

Interactive comment on “High-temperature metamorphism during extreme thinning of the continental crust: a reappraisal of the north Pyrenean paleo-passive margin” by C. Clerc et al.

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Reviewers comments to manuscript:

“High-temperature metamorphism during extreme thinning of the continental crust: a reappraisal of the north Pyrenean paleo-passive margin”, by C. Clerc, A. Lahfid, P. Monié, Y. Lagabrielle, C. Chopin, M. Pujol, P. Boulvais, J.-C. Ringenbach, E. Masini and M. de St Blanquat

General Comments

This paper addresses the thermal history of rocks subject to crustal thinning leading to

C127

the development of a hyperextended margin. With reference to a number of geological studies, the paper emphasizes right at the onset that the rocks of the north Pyrenean zone are the inverted remnants of such a hyperextended margin, and that the HT-LP metamorphism documented in the northern Pyrenees by previous workers allows to unravel details about the thermal history of such margins. The paper presents over one hundred peak-temperature estimates supplemented with 18 new Ar-Ar (amphibole, mica) ages and one U-Pb (titanite) age supported by field data that clearly improves the spatial and time resolution of the HT-LP metamorphism as documented in the northern Pyrenees by previous workers. This new dataset is in my view very welcome and certainly worth to be published.

Having said that, I have the following general comments. For a reader not familiar with the Pyrenees I believe the tectonic setting and background of the rifting process remains rather vague. First, in most of the paper the age of the rifting is not more precisely indicated than Cretaceous. As a reader I conclude, that if the metamorphism is indeed related to the rifting then the rifting should be Albian mainly, possibly starting during the latest Aptian. This interpretation seems consistent with Fig 15 illustrating the rifting process, but I think a somewhat clearer statement on the age of the rifting could be made in e.g. the Introduction. Secondly, while referring to the concept of hyperextended margins, it is not explained nor discussed if and why such margins should be related to HT-LP metamorphism as observed in the Pyrenees. Thirdly, there is current debate about the kinematics of Iberia motion with respect to Europe, in which the development of the margins and the metamorphism should in some way fit. The mere existence of different and currently competing scenarios should be mentioned in a paper attempting to explain the Cretaceous HT-LP metamorphism, as these scenarios should form the background for any physical explanation of the thermal history observed. With these general comments in mind, I now turn to more specific comments

Specific comments

The above criticism could in part be met with in the Introduction, and partly in the Dis-

C128

cussion. I suggest that the concept of heating during hyperextended margin formation might benefit from a reference to a recent modelling study by Huisman and Beaumont 2011, in particular of their type I margins inspired by the west Iberia-Newfoundland conjugate margin system. Their modelling of this type of margin development suggests some but not extensive heating, hence suggests that hyperextension is not a necessary requirement for the metamorphic conditions observed.

I do believe that the introduction should contain some information with regard to the overall Iberia kinematics according to different authors. As a referee I certainly wish to refrain from insisting on personal ideas, but the scissor mode of motion of Iberia during its anticlockwise rotation as discussed by Sibuet et al. 2004 and further investigated by Vissers and Meijer 2012 leads to convergent motions in a time span that the present authors require extension. As the alternative scenario is entirely based on analysis of ocean floor magnetic anomalies, i.e. on a fully independent dataset, I think the mere existence of such scenarios should not be ignored in a paper like the present one on Pyrenean HT-LP metamorphism, the more because, albeit short, Vissers and Meijer 2012 propose an alternative explanation of precisely this HT-LP metamorphism in the northern Pyrenees.

I have no specific comments on sections 2, 3 and 4, aside some minor aspects regarding the figures mentioned below. These sections are well written and concise.

Discussion section 5 starts with a discussion of the large-scale trends, however, uniquely discussed from the point of view of the hitherto poorly defined rifting context. One explanation (ii on page 814) for the regionally higher metamorphic grade seen in the eastern Pyrenees supposes different kinematics (transtensional) in the east as opposed to orthogonal extension in the west, and again this relies heavily on the overall tectonic setting and kinematics of the Iberian plate. I find it difficult to visualize this scenario without further explanation, because the adjacent continental domains of Iberia and Europe do themselves not significantly deform. So why are the kinematics in the east and west different? The discussion of the high gradients at a smaller scale seems

C129

fair, and fluid circulation for example must indeed have played a role in reaching local high gradients.

Again, with my previous comments in mind, the question arises in how far the inferred rifting and development of a hyperextended margin is conclusively confirmed by the metamorphic data. In my view the metamorphism may be consistent with extensional scenarios, but as mentioned before, one might consider alternatives that can possibly not be discarded on the basis of the observed metamorphism and its timing. I believe the paper would benefit by some discussion of these aspects in the Discussion section.

Technical corrections

I suggest that in the Introduction the authors add a sentence referring to their age dating work. As the paper stands, the dating is mentioned in the Abstract but not in the Introduction, while there is an entire section 4 dedicated to geochronology.

Some suggestions on the Figures:

Fig. 3 shows a red-colored field in the eastern domain which westward fades away at the longitude of St Gaudens. I presume this red field denotes the region of highest metamorphic grade. But what does the vertical extent of that field (along the stratigraphic age axis) mean? Do you mean to show the inferred period of metamorphism? Please clarify this in your legend. As a possible alternative, would it be useful to indicate the (climax) metamorphic temperatures along the length of the NPZ (shown by numbers in Fig 2b) as a graph immediately above the current Fig. 3?

Fig. 4 I am not happy with the representation of the lineation data in rose diagrams. I suppose the numbers near the lineation symbols represent plunges (not explicit in legend). Why not show stereonet? Lineations are 3D features after all, rose diagrams are nice to illustrate directions on virtually horizontal surfaces such as river current directions, but obscure finite stretching directions associated with 3D strains.

Fig. 6 is difficult to interpret for readers not familiar with the details of the RSCM

C130

technique. Questions: 1) what are the parameters along the horizontal and vertical axes, 2) are all of these curves shown along the same axes or are they in some way shifted, and 3) is there a third axis as visually suggested by the fact that the blue curves seem to lie in front of the reddish ones? Please clarify.

Fig. 7 and 8. Why is the stratigraphic sequence in the legend of these two figures shown upside down? This is entirely opposite to geological usage and makes interpretation of the maps more difficult than needed (it is now what I would label a “non-ergonomic” legend). Please show older rocks below younger ones!

The reference to Sibuet (line 8-9 on page 833) is incomplete, as he apparently lost his two coauthors. See reference below.

Concluding remarks:

In conclusion, this study contains an important and welcome contribution to the data describing the spatial distribution and timing of the HT-LP metamorphism in the North Pyrenean Zone that is worth to be published. The paper would certainly benefit from a revision in which the general tectonic context is elucidated and in which pros and cons of different views on the Cretaceous history of the Pyrenees are presented and discussed. I should like to encourage the authors to spend some work on this aspect in their revision.

References:

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Sibuet, J.-C., Srivastava, S.P. and Spakman, W.: Pyrenean orogeny and plate kinematics, *J. Geophys. Res.*, 109, B08104, doi:10.1029/2003JB002514, 2004.

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