

# Evidence for the Late Cretaceous Asteroussia event in the Gondwanan Ios basement terranes

Sonia Yeung<sup>1</sup>, Marnie Forster<sup>1</sup>, Emmanuel Skourtsos<sup>2</sup>, Gordon Lister<sup>1</sup>

Authors' responses to the reviewer's comment.

Authors' responses are identified as blue text

## General comments

The manuscript is not concise and explicit

We will review the manuscript prior to resubmission with attention to its brevity and ensuring concise and explicit links to relevant material.

The manuscript has incomplete and/or illegible figures

We will review the manuscript prior to resubmission with attention to this aspect. We note that the submitted version had no problems in respect to incomplete or illegible figures.

The manuscript has incomplete figure captions

We will review the manuscript prior to resubmission with attention to this aspect.

Tables in the manuscript are improperly formatted

We will review the manuscript prior to resubmission with attention to this aspect.

The separation between original and recycled data is not clear.

We will review the manuscript prior to resubmission with attention to this aspect. Previously published data was explicitly identified in the submitted manuscript. However, it was not made clear that the submitted manuscript had new figures based on the analysis of these data.

Many statements about mineral chemistry remain unproven or not documented.

We will provide the data for mineral chemistry in the supplementary material.

Analytical errors are not shown in the mineral chemistry graphs.

We will review the manuscript prior to resubmission with attention to this aspect.

The manuscript does not provide tectonic background

This is not entirely correct – please see the section in the introduction. The resubmitted manuscript will more explicitly draw attention to the tectonic background as a separate section.

The manuscript does not differentiate deformation events (D1, D2, etc.)

This is correct, for the reason given in Forster and Lister (2008). Geochronology has shown that the tectonic evolution of the Cyclades is far more complex than the current simple D<sub>1</sub>, D<sub>2</sub>, D<sub>3</sub> scheme allows. We will mention this in the introduction. The paper has tried not to get entangled in the consequences of this failure, though we could suggest reform of current structural geology methodology is necessary.

The manuscript does not assign the different mineral generations (wm1, wm2, ect.) to D1, D2, etc.) events.

This is correct, as given above, but also because there is no reason that an episode of metamorphic mineral growth should *a priori* be linked to a deformation event. The paper uses Tectonic Sequence Diagrams (TSDs), which focus on reporting observational data. TSDs used in the paper include observed microstructural sequences linked to outcrop related sequences of deformation and metamorphic mineral growth events. Thereby we avoid model-based assumptions. The resubmitted manuscript will draw more attention to this aspect.

A proper structural map or cross section is missing.

The structural map and cross-section are published in Forster et al. 2009. The resubmitted manuscript will explicitly draw attention to this point.

The methodology is poorly described in terms of sample preparation, sample size, cleaning and measuring procedure (e.g., blank values and standard age values are not reported).

We have reviewed the manuscript with attention to this aspect. To ensure the storyline of the paper, detailed description of the methodology will be placed in the supplementary material with the manuscript explicitly drawing attention to this supplementary material.

In many paragraphs the headings are misleading and do not fit to the text.

We have reviewed the manuscript with attention to this aspect.

---

---

#### **Specific and editorial remarks:**

##### **Abstract:**

The abstract is not explicit enough and in parts speculative.

All authors will be consulted, and the abstract will be revised in the resubmitted version.

Also the phrase that "Ar geochronology...demonstrates...metamorphic event" is misleading, metamorphic events are determined by petrology and these events might be dated by geochronology.  
The sentence will be revised in the resubmitted version.

##### **Introduction:**

The reviewer mentioned different aspects of the introduction that required further editing. We provide individual comment to each of the aspect and include our suggested structural change in the introduction to acknowledge the opinion of the reviewer.

The introduction does not introduce the main problem and ongoing discussion in literature adequately.  
We agree with the reviewer and the introduction will be revised in the resubmitted version.

The introduction does not introduce the controversy in interpreting Ar-data of HP rocks.

We agree with the reviewer and the introduction with special attention to this aspect.

The introduction does not introduce what plates/ terranes are involved while some information are provided in figure 2 only.

Same comment as above, we will reformulate the text to give some connection between the figure and the text early in the paper.

The “Late Cretaceous metamorphic event” is not clear in the introduction (line 22).

The focus of this sentence is the identification of a metamorphic event at the time of Late Cretaceous Asteroussia age. Based on the reviewer’s suggestion, we now changed it to “Late Cretaceous high pressure, medium temperature metamorphic event” to be more specific.

