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Evolution of the Tazones Lighthouse slope (Cantabrian coast, N Spain). Multidisciplinary monitoring between 2018 and 2020

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Dear Dr. Alan Trenhaile,

We are very grateful for your review of our manuscript. Thank you very much for your constructive comments and suggestions. We consider that they have contributed to improve our manuscript and we really appreciate your effort.

In the new version of the manuscript, we have incorporated all your observations. Please, check out our point-by-point answers below.

Sincerely

María José Domínguez-Cuesta (on behalf of the co-authors)

Point-by-point response

GENERAL COMMENTS

1. This is an interesting paper which is most notable perhaps for the frequent (monthly) monitoring of slope movement, and associated opening of fissures, on top of a cliff in northern Spain. It will make a useful contribution to the coastal literature once some changes have been made, the most important of which is to the English, which at present is rather poor. I have used the abstract in an attached copy of the manuscript to provide an example of the amount of work that needs to be undertaken on this aspect of the manuscript, but given the problem is throughout the paper I have limited most grammatical comments to only this section.

Response. We are delighted that Dr. Trenhaile finds our paper interesting and notable and will make a useful contribution to the coastal literature.

We really appreciate the efforts to improve the English of the abstract. The new version of the manuscript has been revised in detail and edited by a native English speaker. The remaining suggestions by Dr. Trenhaile are explained in the following paragraphs.

2. I am also opposed to the results and discussion being combined in a paper. The results simply provide data, statistical analysis, and other qualitative or quantitative findings from a research project, whereas the discussion is used to discuss interpretations, implications, models, etc derived from the results. I find the Results and Discussion section to be poorly organised. Some of it belongs in the study area section and others in a Discussion rather than results section. I would begin this section with the displacement data from which everything else follows (interpretations, relationships with geology etc).

Response. After reading the comments of the Referee, we have adequately separated Results from Discussion in the new version of the manuscript, following the Referee's indications. We also have re-organized both sections and we have moved some sentences to the Setting section as suggested by the Referee.

3. I also wonder about the assumption that mass movements in this area are generally fairly small. Surely, despite the lack of historical records at this particular site, the rapid opening up of some of the fissures must lead to a large slope failure. Depending on the depth of the failure surface this may only involve shearing of material from the upper part of the cliff but even this, given minimum depths and the distance of the fissures from the cliff edge, would involve a huge amount of material. I would like to see more discussion of this possibility and also an explanation of why there has been such a dramatic increase in the width of some fissures in the last few years.

Response. We have clarified the influence of family joints in the movement evolution. We have added a new figure with the stereographic projection of the family joints and an histogram of the joint spacing (J_v , that gives the number of discontinuities per cubic meter). This allows us to better illustrate and discuss about the state of fracturing of the rock, as well as the size of the blocks that are gradually and progressively being released from the cliff. We think that the very opening of the cracks prevents surface runoff and favors infiltration. The water lubricates the marls that act as sliding surfaces. The characterization of the massif was carried out in the geotechnical stations where, in addition to taking structural data, an identification of the lithologies was carried out, accompanied by the maximum specialists of the Jurassic in Asturias. The degree of alteration of the massif has been revealed, which on the surface is much greater than in depth and, depending on the lithology, increases rapidly with exposure to meteorological agents. Main properties of sandstone and marl lithotypes (density, porosity, uniaxial compressive strength) have been determined, both under dry and saturated conditions.

4. There is also an implication in places in this paper that mass movement is the main mechanism rather than marine processes. Steep sea cliffs occur along coasts for one reason, which is oversteeping and resulting instability due to marine (usually waves in temperate regions). Without marine processes there would be no steep cliff and no mass movement. Precipitation may trigger mass movements (that is determine when they occur) but the conditions for their occurrence is determined by the sea. Incidentally, the present dominance of blocks on the beach (relative to pebbles) is not evidence of mass movement dominance. If mass movement blocks were dominant here it would prevent marine erosion of an increasingly buried cliff foot. The cliff would then be essentially abandoned by the sea and would gradually become less steeply sloping and more vegetated. This is not happening - this is an active sea cliff with a steepness and internal geology that promotes a certain suite of mass movements.

Response. We fully agree with the Referee's judgments and opinions. We recognize that, in the first version of the manuscript, we did not discuss adequately the marine role in the evolution of the cliff. In the new version, we will consider it more appropriately. In fact, we have included a discussion on the influence of two factors: 1) the lithological weakness of the blocks present at the foot of the cliff, which allows their rapid erosion and re-loosening by the waves and 2) the exposure of the cliff to the action of the predominant maritime storms, which come from the NW. Moreover, in the new version of the manuscript, we have rewritten some sentences more clearly to avoid confusion and misunderstandings.

