Response to the Reviewer

Ms. Ref. No.: esurf-2016-62

Title: Distinct phases of eustatism and tectonics control the late Quaternary landscape evolution at the southern coastline of Crete

In the following paragraphs, we carefully address each of the Reviewer's comments and suggestions (which they appear here in black*). Our responses are in 'red italics'.*

As the Reviewer did not refer to specific line numbers, we present below answers that correspond to each of his comments. All our changes in the revised version submitted here are tracked and reflect our effort to satisfy the Reviewer of this manuscript as well as the compilers of the short-comments submitted during the online interactive discussion.

We thank the Reviewer for his overall positive comments and constructive criticism. From our understanding, his/her main concern is the unsatisfactory results of the luminescence dating. We totally agree, as we clearly state in the manuscript, that the luminescence results have large uncertainties and are, therefore, unsatisfactory. However, our sequence of events presented in this manuscript is not based on the luminescence dating. It is based on, and demanded by, the stratigraphy and the stratigraphic relationships that we recorded at Domata.

Before we go addressing in some detail this and other secondary remarks made by the Reviewer, we would like to make a general statement about the objectives of our work and constrain its scope. This may help allay some concerns expressed by the Reviewer.

Our primary interest in our work on Crete is to help constrain its late Quaternary tectonic development. With this work we aim to use first-order geomorphic features and stratigraphic relationships to understand the late Quaternary vertical deformation of western Crete. In doing so, we recognised the importance of the Domata fan sequence and the important marine bench cut in upper-fan at Domata. This feature allows us to independently derive a late Quaternary uplift rate from this section of western Crete. The paper is important because of this independence from previously derived uplift rates on western Crete (e.g., Shaw et al., 2008; Strasser et al., 2011; Tiberti et al., 2014; Mouslopoulou et al., 2015 – all references included in the submitted version).

To achieve these objectives, we needed to understand the first order fan geomorphology and from it dissect out the sequence of events required in landscape evolution. ***We derived a basic sequence of events that is demanded by the stratigraphic relationships present at Domata and present these in the manuscript.*** *We have gone to some effort to place the Domata fan sequence within its stratigraphic and chronologic context so that we fully understand the uplift rate derived. The final piece of the puzzle required to derive our uplift rate was its integration with a high quality sea level curve for the last 125 kyr. We chose Siddall et al.'s (2003) sea level curve because of its precision, relative proximity to the Mediterranean, yet its isolation from the variable tectonic signatures and isostatic problems associated with glacial loading of that region, and for its similarity with the Lisiecki & Raymo (2005) stacked curve.*

The luminescence dating we undertook simply provides confirmation of the chronological framework for the events that we had previously deduced with reasonable confidence from other stratigraphic and geomorphic observations. We completely agree with the reviewer that our luminescence dating, with its large uncertainties, cannot provide adequate resolution to separate the individual events presented here. The landscape evolution proposed in Figure 10 is not based on the luminescence *dating: it is based on the **sequence of events** that is demanded by the stratigraphic relationships present at Domata. The luminescence dating comes only to provide the chronologic frame (MIS 3) within which this sequence of events took place.*

For detailed discussion on the major issues relating to the IRSL dating we kindly direct the Reviewer to Pages 3-4 of our response to the short comment of Gallen and Wegmann (dated 27 Jan 2017) during our online interactive discussion.

In the revised version we have put some effort to:
- rephrase the scope of this paper,
- more clearly describe the main geomorphic features observed and
- more carefully present their interrelations

by:

- *Including additional text (see tracked changes throughout our manuscript),*
- *Modifying our former Figure 5 to include schematic sketch of the volumes of the upper and lower fan materials and the stratigraphic position of each of our IRSL samples within these volumes.*
- *Re-annotating/modifying existing figures (Fig. 6b) or introducing new figures (Fig. 6c).*
- *Including discussion on the important work of Pope et al. (2016), that was missing from our originally submitted version as its publication post-dated our work.*
- *Updating our reference list.*

In addition, we have modified accordingly the revised version to accommodate all other specific comments of the Reviewer as well as comments from the other two commentators during the online interactive discussion.

