in supplement. All the corrected parts in the manuscript are highlighted with red.

Replies:

1)*Title: In order to avoid a lot of confusion, "plates" should be replaced with "slabs"

Corrected

2)*Page 825, lines 17-18: It is not correct to talk of the Izu-Bonin-Mariana arc, because this subduction segment, which forms part of the Kamchatka-Kuril-Japan-Izu-Bonin-Mariana subduction zone, consists of two arcs, namely the Mariana arc and the Izu-Bonin arc, with a clear geometrical cusp in between.

REP 1: We agree that IBM is not a single arc. In the text we have replaced IBM arc with IBM arc system.

3)*Page 825, lines 26-27: It is not generally accepted that opening of the Mariana Trough caused oceanward displacement of the Mariana trench. In fact, it is generally argued that opening of the Mariana Trough is mainly a consequence of relatively rapid westward motion of the overriding Philippine plate with a relatively slowly westward moving Mariana Trench [e.g. Carlson and Mortera-Gutierrez, Tectonophysics1990].

REP 2: We looked deep through the literature proposed by the reviewer and finally turned to be almost convinced by his arguments. Based on his suggestions, we have proposed another scenario which is based on the Asia fixed reference framework (close to the case 2 in Figure 1 of Schellart et al., 2008) which is shown in Figure 9 and described in Lines 327-350. Although we find this model most plausible to explain the general kinematics of the subducting plates, we still present the older model, as an alternative scenario. We believe that the relative displacements of the trench in the local reference framework might appear to be also important in forming regional features of the subduction styles and should be also considered. In the introduction we have included a paragraph about difficulties of selecting an appropriate reference frame

for describing the plate motions (Lines 74-91) which take into account the comments of the reviewer.

4)*Page 826, lines 1-2: "The rate of the Pacific plate subduction in respect to the Philippine Plate . . ." The rate of subduction is an absolute rate and is not dependent on a reference frame, so "in respect to the Philippine plate" should be deleted.

REP 3: We agree that this statement was incorrect. We have replaced "subduction" with "motion": "The rate of the Pacific plate motion near the trench in respect to the Philippine Plate..."

5)*Page 826, lines 4-5: "The rate of eastward displacement of the Mariana trench is about 2 cm/yr (DeMets et al., 2010)". The Mariana Trench is currently not migrating eastward (retreating), it is migrating westward (advancing). This has been shown in earlier works on plate kinematics for the last 5 Myr [e.g. Carlson and Mortera-Gutierrez, Tectonophysics1990], and more recently it has been shown to be the case for geodetic and geological relative plate motion models in several "absolute" reference frames, such as the Indo-Atlantic hotspot reference frame, the Pacific hotspot reference frame, and the no-net-rotation reference frame [Schellart et al., Earth-Science Reviews 2008]. In the Indo-Atlantic HS frame from O'Neill et al. [G-cubed 2005] and the NNR frame from Kreemer et al. [GJI 2003] it is advancing westward about 1-2 cm/yr, while in the Pacific HS frame from Gripp and Gordon [GJI 2002] it is advancing westward at about 3-5 cm/yr. So in all likelihood, using the DeMets et al. [2010] plate motion model, the trench is not retreating eastward at 2 cm/yr. Even if it is the case, which I doubt, then you need to discuss that in most other reference frames it is actually advancing westward rather than retreating eastward.

REP 4: We are now convinced on most issues (See REP 2), except for the statement:"So in all likelihood, using the DeMets et al. [2010] plate motion model, the trench is not retreating eastward at 2 cm/yr". Below (Fig1) is the map by DeMets et al., (2010) which clearly shows the retreat of the Mariana trench in respect to the middle

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of the PSP.

6)*Page 827, lines 11-16: "We did not find in the literature any evidence of forward displacement of the Mariana segment of the trench (Seno and Maruyama, 1984; Seno et al., 1993; Hall et al., 1995a, b; Hall, 2002); just opposite, most authors show the backward displacement. In the discussion session we will propose an alternative point of view based on our tomography results." There is certainly literature that shows the westward migration of the Mariana trench. The plate kinematic work of Carlson and Mortera-Gutierrez [Tectonophysics, 1990] has shown that the Mariana trench has been advancing westward since 5 Ma, and the authors argued that such advance causes the Mariana slab dip angle to increase. More recently, the plate kinematic work of Sdrolias and Muller [G-cubed 2006] show the episodic migration of the Mariana trench with a stable trench at 50-25 Ma, a retreating trench at 25-5 Ma and an advancing trench at 5-0 Ma. Most recently, the work of Schellart [GRL 2011] combines trench migration calculations for several subduction zone segments in the western Pacific for the last 20 Myr with slab structures as deduced from seismicity and seismic tomography and slab structures as deduced from geodynamic subduction models. This work shows that the Mariana slab, with a relatively steep upper mantle slab and possible slap piling and folding near and below the 660 km discontinuity, can be largely explained with a relatively stable trench for the last 20 Myr, with, on average, slow trench retreat at 20-10 Ma and with, on average, slow trench advance at 10-5 Ma. In any case, it is clear that there is considerable literature that discusses the advance of the Mariana trench, several of which also relate this to the Mariana slab structure. The authors will need to discuss these works (and possibly others) in their revised manuscript to give a balanced view of the literature.

