nature portfolio

Peer Review File

Seafloor earthquake ruptures and mass wasting from the 2004 Mw 6.3 Les Saintes submarine earthquake

Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality

This manuscript has been previously reviewed at another Nature Portfolio journal. This document only contains reviewer comments and rebuttal letters for versions considered at Communications Earth & Environment. Mentions of the other journal have been redacted.

27th Oct 22

Dear Dr Hughes,

Your manuscript titled "Linking seafloor earthquake ruptures and mass wasting along submarine normal faults" has now been seen by 3 reviewers, and I include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

All three reviewers agree that this dataset is valuable and important for the understanding of submarine earthquakes and landslides. However, two of them raise major concerns over the presentation of the dataset and the level of insightful conceptual scientific advance. Please ensure that in your revised abstract you re-focus the discussion to clearly explain and discuss how your findings represent and advance over previous understanding.

Please also note that in Communications Earth & Environment we allow up to 5,000 words and 10 display items (figures or tables) in the main text, in addition to unlimited space for Methods.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter) and the completed checklist:

[link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

Please do not hesitate to contact me if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Teng Wang, PhD

Editorial Board Member

Communications Earth & Environment

0000-0003-3729-0139

Joe Aslin

Senior Editor

Communications Earth & Environment

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

Editorial Policy: Policy requirements (Download the link to your computer as a PDF.)

Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:

Communications Earth & Environment formatting checklist

and also in our style and formatting guide Communications Earth & Environment formatting guide .

*** DATA: Communications Earth & Environment endorses the principles of the Enabling FAIR data project (http://www.copdess.org/enabling-fair-data-project/). We ask authors to make the data that support their conclusions available in permanent, publically accessible data repositories. (Please contact the editor if you are unable to make your data available).

All Communications Earth & Environment manuscripts must include a section titled "Data Availability" at the end of the Methods section or main text (if no Methods). More information on this policy, is available at http://www.nature.com/authors/policies/data/data-availability-statements-data-citations.pdf.

In particular, the Data availability statement should include:

- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)

- Accession codes where appropriate

- If applicable, a statement regarding data available with restrictions

- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital

Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

It has been my pleasure to review this paper and become acquainted with the unique dataset presented here, in Escartin et al (2016), and in Hughes et al (2021). The highly detailed slip analysis from AUV and ROV data is an impressive new result.

The main finding of the paper relates to fault scarp formation and mass wasting – reflected in the title. The results of the study are also put forward as being valuable for informing tsunami and earthquake hazard studies.

The paper concludes that landslides in this event occurred co-seismically and there was little post seismic activity. This is based on a time period between two surveys in 2013 and 2017, while ethe earthquake was in 2004. I agree with this result but do not find it particularly special. There could well have been mass wasting between 2004 and 2013. Other studies have shown direct evidence for co-seismic submarine landslides from repeat surveys (e.g. in the 2016 Kaikoura Earthquake).

Regarding tsunami and earthquake hazard implications it seems that the earthquake characteristics (e.g. SRL) are captured by known scaling relationships. The results of this study which include very detailed analysis of slip behaviour have not been used to develop any new methods that might be applied to other earthquakes (i.e. on segmented normal faults) which seems like a lost opportunity. The end of the discussion and abstract hint that there are implications from this work and that it is important but do not go as far and making the link to what the game changing conclusion is – something I would expect for this journal.

To summarise this is a great data set and it is nicely laid out in the supplementary info. I don't think there are sufficient insights to warrant publication in such a high impact journal as this. I think those insights probably could be gained from the datasets but that will require careful consideration of how this would change the scientific field’s understanding of normal fault surface ruptures and mass wasting.

Reviewer #2 (Remarks to the Author):

This manuscript by Hughes et al. presents a set of very interesting and compelling data along the Roseau fault, a normal fault that ruptured recently during the 2004 M6.3 event. They thoroughly analyze the coseismic offset that occurred along the fault, as well as the post-seismic mass transport across the fresh scarp face using underwater vehicles. I enjoyed reading this paper and have the following four overarching points to make in this review.

1) The data and observations are unique, novel, and important.

2) This study and the manuscript as presented are not ideally suited for a short format paper. Many of the key observations and and interpretations are in the supplement. In other words, I was not able to fully understand the key observations, or even determine if the interpretations presented were fully supported by the data, without spending substantial time studying the Supplementary Information.