The revised Introduction will take specific note of the following in response to the reviewer’s comment:

- (1) The significant knowledge gap that exists in understanding old events in the Los basement terrane prior to Alpine deformation events.
- (2) The consequences of accreting this Gondwanan terrane to the Alpine terrane stack such as the extreme crustal extension after accretion, followed by magmatic event in Oligocene-Miocene period lack proper explanation.
- (3) Until this work, it is largely assumed that the Los basement is not affected by pre-Alpine deformation since ~300 Ma (hence referred as the Hercynian basement).
- (4) Previous data did not recognize high-pressure rocks in the Los basement and its tectonic history is much more complicated than a single  $M_0$  event can define.
- (5) Referring all older events as  $M_0$  (pre-HP metamorphic event) results in little to no attention on older events prior to accretion in the evolution of the European terrane stacks.
- (6) Recognition of the exhumed Asteroussia terrane across the terrane stack in this study enabled us to identify a subduction jump that is impossible without a tectonic mode switch.
- (7) Our proposed model on the subduction jump is able to capture and explain the extreme extension after accretion, formation of Cycladic metamorphic core complexes and the later Oligocene-Miocene magmatic event.

**The Asteroussia Nappe (section 2):**

The reviewer mentioned different aspects of this specific introduction section to the Asteroussia Nappe that requires further editing. We address each of the comments as follows. These aspects will be considered and revised in the resubmitted version.

The idea of “the same metamorphic age” outcropped in various Cycladic islands is unspecified (line 58)

This particular sentence follows the deduction from line 54, discussing outcrops of the Asteroussia nappe across the Greek Cyclades. The main focus is the late Cretaceous 70-80 Ma age observed across all outcrops of the Asteroussia terrane (as summarised in table 2). The resubmitted manuscript will link this sentence to table 2 to make the idea more concise.

The published Rb-Sr dates mentioned does not include details to its interpretation (line 61).

We agree with the reviewer, the revised manuscript will pay special attention to the background behind such statement for better presentation.

The reviewer suggests replacing “low-pressure” by “retrograde” in line 65.

We found “overprinted by low-pressure greenschist facies” better to describing the occurrence of a younger deformation event with different property instead of saying that the rock experienced “retrograde” metamorphism due to the complexity of deformation and mineral growths associated. All authors will be consulted, and the sentence will be revised in the resubmitted version.

The reviewer suggests reformatting section 2.2 (which include the main research hypothesis/question) to link it with the Introduction and integrate research methodology in this section.

We agree with the reviewer, details to the proposed introduction are discussed above. The resubmitted manuscript will consider linking section 2.2 to detailed research methodology in the supplementary material.

The reviewer suggests adding references in line 77-78.

We agree with the reviewer, this has been corrected.

This section failed to present the field results demonstrating different deformation events

The revised manuscript will include details to explicitly draw attention to structural results on the various deformation events.

Tables of quantitative white mica data is missing in this section

The revised manuscript will provide connection between the text and the analytical results in the supplementary material.

### **Microstructural analysis and mineral chemistry (section 3):**

The reviewer suggested various changes to this result section. We address each of the comment separately and will revise the raised concern in the resubmitted version.

A large portion of this paragraph should be shifted into the former section to describe and introduce the deformation zones and deformation phases.

We agree with the reviewer, the resubmitted manuscript will pay special attention to this recommendation. Section 2.2 (The Asteroussia event on Ios) will be revised:

- (1) Introduction of the four terrane slices in Ios. This will include a summary of the literature review and controversies on the structure of the terrane stack outcropped in Ios
- (2) Deformation zones and events recorded in this study will be presented
- (3) The section will conclude why the identification of the Asteroussia event on Ios will provide a significant knowledge advancement in the tectonic architecture in Ios and the Cyclades, hence this paper.

Quantitative data should be given in tables, e.g. in supplements

The revised manuscript will include text in this section explicitly drawing attention to the supplementary material with quantitative data and its methodology.

The reviewer suggests shifting the sentence in line 100-103 to the introduction.

We agree with the reviewer and have changed accordingly.

The reviewer suggests shifting the sentence in line 104-106 to section 2 – the Asteroussia nappe.

We agree with the reviewer and have changed accordingly.

The reviewer suggests enlarging the text in figure 3.

We agree with the reviewer and have changed accordingly.

The reviewer suggests shifting the sentence in line 111-112 to section 2 – the Asteroussia nappe. The reviewer also suggests providing field evidences to this sentence.

We agree with the reviewer regarding the new location of this sentence. If we show the field evidence of these event, this will entail the addition of a new figure, altering the entire manuscript to suit.

The reviewer suggests specifying the term “both tectonic silvers” in line 113-114.

We agree with the reviewer and have changed accordingly.

The reviewer suggests re-organising table 1 to be more space efficient.

