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Interactive comment on "Tectonic evolution and high-pressure rock exhumation in the Qiangtang Terrane, Central Tibet" *by* Z. Zhao et al.

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We thank the reviewer for the comments and suggestions. Our reply is given first and suggested changes to the manuscript are listed at the end of this reply.

‘ This paper, which deals with the tectonic evolution of a Paleozoic suture in Central Tibet, China, provides new structural, geological and lithostratigraphic data on this suture zone and associated lithologies and provides a geodynamic reconstruction for its evolution from Permian to Jurassic times. This study is important because it addresses the question of the former existence of an ancient oceanic realm followed by its closure and subsequent continental collision. This work also has some implications for regional paleogeographic reconstructions in late Paleozoic and early Mesozoic times. This paper is nicely written, well organized and the English quality is good. The overall model

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and geodynamic reconstruction seem reasonable and for a large part supported by lithostratigraphic and geological data provided by the authors. In particular, this paper proposes that the exhumation of HP rocks, now sandwiched in a nappe stack visible within this suture zone, may be related to an extensional event associated with a "break-off-like" / or "asthenospheric upwelling" event, based on regional sedimentary record arguments.

However, when reading this interesting manuscript, I felt a bit frustrated because of the absence of petrological and micro-structural description of the rocks lining the boundaries between the different "slices" identified in the field. This information from samples collected along these shear zones would be capital to assess the depth of tectonic juxtaposition and the thermal regime associated. In which tectonic environment did this juxtaposition take place? '

The petrology of the high-pressure rocks has already been investigated in detail (e.g. Kapp et al. 2003, Liu et al. 2011), and we therefore did not focus on petrology in this study. However, we welcome the question by the reviewer to provide additional information. The crucial contact here is between the high-pressure rocks and overlying low-grade mélange and sediments. Rocks deriving from $\geq$500°C and >1 GPa came into contact with essentially non-metamorphic rocks (Fig. 6C). Liu et al. (2011) showed that decompression down to at least about 0.7 GPa was approximately isothermal. Juxtaposition of the two rock units would be expected to heat the base of the overlying rocks. It is indeed observed that the Permian limestones, overlying blueschists NE of Rongma become sheared marbles towards the contact. These marble contain the assemblage calcite + tremolitic amphibole $\pm$ epidote $\pm$ garnet $\pm$ quartz, which indicates elevated temperature (up to $\sim$500°C), but relatively low pressure. Microstructures (new figure, see below) indicate strong ductile deformation of the calcite (twinning, dynamic recrystallisation) after at least growth of tremolitic amphibole. The garnet, however, appears to have grown post-tectonically, either by heating by the relatively hot blueschists, or related to the proposed mantle upwelling. Detailed petrology, however, was outside the

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scope of this study.

‘ If there has been an ocean there, one should expect remnants from an accretionary wedge there. Do you have any evidence for this? Can we interpret the “sedimentary mélange” reported here as part of an accretionary system? ‘

Indeed, the sedimentary mélange is part of the accretionary system that forms at the northernmost suture. This is illustrated in fig. 6, which is unfortunately strongly reduced in size. We hope that the figure will be larger in the final version of the paper.

‘ I have another concern: an asthenospheric upwelling like the one illustrated in figure 6d should not only lead to some magmatic production (as reported here) but also leave a very diagnostic –high-temperature- petrological and microstructural imprint in the rock fabric. And this is not mentioned here –neither in the literature- which makes me suspicious with this specific part of the final geodynamic model. Could slab roll-back could also be considered as a possibility to explain blueschist exhumation in a convergent setting (e.g. Egean domain)? ‘

The exhumation model, illustrated in Fig. 6c, is novel, although there are some similarities with models for exhumation by slab rotation (Hacker et al. 2000; Webb et al., 2013) or slab eduction (Anderson et al., 1991; Duretz et al., 2012) (now added in the revised text). There is thus no mention in the literature yet on the expected temperature and petrological impacts. Most published petrological work on the Qiangtang area focused on the peak HP metamorphism. Indications for a thermal overprint are already discussed above in the reply to the first comment. A model for the area should be able to explain the blueschist exhumation and mafic eruptions, both Late Triassic. Both rocks are incorporated into the thrust sheets. This is difficult to reconcile with the underthrust model, as the mafics would result from the decompression in an extensional setting during doming that exhumed the blueschists. Rollback could explain mantle upwelling and ensuing igneous activity (as already proposed by Soesoo et al. 1997, for the Lachlan Fold Belt), but not necessarily blueschist exhumation at the same

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time. An explanation for the juxtaposition of the blueschists and sedimentary mélange needs to be found in addition, which is what led us to the proposed model. Most authors agree that some form of astenosphere upwelling occurred by some mechanism, such as slab break-off or core-complex formation. We would argue that our model provides a simple, although not yet published as such, explanation for all the observations in the area. It should be noted that Fig. 6d shows a stage of local extension (at the southern suture), although the overall setting is that of convergence of the North and South Qiangtang terranes, leading to final collision by about 210 Ma. This overall convergence was mentioned in the original text on page 352, lines 7-8. Finally we wish to note that figure 6 is a sketch of the envisaged tectonic evolutions. We cannot tell how wide the "gap" in Fig. 6d was, if there ever was a real gap.