3) I am not aware of major debates or unresolved questions in the submarine geology fields pertaining to punctuated versus continuous mass wasting of continental slopes, especially over the time period of observation here (3 years). Is there any reason to think there should be continuous mass transport along the seabed in a deepwater environment located away from terrestrial sediment sources, like the Roseau fault? The observations of scarp formation and subsequent mass transport are important and unique, but it's not clear how this observation changes our understanding of fault behavior, either onshore or offshore, or changes our understanding of primary triggering mechanisms for submarine mass transport.

4) I am not an expert in Caribbean geology, but a quick catalog search reminded me of the 2007 M7.4 Martinique earthquake, with a hypocenter located within 80 km of the Roseau Fault. Appears that estimated PGA values along the Roseau fault from this 2007 event were between 0.1g and 0.2g. This seems like something that needs to be discussed as another potential trigger of mass transport in the study region subsequent to the 2004 event and before the AUV/ROV surveys.

In addition to the above points, I wondered if the significance of the observations/interpretations could be framed in a slightly different way. There is a growing body of literature in the lacustrine realm, with a few in the marine realm, that examine how lake sediments respond to shaking during historical and prehistoric earthquakes (search recent Van Daele et al., and Moernault et al. papers from Alaska and Chile). To me, one of the more interesting aspects of the present study involves the threshold shaking intensity required to trigger mass transport on a submarine slope. And also the idea that the 2004 event may demonstrate how MTDs can be triggered by relatively small earthquakes, which has implications for marine paleoseismology in general (ie seismoturbidites). Along these lines, there's a new paper by Hill et al. (2022) looking at sources of landslides and MTDs along Cascadia... minimum shaking intensities required to trigger failure and MTDs is a very important topic on most active margins, and this paper demonstrates the incredible value in high resolution AUV/ROV datasets.

In summary, I struggled to see how the results necessitate reevaluation of our understanding of submarine tectonic geomorphology/coseismic fault behavior. But observations in this study are very important, it sets the stage for many future studies of this nature, and presents critical baseline datasets that could lead to fundamental changes in our understanding of these processes after the next big earthquake occurs in the region. My recommendation is to fully showcase the beautiful data they present (most of which is currently packed into the Supplement) in a longer format article, and allow readers to fully absorb the unique observations.

Reviewer #3 (Remarks to the Author):

This paper is an important discovery and detailed report that can clarify the generation mechanism of submarine landslides in the latest activity of normal faults as active faults. Evidence for this paper is detailed seafloor topography, deep-sea images, and seismic acceleration. Based on these lines of evidence, we were able to quantify the relationship between earthquake magnitude, seismic acceleration and submarine landslides. As the author says, I also think that this is an important finding in considering the impact of submarine landslides on submarine earthquake hazards. All the lines of evidence are clearly and concretely stated, and are comparable to the papers. Only one point, if there is any seismic survey record, I would like you to present an image of the subsurface structure of the target normal fault. In other words, when considering these relationships, I believe that a three-dimensional interpretation that includes the underground structures will lead to a better understanding.

REVIEWER COMMENTS:

Replies in blue

Reviewer #1 (Remarks to the Author):

It has been my pleasure to review this paper and become acquainted with the unique dataset presented here, in Escartin et al (2016), and in Hughes et al (2021). The highly detailed slip analysis from AUV and ROV data is an impressive new result. The main finding of the paper relates to fault scarp formation and mass wasting – reflected in the title. The results of the study are also put forward as being valuable for informing tsunami and earthquake hazard studies.

The paper concludes that landslides in this event occurred co-seismically and there was little post seismic activity. This is based on a time period between two surveys in 2013 and 2017, while ethe earthquake was in 2004. I agree with this result but do not find it particularly special There could well have been mass wasting between 2004 and 2013

We argue that mass wasting did not occur from 2004-2013 based on the following:

1) In the case of the Roseau fault, possible non-tectonic triggers for mass wasting of coarse sediment and rubble are limited to weathering, alteration, or abrasion by currents. We have no data on the rates that these processes occur other than the repeat seafloor surveys which indicate that they do not trigger mass wasting on 3.5-year timescales.
2) We frequently observe piles of rubble and sediment covering the coseismic ribbon by over a meter (see figure 4 for some examples). If these mass wasting events were triggered by some punctuated but frequent non-tectonic process then we should see widespread evidence for mass wasting in the repeat surveys, but we do not.
3) We note that on land in the Lesser Antilles in the same lithological setting, physical erosion is driven mainly by discrete landslides that occur during frequent tropical storms. Despite some of the highest weathering rates globally, no landslides occur during dry periods. This indicates that on decadal timescales intense weathering acts to weaken the bedrock, but it still requires some external forcing to induce mass wasting. In the absence of intense rainfall on the Roseau fault, the only plausible trigger is ground shaking during earthquakes.
4) The absence of mass wasting in the repeat surveys corresponds a period where there is extremely low ground shaking from earthquakes (>0.01 g). Ground shaking levels are similarly low for the period 2004-2017 outside of the 2004 main shock and the largest aftershock.