REP 5: Thanks a lot for this overview which was very useful to enlarge our knowledge on the topic of the paper. Most of the mentioned studies were considered and added to the manuscript. (see also REP 2).

7)*Page 832, line 4: Cross-section 1 does not cross the northern part of the Izu-Bonin

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arc, it crosses the Japan (Honshu) arc.

REP 6: We have corrected the reference names for this section (See lines 210-214). We have also included one more section at the transition of Japan arc to Izu-Bonin arc. See figure 4.

8)*Page 832, lines 9-13: "For Sect. 2, the slab becomes steeper, but in the transition zone between 400 and 600 km depth it turns to be horizontal. In this section, an enigmatic feature is a prominent positive anomaly in the lower mantle which is clearly seen in both P- and S-models, though with different shapes. Note that in the neighboring sections 1 and 3, this anomaly is not observed.". Is this lower mantle high-velocity anomaly also observed in other tomography models? For example, the tomography model from Huang and Zhao [JGR 2006] does not show it. They only show a flab slab segment at 600 km depth. This requires some discussion.

REP 7: Here (Fig2, Fig3) we present cross sections corresponding to several previously published models in compare with our ones. The discussed high-velocity anomaly is located in northernmost part of Izu-Bonin trench. Huang and Zhao (2006) observed a similar feature, did not specially discuss it in their paper. In (Widiyantoro et al.1999) high velocity anomaly related to the slab doesn't penetrate lower than 660 km, but a few high-velocity anomalies are observed in the lower part of section, especially in the S-wave model. Miller's model shows horizontal orientation of slab related high-velocity anomaly at the transition zone, but it may be noticed that lower part of this anomaly is extended downward lower than 660 km. We made the corresponding changes in the text (see lines 217-221).

9)*Page 837, paragraph at the top: The apparent absence of slab material at 0-400 km depth at the corner between the Mariana and Izu-Bonin segments is based on the absence of a high-velocity anomaly there in the tomography models. However, Fig. 4, section 5 shows there is seismicity in this region down to 300 km depth, suggesting the presence of a slab at least down to 300 km depth. Furthermore, the checkerboard

tests in Fig. 6 show that the return amplitude at 100 km and 220 km depth in this region is rather low, probably the lowest compared to regions to the north and south. So one could think that the absence of a tomographic high-velocity anomaly is the sign of insufficient seismic ray coverage in this area. In any case, this section requires more discussion to explain the potential problems noted above.

REP 8: Low resolution at 100 km and 220 km is observed throughout the whole map, not only between Mariana and Izu-Bonin segments, except northernmost part, however, high-velocity anomaly upper than 300 km is observed in other cross-sections. It should also be noted that in the result of slab-shaped synthetic test (Section 3, Fig.7) is shown just such situation (how it looks in results, when positive anomaly is absent). In the new version of the paper we discuss this contradiction (L 359-364): "A problem of this model is the existence of deep seismicity in the gap area where the high-velocity slab is not observed. We propose that the gap area is formed by plastic extension of the subducting plate. In this case the resolution of the tomography model might be not sufficient to resolve the thinned part of the slab in the extension zone. Furthermore, the presence of remnant heat beneath the Ogasawara plateau might lead to degrading some physical properties of the slab and to decreasing seismic velocities."

10)*Pages 837-838, conclusions: "We propose the scenario which explains the variable dipping angle of the slab beneath the IBM arc. In the northernmost part of the Izu-Bonin zone, the lithosphere is relatively young and buoyant. This and also the trench retreat can explain a gentle deepening of the slab to the angle of about 35 degrees.". The role played by trench retreat makes sense, as subduction models also show that with rapid trench retreat the slab dip angle decreases. The role of lithosphere age does not make sense, because along the entire Japan-Izu-Bonin-Mariana trench it is very old, and there is no reason to assume that the increase from 130 Ma in the north to 150 Ma in the south will have a significant impact on the rheological and thermal properties of the lithosphere and thus on its geometry.

REP 9: We are convinced by the reviewer; therefore we have removed any reference

on this factor. In the new version of the paper we are trying to find the explanations in different things.

