

Interactive comment on “Exhumation of metamorphic rocks in N Aegean: the path from shortening to extension and extrusion” by R. Lacassin et al.

Anonymous Referee #2

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General Comments:

Overall, this paper presents new Ar-Ar dating and exhumation data from the western N Aegean. These data are used to interpret different phases of deformation in the area with the view to differentiating driving mechanisms and history of extension. Although the geo- and thermochronology data are clearly new and valuable, I question some of the interpretations of regional tectonics and believe a more thorough and careful analysis must be made before this paper is published. Implications for the conclusions of the paper are therefore fairly significant. My area of expertise is mostly in the recent tectonics of the area. I am not an expert on Ar-Ar dating, metamorphism or exhuma-

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tion histories, therefore will leave more specific comment on these sections to other reviewers.

1. In general, some parts of the paper were unclearly written and therefore difficult to comprehend without taking considerable time. This must be addressed before publication can proceed.

2. The tectonic interpretation (introduction and conclusions) makes assumptions about our knowledge of the region - conclusions are made without mention or exploration of other driving mechanisms. E.g., it is not a certainty that the NAF propagated into this part of the Aegean at 4-5 Ma and that this drove the tectonics of the area rather than other mechanisms. The authors base their conclusions and hypotheses on other hypotheses which are portrayed as certain. This is a recurring theme, so mentioned several times below. Also, tectonic rotation is not mentioned at all and surely this must be relevant when considering a variety of fault orientations and considering which belong to which mode/phase of extension. Block rotations within general models of Aegean deformation are significant (supported by plenty of documented evidence of rotation) and surely should be mentioned here. I would presume that this would open up other possible models of extension in the western N Aegean, possibly even simplifying the tectonic picture?

3. The Ar-Ar geochronology and thermochronology data are valuable, adding to the current database and providing a means of interpreting the regional tectonic history. However, a tighter and more thorough tectonic interpretation is needed.

Specific Comments through the Manuscript:

Abstract ~13 - check grammar of last sentence. "Ě. Propagation of the NAFĚ known..". Is this really true, that we know the nature and timing of propagation of the NAF into the Aegean? I would say this is not certain, despite data and models presented in previous publications mentioned here (Armijo et al., 1996; 1999). Having more closely re-read these 2 papers, I find that many arguments are internally derived and not categorically

proven by external data or evidence. Amongst other authors, there is certainly debate about the age of different parts of the NAF and its likely growth pattern - regardless of one's opinion about these various hypotheses, an impression of the level uncertainty is not given in this current paper. Therefore this model (NAF propagation) could be linked to the W N Aegean deformation as a possible mechanism for the deformation presented in this paper but should not be to the exclusion of other hypotheses or its interaction with them.

Introduction First paragraph - nicely explained background. p.3, l 10 - Extension of NAF into Aegean. Should elaborate here on this theory, what it is based on and other ideas about the timing of this fault in the area. L 16 - is extension controlled by the NAF or vice versa? This is a good question but I don't believe realistic to fully answer it in this paper. Reading on, the authors seem to assume that extension is controlled by the NAF rather than proving it. L20 - "culminations affecting thrust-nappes". Not clearly written, please rephrase. L 25 - "normal faults that splay from the NAF". Again, do you know with certainty that these faults are splays of the NAF? See below for more comment.

2.1 First paragraph: This is very difficult to decipher! There are so many different orientations provided (some here and later in different formats, eg ESE vs N110E) that it is difficult for the reader to visualise what is described. In addition, Figure 2a is small and not entirely clear - not portraying these various orientations and their relationships clearly. I'm afraid I therefore cannot provide a thorough analysis of this material. L 7 - How well constrained is the relationship between the faults (plus the nature and orientation of faulting) at the western end of the N Aegean and the NAF (particularly offshore)? I agree that the bathymetry of Papanikolaou et al is compelling but presumably both tectonic and erosional processes are producing the seafloor morphology here. The juxtaposition of faults $\sim 90^\circ$ to each other in the S or SW corner of the data and figure 1 fault map suggests this could be an issue - I see interpretation here is different from Papanikolaou but on what basis are faults interpreted as either strike-