General Comments

The Mouslopoulou et al. paper deals with a topic that has both environmental and tectonic implications, focusing on a well-expressed sea-side alluvial fan. Compared to the other fans that make up the coastal bajada of south Crete that develops ca 20 km further east, Domata fan is a relatively small one (area c. 0.2 km_2), along with a string of other isolated fans that border the steep southern Cretan coast. Nonetheless, its stepped morphology, with an escarpment running roughly parallel to the present-day coastline may be indicative of processes that significantly affect fan-shape evolution, as the 'marine trimming' suggested by the authors. Indeed, Mouslopoulou et al. have tried to link fan evolution to climatic changes, coupled with uplift rate scenarios for the past few kyr and come up with a scenario that ties the evolutionary stages of the fan to successive marine high- and lowstands.

To achieve such a target, one has to resort to high-res geochronology, something that is not always feasible. Her lies, in my opinion, the main drawback of Mouslopoulou et al.'s work, which is found in their sampling strategy and the resulting dating accuracy: while the latter may not be the authors' fault, the former is a weak point in this work. Sampling did not include the body of the 'lower fan': this might clarify –and probably strengthen the authors' distinction of the Domata fan in an 'upper' and a 'lower' one. (Of course, this might not help, either, as the results from the other samples contain significant errors).

Having said these, I acknowledge the fact that the number of dated samples (and possibly the range of dating methods applied) are dictated by research funding; nonetheless, one has to make do with what they have, I'm afraid. At any rate, the resulting OSL ages contain significant errors (as also acknowledged by the authors: P.8, l. 14); it is also unclear whether standard deviation and standard error refer to 1-σ or 2-σ *(they refer to 1σ, as it is stated in Figure 9).* Hence, temporal resolution is too poor to support such a detailed evolution scenario, whose resolution is as high as 1kyr, while most ages overlap significantly and the correlation of successive events to KDE_{max} is not satisfactorily constrained. *For this comment, please see our introductory statement above.*

The lithostratigraphy of the Domata fan is poorly described; lithostratigraphic logs are missing – and these could help place the obtained samples in a coherent geological context. Moreover, it might clarify any probable lithological or other difference between the units described as "upper" and "lower" fan. This could also be aided if appropriate figures (esp. photographs) were included, to show the lithological composition of the fan(s). Panoramic photos are fine, but some close-ups would be very useful for the reader to understand the distinction made between Upper and Lower Fans. Figure 8 (b and c) focus on the soil cover and do not serve this purpose.

The above stated objectives do not include a comprehensive description of the materials of the Domata fans (lithostratigraphic logs) and their developmental chronology, as has been undertaken for other fans of southern Crete by others (e.g., Nemec & Postma, 1993; Gallen et al., 2014; Pope et al., 2008, 2016). Nevertheless, we have rephrased the text in the revised version of our manuscript to better describe these geomorphic features and their interrelations. Besides, to better illustrate the first-order stratigraphic relationships between the main geomorphic features, we have now modified Figure 5 by illustrating schematically the volumes beneath the measured profiles to indicate the likely extent of the volumes of upper fan and lower fan materials. We have also added the locations of each of the luminescence samples. We have further followed the Reviewer's advice and we have modified Figure 6b to better reflect the relationships between lower and upper fan units. In addition, we have also included a close-up image (Fig. 6c) to better reflect the relationship between the unconformity at the base of the fan sequence and the AD365 bioerosional notch.