The above points are all documented in the discussion and we suggest that these observations support the hypothesis that mass wasting of coarse sediment and rubble occurs primarily during earthquakes but is facilitated by ongoing weakening of the bedrock by non-tectonic processes. However, we acknowledge that our data does not allow us to comprehensively rule out mass wasting from 2004-2013. We state as much in the text and have added appropriate caveats in the discussion to be upfront about our assumptions and uncertainties.

Other studies have shown direct evidence for co-seismic submarine landslides from repeat surveys (e.g. in the 2016 Kaikoura Earthquake).
We thank the reviewer for pointing out the links between submarine mass wasting and earthquakes from the Kaikoura earthquake and have included some of the cool papers around the submarine erosion resulting from this earthquake in the introduction and discussion.

Regarding tsunami and earthquake hazard implications it seems that the earthquake characteristics (e.g. SRL) are captured by known scaling relationships. The results of this study which include very detailed analysis of slip behaviour have not been used to develop any new methods that might be applied to other earthquakes (i.e. on segmented normal faults) which seems like a lost opportunity.
We have developed the comparison of the Les Saintes earthquake with other global normal fault earthquakes in terms of the rupture profile and the rupture parameters in the new figure 6 amended from the previous figure S9. However, we disagree that there are no new methods presented here. Our whole approach using underwater vehicles to comprehensively map a submarine rupture and applying structure-from-motion on ROV video imagery to quantify the rupture is novel. Indeed, the second reviewer indicates as much and suggests that we should make more of the fact that our work demonstrates the applicability of underwater vehicles for this type of study. In response, we have talked up the application of underwater vehicles for mapping submarine ruptures in the abstract and conclusion.

The end of the discussion and abstract hint that there are implications from this work and that it is important but do not go as far and making the link to what the game changing conclusion is – something I would expect for this journal
This is a good point. We have developed to discussion and conclusion to focus on the applicability of scaling relationships to submarine faults, the implications for triggering thresholds in submarine settings, and the applicability of underwater vehicles to study submarine ruptures.

To summarise this is a great data set and it is nicely laid out in the supplementary info.

Thanks! We have moved several of the supplementary figures in to the main manuscript so that there are now 7 figures in the main text and only 4 figures in the supplement. We have left all the data in one supplementary excel file because there is a large amount of data and it makes both the data and the paper easier to digest if all the data accessible from one place.

I don’t think there are sufficient insights to warrant publication in such a high impact journal as this. I think those insights probably could be gained from the datasets but that will require careful consideration of how this would change the scientific field’s understanding of normal fault surface ruptures and mass wasting.

We have taken onboard the reviewers’ comments and developed to discussion and conclusion to focus on the applicability of scaling relationships to submarine faults, the implications for triggering thresholds in submarine settings, and the applicability of underwater vehicles to study submarine ruptures. With regards to the latter, our methodology provides a blueprint for future studies of seafloor ruptures which will have implications in other fields of hazard modelling (e.g., ground truthing tsunami models, stress models, paleoseismic studies) and submarine landscape evolution modelling.

Reviewer #2 (Remarks to the Author):

This manuscript by Hughes et al. presents a set of very interesting and compelling data along the Roseau fault, a normal fault that ruptured recently during the 2004 M6.3 event. They thoroughly analyze the coseismic offset that occurred along the fault, as well as the post-seismic mass transport across the fresh scarp face using underwater vehicles. I enjoyed reading this paper and have the following four overarching points to make in this review.

1) The data and observations are unique, novel, and important.
Thanks ☺

2) This study and the manuscript as presented are not ideally suited for a short format paper. Many of the key observations and interpretations are in the supplement. In other words, I was not able to fully understand the key observations, or even determine if the interpretations presented were fully supported by the data, without spending substantial time studying the Supplementary Information

The previous layout resulted from the fact that we did not reformat the paper after our initial submission to [redacted]. However, given Communications Earth & Environ ment allows for up to 10 figures and 5000 words there was plenty of scope to rearran ge the paper and present more of the figures in the main manuscript in addition to more discussion in the text. As mentioned above, we have moved several of the supplementary figures in to the main manuscript so that there are now 7 figures in the main text and only 4 figures in the supplement. We have left all the data in one supplementary excel file because there is a large amount of data and it makes both the data and the paper easier to digest if all the data accessible from one place.