We agree with the reviewer and have changed accordingly.

The reviewer suggests introducing all metamorphic events (including the “ $\Delta_{1D}$  event” in Forster et al. (2020)) in the introduction.

We agree with the reviewer. Revision to the introduction is discussed above.

The reviewer suggests specifying the deformation event associated to the described deformation in line 124-125.

We agree with the reviewer and have changed accordingly.

The reviewer suggests providing structural description in terms of a map and cross section(s) to illustrate the deformation event associated to the described deformation in line 125-127.

We agree with the reviewer. We will adjust and correlate this sentence to in text figures and supplementary materials accordingly.

The two white mica generations need to be clearer in figure 4 with added sample details.

We acknowledge the reviewer’s opinion. We will add details to this part (both in text and as figure – higher resolution image) to provide further details to the observation in the resubmitted manuscript.

Figure 4c need more statistical information.

We acknowledge the reviewer’s opinion. The data presented in this chart is the exact value calculated from experimental data, but we will provide calculation details and background in text.

Differentiation of the different white mica generations is not concise in line 140-142.

We acknowledge the reviewer’s opinion. We will include a detailed photo illustrating the crosscutting relation of the two white mica generations.

The concluding sentence in line 145-146 need evidence.

In the previous sentence, we provide an estimated peak metamorphic P-T condition based on phengite Si-content. This led to our “conclusion” in this sentence. We will be more specific in the sentence by provide a stronger deductive linkage in the resubmitted manuscript.

Sample number is needed in Figure 5 caption.

We agree with the reviewer. This is corrected in the revised manuscript.

Further specification is needed in describing the “non-end member” garnet in line 154-155.

We agree with the reviewer. We will provide further information in the supplementary material and directions to refer to such result in text.

Further specification is needed in differentiate between two iron ions in composition calculation in line 155-156, and data is to be supplied.

We agree with the reviewer. We will reformulate the statement and provide the data in the supplementary material.

Words that are ‘interpretations’ should be corrected to words that ‘present’ the result in line 156-157.

We agree with the reviewer, the sentence is corrected accordingly in the revised manuscript.

Replace “shear zone operation” by “shearing” in line 161-162.

We agree with the reviewer, this is corrected in the revised manuscript.

Rephrase line 162-163 to include argument for more intense deformation mentioned in text.

We attempt to compare between deformation fabrics in sample IO17-03 and IO18-05. The sentence is rephrased.

Data presented in figure 6c needs further specification on statistical details

The error bars are initially omitted in the figure to avoid confusion as some data points cluster tightly together. This will be discussed among all authors.

A change of line spacing in line 170

This is corrected in the revised manuscript.

The reviewer think it is unnecessary to highlight the idea of “non-endmember garnet” in line 171-172 as most garnets are mixed crystals.

We agree with the reviewer and now describe the garnets as “garnet porphyroblasts with chemical composition between almandine -grossular” and refer to data in the supplementary material.

The reviewer thinks the differentiation between these two groups is not convincing in line 180-181. And ask for reference to the barometer used.

We acknowledge the reviewer’s suggestion. The sentence will be re-structured in the resubmitted manuscript. References of the used barometer are added, how the result is deduced will also be included in text, with reference to the supplementary material if needed.

The structural unit and sample name of the sample is missing in figure 7

We agree with the reviewer and have added the suggested details to the figure caption.

Line 190-192 should be shifter to section 2 to describe observation in a more systematic way.

We acknowledge the reviewer’s suggestion and will revise the sentence in such the information is (1) mentioned in section 2 and (2) relates observation in section 2 to analytical results presented in this section (section 3).

The phrase “Thin-section parallel to the stretching lineation” in line 194 needs clarification and should be added to the figure caption of figure 7.

We acknowledge the reviewer’s suggestion and will revise the sentence accordingly.

The reviewer suggests the connection of “quartz filled cracks created by crustal stretching” in line 196 is an interpretation that should go into the discussion.

We agree with the reviewer that this is indeed an interpretation hence need reformatting in the result section of the paper. This suggestion will be considered when reformulating the resubmitted manuscript accordingly.

The reviewer suggests adding details on sample preparation as artificial small grains might be resulted when reducing a rock sample to grains in line 220.

We acknowledge the reviewer’s opinion. We will provide more details and reasoning in methodology selection in the supplementary material with some connection between the text and the supplementary material. The diffusion domain for argon can be significantly smaller than the grain radius, hence artificial small grains is unlikely to cause significant impact on data quality.

The reviewer suggests reformatting line 210-211 to be more explicit.

We agree with the reviewer and will reformulate this particular sentence in the resubmitted manuscript.