

Dear editor,

It is our pleasure to submit a newly revised version of our manuscript se-2021-82 entitled : Dating folding beyond folding, from layer-parallel shortening to fold tightening, using mesostructures: Lessons from the Apennines, Pyrenees and Rocky Mountains.

We would like to thank the reviewers for their constructive comments, that we have carefully considered.

Please find below the comments by the reviewers and our reply (comment/**reply**/changes in the revised manuscript highlighted in yellow).

The additional queries by the Topical Editor, including a summary of our answer to RC1 and the careful checking of the english language, have been carefully considered (changes in the cover letter and revised manuscript highlighted in blue).

COMMENTS BY REVIEWER 1 :

*Internal shortening of strata replaced by internal strain of strata : **done**

*mesostructures developed during extension at fold hinge replaced by syn-folding mesostructures : **done**

*Early-folding layer-parallel shortening : **added**

*Less instead of little : **done**

*preserved growth strata are not ubiquitous/are rare, and the folded multilayer typically includes only pre-growth strata. Also, **added**

*Where available : **added**

*Tavani et al, 2012 : **reference added**

*and tangential longitudinal strain (outer arc extension and inner arc compression) : **added**

*Cruset et al, 2021 : **reference added. we also added Cruset et al 2020 and Grobe et al 2019 for a fair acknowledgement of previous work.**

*which is evidenced by the paucity of fracture studies in syn-tectonic strata (e.g., Shackleton et al., 2011) : **added**

*neither at the macro- nor at the micro-scale : **added**

*from well data : **removed**

*and/or exposed stratigraphic successions : **added**

*- both veins and tectonic stylolites being vertical regardless of the bedding dip - : **added**

*Fm. : **changed**

*Vidal Royo et al., 2009 : **reference added**

*Note that age overlaps could relate also with the fact that LPS and fold growth overlap in some cases, as documented in the Sibillini thrust anticline, i.e. the southern continuation of the San Vicino anticline (Tavani et al., 2012) : **added**

*Fig.5 instead of Fig.4 : **done**

*How does this influence the fracture pattern? any insight from these examples?

Taking ‘fracture pattern’ in the sense of Tavani et al (2015), no notable difference was observed for the type and sequence of mesostructures occurring during layer-parallel shortening, fold growth and late fold tightening for the studied fold examples despite the duration of the folding event was different among the folds. We think this reflects that fracture formation is fast enough to occur whatever the duration of the folding event and related substages.

We added: it is worth to note that at first glance the fracture pattern (eg, Tavani et al., 2015) remains basically similar whatever the overall duration of the folding event and of the related deformation stages.

*It would be great to have an idea, even approximated, about the shortening rate, for both LPS and fold growth stages.

We agree with the comment but it is currently out of reach to discuss the shortening rate in a proper way, even though the duration of deformation stages is now better constrained.

On one hand, it is nearly impossible to quantify the amount of shortening related to early-folding layer-parallel shortening and late fold tightening. Such quantification would have required a complete strain analysis which is out of the scope of the paper and remains very complex to perform since internal strain is strongly partitioned and accommodated not only by fractures, but also by pressure solution, porosity reduction, calcite twinning strain, etc.

On the other hand, constraining the duration of the folding event requires a fair amount of work (spanning from understanding the fracture network and fold formation to absolute chronology) that is seldom to find in the literature. Hence we have a limited choice of folds available to perform our study, and these are not the friendliest ones to carry out shortening estimates, even when focusing on the fold growth itself. Indeed, in the case of the Pico del Aguila, the rotation occurring during layer-parallel shortening and fold growth makes it even more complex to evaluate the shortening. There is room for interpretation of the deep structure of the Sheep Mountain Anticline (Bellahsen et al., 2006) even if most authors agree with underlying high-angle basement thrusting. Out of the four folds studied, some rough shortening estimates could be proposed for San Vicino and Cingoli on the basis of existing literature that propose balanced cross-sections, yet the in-depth structure is still debated in the Umbria- Marches (Scisciani et al., 2014). Thus, we believe that although being of great interest, a discussion about the shortening rate versus duration of deformation actually is one of the next steps our study allows, but it requires a complex, stand-alone structural study, or to focus on other targets for which the data are not yet available.

As a result, considering the few fold examples for which absolute ages of related mesostructures are available, neither estimates of shortening rates related to LPS and fold growth nor a meaningful comparison among them are feasible. For LPS, the suggested estimates would require a full strain analysis, which is not realistic in the brittle field. For fold growth, the suggested estimates would require a thorough balancing of sections across the studied folds, which is out of reach since the deep structure of most of them is still debated.

To sum-up, estimates of shortening rates would need months of additional work together with new data acquisition. We nevertheless think that as it stands our present study provides valuable time constraints on the duration of the entire folding event for different types of folds, which has never been proposed before, and, therefore, that it consists of a significant step forward which paves the way for future investigations on this topic.

*AS (Adriatic Sea) : **corrected in Fig.3**

*Caption of Fig.2 : **corrected (B<->C)**

COMMENTS BY REVIEWER 2 :

*14 fold hinges I think : **modified according to reviewer 1**

*19 a function : **done**

*20 appraisal : **cannot understand the comment. appraisal remains**

*40 I think that is a repetition in the sentence, first discontinuous and then at the end you say “rather than occurring in a continuum”. I think you can just leave this last part out : **done**

*88 “examples of fold” seems wrong, maybe example folds that we investigate? : **done**

*149 set I consists of : **done**

*150 I think stylolite teeth cannot really strike, I would call this “trending” and plunging, they are a lineation : **done**

*151 plunging parallel to bedding, which, after....**done**

*192 “younger” younging? **done**

*193 rotation around a vertical axis : **done**

*195 The field study , and what do you mean by “later” : **done**

*207 The Sheep Mountain... **done**

*209 consists of : **done**

*276 folding shortening? What do you mean? : **done**

We hope that we have satisfactorily addressed the reviewers’ comments and that the manuscript will now be acceptable for publication.

Sincerely

Olivier Lacombe, on behalf of co-authors