Between Domata and Sougia (c. 9 km to the west) there is a number of fans in practically the same a geomorphological and geological environment (the same could also be supported for the bajada the east, with Sfakia fan being its westernmost member). Processes suggested in this paper (i.e. "marine trimming") are not localized ones and affect extended tracts of land. So if such a process was responsible for the modification of the Domata fan, why it is not found elsewhere along this coast?
It is true that along the southwestern coastline of Crete (e.g., east and west of Domata), there is a number of alluvial fans in roughly the same geomorphological setting. Many of these fans are indeed clearly truncated by the sea (Figure A below, near Trypiti, west of Domata). Although the 'double trimmed' alluvial fan-system at Domata is unique in its kind (as each episode of the two alluvial fan-building episodes has been followed by episodes of alluvial incision and subsequent marine trimming), evidence for 'double marine trimmings' exists elsewhere on western Crete as well. In Figure B below, for example, we provide evidence for a similar geomorphic feature that occurs at Agia Roumeli (about 4 km east of Domata), where an alluvial fan-system is truncated by two distinct marine-trimming events. It is hard to argue that these cliffs (illustrated in Photo B) are not trimmed by marine processes as they are parallel to the coast and on steeply sloping fans. Besides, on the upper cliff, the one with the sea-caves (where the hiking-track from Domata to Agia Roumeli passes through), we have found beachrock with shell-hash.

Figure A: Marine-trimmed alluvial fan near Trypiti (west of Domata)

Figure B: Double marine trimming of alluvial fan-system at Agia Roumeli (east of Domata).

The authors did not take into account the work by Pope et al., (2016), on the nearby, wellstudied Sfakia fan. This may be due to the fact that the m/s postdated the publication date of this paper, but nonetheless, the authors should take it into consideration in their revised version.
That is correct. When our research was compiled the work of Pope et al. (2016) was not yet published; this is why we did not include it in the submitted version. In the revised version, not only have we included reference to Pope et al. but we have added the following extensive comment relating our main findings to those of Pope et al. (2016):

'This work was undertaken prior to the publication of the latest results of OSL and U series dating of the Sfakia fan sequence (Pope et al., 2016). Intriguing conclusions of their high resolution dating work include that at Sfakia, three sometimes overlapping phases of fan deposition since the last interglacial are separated by two phases of fan entrenchment, the first close to the MIS 5/4 (c. 70 kyr) boundary, the other close to the MIS 2/1 boundary (c. 14 kyr), triggered by major climatic changes. Fan deposition there has to a large degree persisted through stadial and interstadial periods during the last 125 kyr. Periods of entrenchment at Sfakia do not appear to correlate with the two entrenchment periods at Domata. The Sfakia fan is significantly different from the Domata fan in catchment size (c. 28 km^2 compared with c. 11 km^2), fan size (5.3 km^2 compared with 0.1 km^2), the presence of more than one feeder channel at Sfakia, and in the nature of deposits (primarily clast-supported gravels compared with primarily matrix-supported gravels). Whether these differences are responsible for differences in depositional and entrenchment histories and in preservation of marine cliffs at Sfakia, or differences in local climatic regimes or vegetation changes is uncertain. However, one compatible conclusion of their work with our own is recognition of the importance of base level (sea level) change to the process of entrenchment.'