3) I am not aware of major debates or unresolved questions in the submarine geology fields pertaining to punctuated versus continuous mass wasting of continental slopes, especially over the time period of observation here (3 years) Is there any reason to think there should be continuous mass transport along the seabed in a deepwater environment located away from terrestrial sediment sources, like the Roseau fault?
In hindsight, the debate is more from a modelling perspective in terms of to what extent do earthquakes drive erosion on the seafloor. To investigate that, we need to establish a link between earthquakes and submarine mass wasting so having an idea of the contribution of ‘continuous’ versus tectonic mass wasting is useful. As the reviewer points out, the triggering threshold aspect folds into this debate but also has implications for hazard analysis. Therefore, we took onboard the reviewers’ suggestion and developed some analysis and discussion of triggering thresholds.

The observations of scarp formation and subsequent mass transport are important and unique, but it's not clear how this observation changes our understanding of fault behavior, either onshore or offshore, or changes our understanding of primary triggering mechanisms for submarine mass transport.
We have focused the discussion on rupture to debate on the applicability of scaling relationships to submarine faults. We have also developed the mass wasting element to focus on triggering thresholds and suggest that the over steeping of the scarp in strong bedrock can decrease triggering thresholds due to inherent instability. We also point out the novel aspect of our approach and how similar future studies have the potential to provide insights for numerous aspects of submarine geohazards.

4) I am not an expert in Caribbean geology, but a quick catalog search reminded me of the 2007 M7.4 Martinique earthquake, with a hypocenter located within 80 km of the Roseau Fault. Appears that estimated PGA values along the Roseau fault from this 2007 event were between 0.1g and 0.2g. This seems like something that needs to be discussed as another potential trigger of mass transport in the study region subsequent to the 2004 event and before the AUV/ROV surveys.
We thank the reviewer for pointing this out. This was a previous oversight on our part that stemmed from us setting our search parameters for earthquakes within a 50 km radius of the 2004 epicenter. We have subsequently searched the USGS catalogue and the 2007 earthquakes is the only other regional event from 2004-2007 that could potentially have induced significant ground shaking on the Roseau fault. While the USGS calculate 0.1-0.2g associated with the 2007 earthquake, our calculations using the locally calibrated ground motion predictive equation from Beauducel et al., [2011] suggest a maximum of 0.02 g on the Roseau fault, likely below the threshold to trigger mass wasting. We have added the earthquake to figure 7 with the PGA map and mention the PGA associated with it briefly in the text.

In addition to the above points, I wondered if the significance of the observations/interpretations could be framed in a slightly different way. There is a growing body of literature in the lacustrine realm, with a few in the marine realm, that examine how lake sediments respond to shaking during historical and prehistoric earthquakes (search recent Van Daele et al., and Moernault et al. papers from Alaska and Chile [We have made reference to some of their work in the introduction]). To me, one of the more interesting aspects of the present study involves the threshold shaking intensity required to trigger mass transport on a submarine slope. And also the idea that the 2004 event may demonstrate how MTDs can be triggered by relatively small earthquakes, which has implications for marine paleoseismology in general (ie seismoturbidites). Along these lines, there's a new paper by Hill et al. (2022) looking at sources of landslides and MTDs along Cascadia... minimum shaking intensities required to trigger failure and MTDs is a very important topic on most active margins, and this paper demonstrates the incredible value in high resolution AUV/ROV datasets.
We thank the reviewer for this thoughtful and instructive comment. We have reframed the discussion around the mass wasting to discuss triggering thresholds. We associate the relatively low triggering threshold (compared to continental slope sediments during Kaikoura) for the Roseau fault to the capacity of strong bedrock to form over steepened scarps which are inherently unstable. We have also incorporated some of the suggested references into the text and discussion.

In summary, I struggled to see how the results necessitate reevaluation of our understanding of submarine tectonic geomorphology/coseismic fault behavior. But observations in this study are very important, it sets the stage for many future studies of this nature, and presents critical baseline datasets that could lead to fundamental changes in our understanding of these processes after the next big earthquake occurs in the region. My recommendation is to fully showcase the beautiful data they present (most of which is currently packed into the Supplement) in a longer format article, and allow readers to fully absorb the unique observations.

This journal actually has a fairly generous word and figure allowance so it was not difficult to move most of the figures that were previously in the supplement into the main manuscript and develop some of the themes are noted above.