‘ As a conclusion, I would recommend before acceptation of this manuscript for publication to better document the P-T conditions of deformation along the shear zones within this slice stack and to provide further arguments supporting the “asthenospheric upwelling model”. ‘

We hope that the reviewer is satisfied with the above replies. Based on these we propose to make the following changes to the manuscript:

page 340, line 27, add: However, the Permian limestones in contact with blueschists NE of Rongma trend towards strongly deformed marbles at that contact. The marbles contain assemblages of calcite + tremolitic amphibole $\pm$ epidote $\pm$ garnet $\pm$ quartz, which indicates elevated temperatures (up to $\sim$500°C), but relatively low pressure (Bucher and Frey, 2002). Microstructures indicate strong ductile deformation of the calcite (twinning, dynamic recrystallisation) after at least growth of tremolitic amphibole (Fig. 4a). The garnet, however, appears to have grown post-tectonically implying a syn- to post-tectonic thermal event (Fig. 4b).

Note: All subsequent figure numbers are increased by one.

Page 352, after line 5, new paragraph: Liu et al. (2011) showed that exhumation of the

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high-pressure rocks was approximately isothermal (∼500°C) down to at least ∼7 kbar, suggesting rapid exhumation that is in accordance with the proposed model. Juxtaposition of the still relatively hot exhuming blueschists and non-metamorphic sedimentary mélange and sediments can explain the formation of epidote, tremolitic amphibole and garnet bearing marbles at the contact (Fig. 4). Additional heating may have been related to mantle upwelling and concomitant igneous activity.

Page 351, line 9, after "... one to the south." add: A divergent double subduction zone was proposed for the Shuanghu-Tethys by Liu et al. (2011).

Page 351, lines 11-12. Delete part of sentence in "This scenario was proposed for the Shuangu-Tethys by Liu et al. (2011) and is similar to the current situation of the Adria plate ..."

Page 351, line 16. Add: The proposed model for exhumation of high-pressure rocks in a divergent double subduction zone is novel, but bears some similarities with models for exhumation by slab rotation (Hacker et al. 2000; Webb et al., 2013) or slab eduction (Anderson et al., 1991; Duretz et al., 2012). The main difference is that we suggest that the pull of the longer slab is the driving force for slab extraction and resulting exhumation of high-pressure rocks.

References added:

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Duretz, T., Gerya, T.V., Kaus, B.J.P., and Andersen, T.B.: Thermomechanical modelling of slab eduction. J. Geophys. Res., 117, doi: 10.1029/ 2012JB009137, 2012.

Hacker, B. R., Ratschbacher, L., Webb, L.E., McWilliams, M., Ireland, T. R., Calvert, A., Dong, S., Wenk, H.-R., and Chateigner, D.: Exhumation of ultrahigh- pressure continental crust in east-central China: Late Triassic – Early Jurassic tectonic unroofing, J. Geophys. Res., 105, 13,339–13,364, 2000.

Webb, L.E., Baldwin, S.L., Little, T.A., Fitzgerald, P.G.: Can microplate rotation drive subduction inversion? Geology, 36, 823–826, 2008.

Figure 4. Micrographs (crossed polars) of marbles at the contact between Permian limestone and blueschist, NE of Rongma. (a) Deformed and dynamically recrystallised calcite (Cc) with aligned needles of tremolitic amphibole (Tr). (b) Calcite marble with epidote (Ep) and post-tectonic poikiloblastic garnet (Gt).

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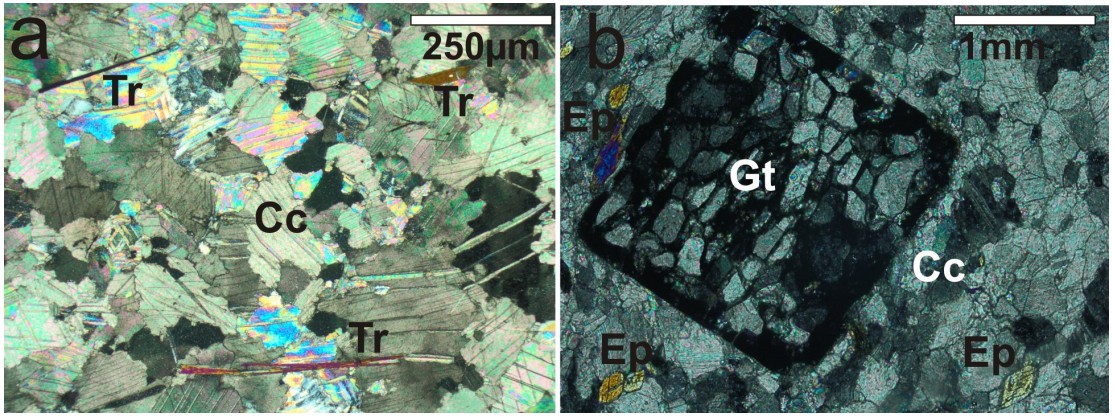

Fig. 1. Micrographs (crossed polars) of marbles at the contact between Permian limestone and blueschist, NE of Rongma. (a) Deformed and dynamically recrystallised calcite (Cc) with aligned needles of tremolit

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