11)*Page 838, lines 3-5: "In the Mariana segment, despite of backward migration of the arc, the slab remains nearly vertical. This can only be explained by jumping the subduction zone from one place to another." As mentioned earlier, the Mariana trench segment has been advancing westward for the last 5-10 Myr, so there is no need to invoke jumping of subduction zones. Indeed, the steep slab geometry can be explained very well with geodynamic subduction models that replicate the subduction kinematics of the region for the last 20 Myr [e.g. Schellart, GRL 2011].

REP 10: We agree that this explanation is more plausible than one proposed in the previous version of the paper. The new model presented in Figure 9 and described in L 327-350 generally agrees with the reviewer's concept.

12)*Fig. 8 and discussion section: The schematic cross-sections illustrating the evolution of the slab geometry in four places are over-simplistic. This is particularly the case because the authors only draw two trench positions: the position of the trench for the present day and for one time in the past, which is only based on the tomography slice at 975 km depth. High-velocity material at 975 km depth represents material subducted tens of millions of years ago, and in this case it might represent slab material subducted possibly 30-40 Myr ago, or even earlier.. In order to deduce the kinematics of subduction and trench migration, so as to deduce the geometrical evolution of the slab, the trench positions need to be reconstructed at shorter time intervals in the past, such as has been done by Sdrolias and Muller [G-cubed 2006], who use 5 Myr intervals.

REP 11: Taking into account the rate of subduction of 5 cm/year, 1000 km distance correspond to 20-25 ma which is larger than our previous estimate, but smaller than the reviewer's one. We made the corresponding corrections in lines 279-282.

Another problem with the reconstructions is that they only show the (oversimplified)

migration of the trench, but they should also show the subduction component due to trenchward subducting plate motion. Only then one can get an estimate of the total amount of subducted lithosphere (and thus an estimate of the slab length) and only then can one quantify the partitioning of subduction between trench migration and trenchward subducting plate motion. This is essential in order to reconstruct the geometric evolution of a slab. Thus, the authors need to use a higher temporal resolution and need to incorporate both components of subduction (trench migration and trenchward subducting plate motion), and then it is possible to make inferences about the migration of the trench and the geometrical evolution of the slab.

REP 12: In figure 8 we have shown the approximate displacement rates which would help to address the points indicated by the reviewer. Note that here we present a very qualitative scheme of the plate motions and we do not pretend revealing details. Higher temporal resolution would require a special research. This paper is just an attempt to explain the images derived by seismic tomography.

13)*Fig. 8: For the present day (blue) cross-section B1-B2 shows a gap of 200-300 km between the 45 degrees dipping slab and the flat segment at 500 km depth. This is not observed in the tomography images, where there is no gap (Fig. 4, section 2), but where the horizontal part at 500 km depth is connected with the Wadati-Benioff zone. This requires discussion.

REP 13: We have removed the blue body to the left of the section which was indeed unrealistic.

14)*Fig. 8: the purple line does not indicate the location of the arc, it indicates the location of the trench.

Corrected.

15)*Fig. 4: The authors should discuss the absence of a high-velocity slab anomaly at 0-400 km depth in section 5 (both P and S), while there is seismicity down to 300 km

depth. The same goes for sections 6 and 9, with an absence of a high-velocity slab anomaly (both P and S) but presence of seismicity at 0-200 km depth.

See REP 8.

Please also note the supplement to this comment:
http://www.solid-earth-discuss.net/4/C655/2012/sed-4-C655-2012-supplement.zip

Interactive comment on Solid Earth Discuss., 4, 823, 2012.