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slip or normal? Is there confirmed pure strike-slip displacement on what is labelled as the NAF in the westernmost N Aegean? Note: there should be some discussion or reference to earthquakes in the broader western N Aegean here to support (or not) interpretation of faults here. For example, McNeill et al. (2004) have a summary of some focal mechanisms. I notice in their paper that there is an E-W (ENE) normal fault event sitting in the Thermaikos Gulf area on top of active faults trending NW-SE from figure 1 of Lacassin et al. How can this be reconciled? L 9 - Is the Chalkidiki peninsula area fault controlled? Presumably yes, but have not stated. Some parts have active faults on your figure 2a and some not but is this a function of the extent of the bathymetry data of Papanikolaou? How well constrained are active faults in this area? Chalikidiki peninsula not labelled on fig. 2a. L 10 - piedmont. If this is what you mean, maybe foothills is more appropriate. Not clear what exactly is meant here or absolute location. L 12 - Are both sets of faults here currently active (not stated), ie N110E faults and range front? L 21 - half-window. What do you mean by this? Unclear. L23 - HP/LT - write out the first time. L 27 - "normal range front fault". Do you mean the N160E fault mentioned above? If so please use same notation for orientation so we can follow the arguments. Plus use same terminology - main range front or normal range front fault? p.5 L 1 - if triangular faceted, is this fault active as well? Does this suggest the range front faults and the "recent normal faults" on the piedmont are active together? If so, how does this fit into interpretation? L 3 - what does 20-30° ENE mean? I presume dip, therefore write E. What is the trend - Is it precisely ENE dip direction? Then should give actual dip and strike (or dip direction). If only giving dip, stick to E. L 8 - "offshore active normal faults to the NE". Which are these from the previous discussion and where on figure 2a? And what is their trend? L 13 - does description of metamorphic and PT conditions here refer only to the Pelion range or throughout? End of section: as much potentially confusing material has been covered you need to produce some summary or clarification here.

2.2 In general, this is not my area of expertise so I can only comment on the more general results and interpretations later in the paper. p.8 L 7 - 10°E dipping fault. How

does this fit in with earlier interpretations of fault populations?

3 p.9 L 12 - same as the stretching direction, not “than”. L 16 - ok, this will be clear if earlier discussion has been clarified. Again, is N-S extension of both onshore and offshore faults supported by focal mechanisms from both offshore and onshore earthquakes? (Only a few localised earthquakes are depicted here).

4 p.10 L 9 - Why is it clear this is a separate phase of extension prior to “Aegean extension”. Do you mean backarc extension in the Aegean? This should be clarified. How well constrained is the timing of onset of Aegean backarc extension and therefore could this be a possible source? In the introduction it’s stated that the onset of this extensional phase could be “more than 24 Ma”. A lot of these fault orientations also fit the general slat model of Taymaz et al. (1991). L 20 - this last statement is fine if the authors feel the timing of “backarc extension” is well constrained. But I do think there needs to be some discussion over how this is defined and timing constrained. L 21 - Again, we have a statement that assumes two things: 1 that the NAF propagated into the western Aegean at this time, and 2 that it is responsible for the extension being documented. There are clearly other models and possible mechanisms for extension in the Aegean, but they appear to be ruled out without further discussion. L 24 - The relationship between different phases (and orientations) of faults is not clear from Fig. 2a as described here. L 28 - Fault orientations at ~5 Ma. It’s clear from this paper and from Fig. 2a that there are many different orientations of faults generated by slightly different phases of extension. One thing not mentioned in this paper is rotation history from paleomag. (more below). Surely with this in mind and therefore the rotation of earlier fault populations, you generate a complex fault pattern with older vs newer fault trends, plus the added complexity of tectonic processes which produce a range of fault orientations within one active period (if fault trends in Fig 2a are correct). Considering these points, it would seem difficult to distinguish (without more elaborate discussion here to justify) a long-lived backarc extension phase from a shorter NAF-driven phase. How is this recent phase distinct from a continuum of changing fault orientations as

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gradual rotation takes place through time? General point - Some general comments needed on impact of rotations on fault orientations and then what drives the extension. Can this process in a context of backarc extension explain some or all of the observations? p. 11 L 1 - associated with changes (not to) L 6 - as before: is the NAF as driver of extension the only possibility here? General backarc extension probably continues into recent times is shown on Fig 5, so should be discussed.

Figures

2a. V small (is this the scale it will be published at?) and not showing faults clearly labelled from discussion on p. 4. If text were improved and annotation of this figure, it might be possible to understand this section more easily. More representative focal mechanisms needed rather than just in one small area? What is the source reference for active faults interpreted and shown in this figure? Goldsworthy et al. (not Goldworthy). 3. Not clear that diagrams of structures are separate insets or linked to the photos above. Probably need separate letters (g, h) so clear in caption. 4. OK 5. Top right figure - this is a cross section so presumably the NAF is being shown here as a horizontal fault?? If not, this sketch is very unclear. What does the box represent?

1) Does the paper address relevant scientific questions within the scope of EE? YES
2) Does the paper present novel concepts, ideas, tools, or data? YES
3) Are substantial conclusions reached? SOMEWHAT
4) Are the scientific methods and assumptions valid and clearly outlined? SOMEWHAT
5) Are the results sufficient to support the interpretations and conclusions? NO
6) Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? NOT MY FIELD
7) Do the authors give proper credit to related work and clearly indicate their own new/original contribution? YES
8) Does the title clearly reflect the contents of the paper? COULD BE MORE SPECIFIC
9) Does the abstract provide a concise and complete summary? YES
10) Is the overall presentation well structured and clear? SOMEWHAT
11) Is the language fluent and precise? SOMEWHAT
12) Are mathematical formulae, symbols, abbreviations, and units cor-

rectly defined and used? YES 13) Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? YES, CLARIFIED 14) Are the number and quality of references appropriate? YES 15) Is the amount and quality of supplementary material appropriate? YES

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