Specific Comments

Page 4, l. 20-21. Bedrock geology is grossly misrepresented, both in terms of lithology and age. Klados Gorge runs through platy crystalline limestones with phyllite intercalations and chertbearing dolomites, chert-nodule-bearing limestones and quartzitic sandstones and shales, not through the platform carbonates of the Tripolis Unit (which is a Mesozoic carbonate platform). Moreover, the aforementioned lithologies (i.e. Kingilos group) belong to the metamorphosed Plattenkalk Unit, also known as Mani Unit. (e.g. Creutzburg and Siedel, 1975; Fassulas et al., 1994; and Jolivet at al., 1996).
This suffices to explain the occurrence of quartz detritus in the Domata fan; the authors, however, did not seem to wonder why a purely carbonate-fed fan (as they describe it), contains so much quartz! *We apologise for this – it slipped out of our attention and the correct rock-type is now included in the revised version. We completely agree with the Reviewer that the Plattenkalk unit outcrops in our study area. Specifically, the platy limestones and the platy limestones with cherts are the main units that occupy the largest part of the Klados gorge valley. The Gigilos layers appear in the northern part of the Klados watershed, which drains mainly towards the Omalos plateau and the northern part of the Samaria Gorge (Fassoulas et al., 2004). However, we doubt that the Gigilos beds (shales and quarzitic sandstones and chert bearing limestones) have been contributing in the mass of sediments within the Klados gorge since they are only outcropping in the northern parts of White Mountains (Lefka Ori) and they are north dipping. In contrast, the Klados gorge developed in the overlying platy limestones with cherts which eventually developed in platy marbles with limited chert intercalations (Unit 4d and 4e at Manutsoglu et al., 2003). Thus, Klados gorge has mainly developed in platy limestones with some cherts and platy marbles and the erosion of these units supplied the Domata area mainly with carbonate clasts and limited chert clasts (from the lower units) which explain the abundance of carbonates in the alluvial fans and fluvial terraces.*

1. *Manutsoglu, E., Soujon, A., and Jacobshagen, V., 2003. Tectonic structure and fabric development of the Plattenkalk unit around the Samaria gorge, Western Crete, Greece. Z. Dtsch. Geol. Ges. 154, 85-100.*
2. *Fassoulas, C., Rahl, J.M., Ague, J., and Henderson K., 2004. Patterns and conditions of deformation in the Plattenkalk nappe, Crete, Greece: a preliminary study. Bull. Geol. Soc. Greece, vol. XXXVI, 1626-1635.*

P.3, l.20. Please use appropriate term instead of "vertical deformation".
We don't understand what the reviewer means. We will change the 'vertical deformation' to 'vertical movement', hoping that this is more appropriate.

P.21, Figure 2. How confident are the authors that the quasi-planar landforms west of the gorge are marine benches? Is there any piece of evidence supporting this suggestion?
These quasi-planar surfaces are very common in southwest Crete and are generally well-studied. As we state in the manuscript, 'while we cannot assign ages to these benches, their altitude and geomorphic similarity with known and dated (MIS5) late Pleistocene marine benches elsewhere in Crete (e.g., Strasser et al., 2011; Gallen et al., 2014; Strobl et al., 2014), provides some stratigraphic and chronologic context for the age of the alluvial fans at Domata (i.e., because of their lower elevation, the alluvial fan surfaces that are subject of this paper are expected to be younger than 125 kyr)'.

Moreover, marine materials (shell-hash beachrock) have been found by the authors on such a planar surface of similar (~100 m) elevation, 2.5 km west of Domata (towards Sougia). However, we did not date these materials as we expect their age to be outside the radiocarbon age-range.

P25, Figure 6b. The red dashed line that is suggested to represent a low terrace riser on the west side of the river seems rather ambiguous; it is hard to say from this photo.
We have now modified and re-annotated 6b to satisfy the Reviewer.

Technical Corrections

N/A

References cited

Creutzburg N., Siedel. E., (1975). Zum stand der Geologie des präneogens auf Kreta. N. Jb. Geol. Paläont. Abh. 149(3): 363-383.

Fassulas, Ch., Kilias, A., Mountrakis, D., (1994). Post-nappe stacking extension and exhumation of the HP/LT rocks in the island of Crete, Greece. Tectonics 13: 127-138.

Jolivet, L., Goffe B., Monie P., Truffert C., Patriat, M., Bonneau M. (1996). Miocene detachment in Crete and exhumation P-T-t paths of high pressure metamorphic rocks. Tectonics 15: 1129-1153.

Pope, R.J.J., Candy, I., Skourtsos, E., (2016). A chronology of alluvial fan response to Late Quaternary sea level and climate change, Crete. Quat. Research 86: 170-183.