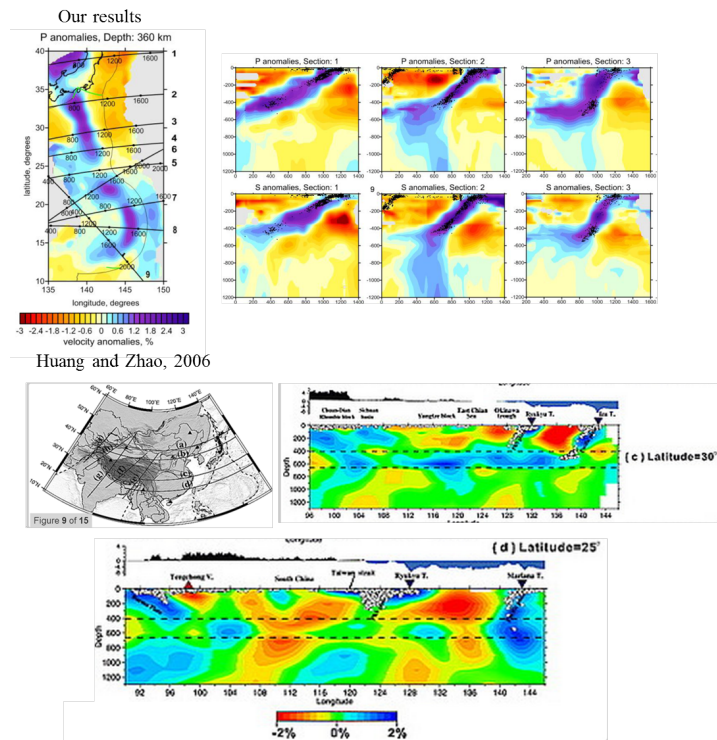C663
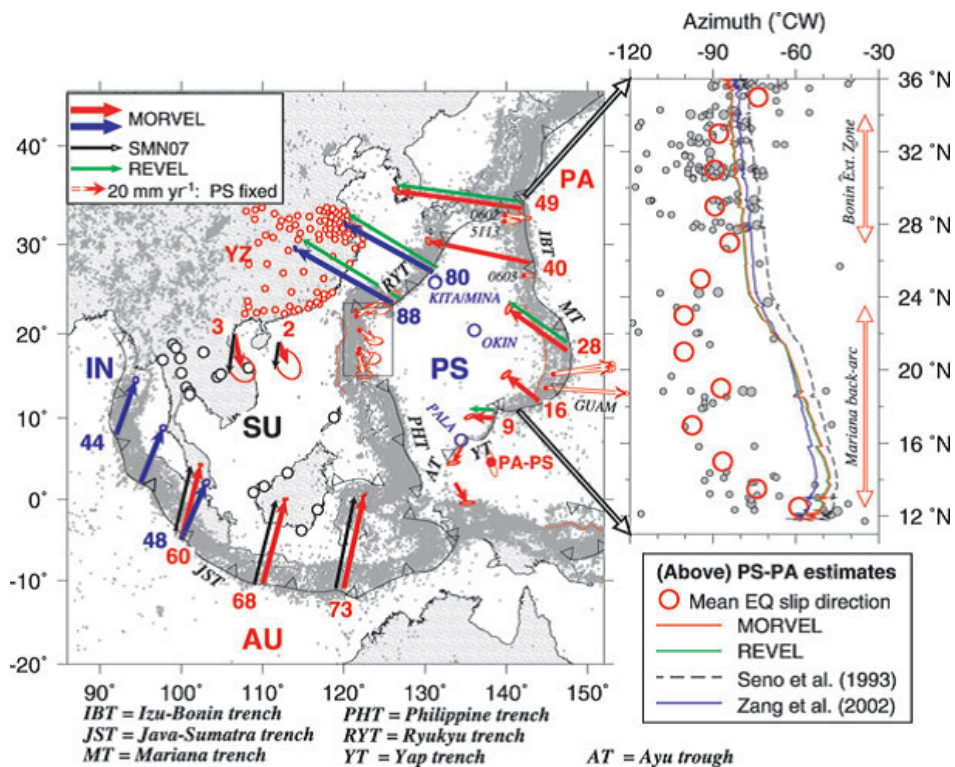
Fig. 1. Map by DeMets et al., 2010 (see REP 2)

Our results

Huang and Zhao, 2006

Fig. 2. Cross sections (see REP 7)

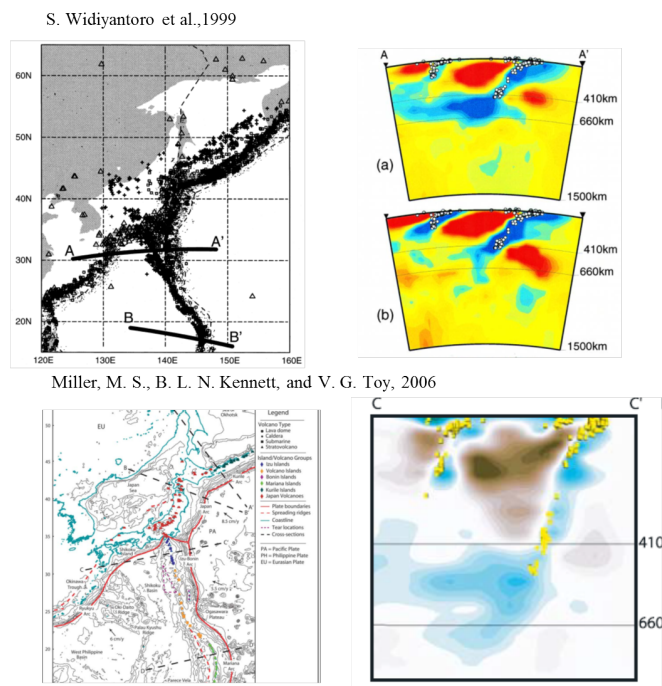C665

S. Widiyantoro et al.,1999

Miller, M. S., B. L. N. Kennett, and V. G. Toy, 2006

Fig. 3. Cross sections (see REP 7)

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