Reviewer #3 (Remarks to the Author):

This paper is an important discovery and detailed report that can clarify the generation mechanism of submarine landslides in the latest activity of normal faults as active faults. Evidence for this paper is detailed seafloor topography, deep-sea images, and seismic acceleration. Based on these lines of evidence, we were able to quantify the relationship between earthquake magnitude, seismic acceleration and submarine landslides. As the author says, I also think that this is an important finding in considering the impact of submarine landslides on submarine earthquake hazards. All the lines of evidence are clearly and concretely stated, and are comparable to the papers. Only one point, if there is any seismic survey record, I would like you to present an image of the subsurface structure of the target normal fault. In other words, when considering these relationships, I believe that a three-dimensional interpretation that includes the underground structures will lead to a better understanding.

We agree with the reviewer that in an ideal world you would analyze the subsurface fault structure in 3D to compare with the mapped surface rupture trace. There are a couple seismic profiles in the study are but they are on the regional scale and spaced several km’s apart. Therefore, the available seismic data is too low-resolution to image fault segmentation at depth or to document the subsurface structure of any mass wasting features.

26th May 23

Dear Dr Hughes,

Please allow us to sincerely apologise for the long delay in sending a decision on your manuscript titled "Seafloor coseismic ruptures and mass wasting from a submarine earthquake". It has now been seen again by Reviewer #3, whose comments appear below. Unfortunately, Reviewers #1 and #2 were unable to provide further second reports. In light of the advice we have received and our editorial judgement I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

EDITORIAL REQUESTS:

Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table".

*****Please take care to match our formatting and policy requirements. We will check revised manuscript and return manuscripts that do not comply. Such requests will lead to delays. *****

Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files as a Related Manuscript file.

If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

SUBMISSION INFORMATION:

In order to accept your paper, we require the files listed at the end of the Editorial Requests Table; the list of required files is also available at https://www.nature.com/documents/commsj-file-checklist.pdf .

OPEN ACCESS:

Communications Earth & Environment is a fully open access journal. Articles are made freely accessible on publication under a CC BY license (Creative Commons Attribution 4.0 International License). This license allows maximum dissemination and re-use of open access materials and is preferred by many research funding bodies.

For further information about article processing charges, open access funding, and advice and support from Nature Research, please visit https://www.nature.com/commsenv/article-processing-charges

At acceptance, you will be provided with instructions for completing this CC BY license on behalf of all authors. This grants us the necessary permissions to publish your paper. Additionally, you will be asked to declare that all required third party permissions have been obtained, and to provide billing information in order to pay the article-processing charge (APC).

Please use the following link to submit the above items:

[link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Teng Wang, PhD

Editorial Board Member

Communications Earth & Environment

0000-0003-3729-0139

Joe Aslin

Senior Editor,

Communications Earth & Environment

https://www.nature.com/commsenv/

Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

I confirmed the revised manuscript. I think that this report should be important for studies in terms of underwater mass wasting and also for constraints to submarine geological risk evaluation. Most of the coastal engineers can not evaluate quantitatively the risks at the moment. We need at least a hint to think about the risks like these studies.

I designate several simple errors below.

Line 157 tubidite flows may be turbidity currents

Line 170 mas should be mass.

Line 174 Fig. may be Figs.

Line 260 Figs may be Fig.

Line 274 Fig. may be Figs.

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

I confirmed the revised manuscript. I think that this report should be important for studies in terms of underwater mass wasting and also for constraints to submarine geological risk evaluation. Most of the coastal engineers cannot evaluate quantitatively the risks at the moment. We need at least a hint to think about the risks like these studies.

I designate several simple errors below.

Line 157 tubidite flows may be turbidity currents
Amended as suggested

Line 170 mas should be mass.
Amended as suggested

Line 174 Fig. may be Figs.
All figure references have been changed to 'Figure' or 'Figures' rather than Fig. or Figs. The references to multiple figures should now all be 'Figures' and single figures, 'Figure'.

Line 260 Figs may be Fig.
All figure references have been changed to 'Figure' or 'Figures' rather than Fig. or Figs.

Line 274 Fig. may be Figs.
All figure references have been changed to 'Figure' or 'Figures' rather than Fig. or Figs.

In addition to the above, we have reworded the text in the final three paragraphs of the discussion to improve the clarity of the concept of a 'threshold stability height' above which steep scarps become inherently unstable and prone to mass wasting.

We have also added a grey polygon to Figure 3C that shows surface slip from geophysical inversion models from Feuillet et al., (2011). The modeled surface slip provides a nice comparison with the measured vertical uplift data from this paper.

We have also added some additional labels to Figures 2 and 4 with the model numbers from Supplementary Table S1.