5. I suspect you are quite right to relate mass movements to precipitation etc but there is also a possibility that wave activity may at least play a role, given that winter storms are also times when waves are highest. This can lead to enhanced undercutting and instability as well as generating vibrations in the cliff materials (eg. Thompson, C.F., Young, A.P., Dickson, M.E., 2019. Wave impacts on coastal cliffs: Do bigger waves drive greater ground motion? *Earth Surface Processes and Landforms*, 44, 2849-2860. and Earlie, C., Masselink, G., Russell, P., 2018. The role of beach morphology on coastal cliff erosion under extreme waves. *Earth Surface Processes and Landforms*, 43, pp.1213-1228).

Response. We totally agree with the Referee's reflection. Undoubtedly, wave activity and, specifically, winter storms, cause vibrations and undercutting of the base of the cliffs, which facilitates their subsequent evolution through gravitational processes. As previously said, we have

modified our allusions in this regard in the new version of the manuscript, complementing them with references such as the one the Referee indicates, among others.

6. The last point in the introduction claims that this research will "provide a solid knowledge base to perform predictive models of coastal retreat in future scenarios". Will it ? In truth while I consider this paper to be a useful addition to the literature, there really isn't anything fundamentally new about the results (no new theory or model, etc). How then do you think it can help us to develop predictive models ? Surely much of what is presented in this and many similar papers is site specific - strongly related to conditions at the study area. Please justify your statement in the conclusions.

Response. Our affirmation was made in order to highlight that our work presents the first results about the coastal retreat of the Cantabrian Coast cliffs, which show great complexity from the lithological and structural points of view. Until now, there is a significant lack of data on the evolution of these cliffs, and particularly, in the contribution of slope instabilities to their retreat. This was the sense in which we made the exposition of the final part of the Introduction of the work. However, we recognize that the claim may be very ambitious as it is an ongoing investigation of which we only have the first results. Consequently, we have rewritten the sentence and have carefully reviewed and eliminated from the manuscript those aspects that cannot be resolved and included in the Conclusions.

SPECIFIC COMMENTS

7. **ABSTRACT.** Writing needs work. The abstract has been modified to illustrate the type and number of changes that should be made throughout the paper.

Response. The abstract has been totally rewritten and, like the rest of the manuscript, the English has been proofread by a native speaker.

8. **Line 28.** The only general review paper dealing with possible impacts of climate change on rock coasts that I am aware of is: Trenhaile, AS (2014) Climate change and the impact on rocky coasts. In Kennedy, D.A., Stephenson, W. J., and Naylor, L.A. (eds), Rock Coast Geomorphology: A Global Synthesis. Memoir 40, Geological Society Books, London, pp 7-17. There are several modelling papers.

Response. The reference Trenhaile, 2014 has been added, following the Referee's suggestion.

9. **Lines 46-47.** Are these granites in Galicia ? If so that's extremely fast.

Response. The retreat data refer to granite bedrock in Galicia (Finisterre area). A mistake was detected because the data previously provided (range 0.03 - 2.78 m y⁻¹) had been taken from a synthesis table published by Gómez-Pujol et al. (2014). In the original work (Alberti et al., 2013) it is indicated that the recorded retreat values range between: 0.01 and 7.82 m y⁻¹ and the average of the sector with the maximum retreat is 1.18 m y⁻¹, for the period 2003 – 2008. It has been corrected in the new version of the manuscript, specifying that these data are referred to granites.

10. **Lines 49-50.** Clay! If you are going to compare rates then you must state the rock types or the comparisons are meaningless.

Response. The lithology has been specified for each example of rocky coast retreat mentioned.

11. **Lines 53-54.** It is not 'mainly due' to mass movements ! There would be no retreat without marine undercutting and oversteepening. That is the reason for cliff retreat - mass movements are simply a response to that oversteepening !

Response. We totally agree with the Referee's assessment and, to avoid confusion, we have rewritten the sentence.

12. **Line 82.** Is this the thickness ?

Response. It has been specified that the sandstone appear in 1-10 m thickness layers. Moreover, we have done a new figure in which the stereographic projection of the family joints and a histogram of the joint spacing are shown.

13. Line 93. Old mine or do you mean mining exploration ?

Response. In their compilation work on jet mines in Asturias, Bahamonde et al. (1986) referred the possible presence of ancient mining in the area. No evidence of the existence of jet mining galleries has been recognized during the fieldwork. It remains unclear if there came to be a mining operation or simply was a mining exploration. We have added some phrases to clarify this aspect.

14. Line 111. Listening to the sounds of the body - usually with a stethoscope ? (English definition)

Response. The sentence has been rewritten.

15. Line 118. Describe these.

Response. An explanatory paragraph to explain what a feno-type marker is has been added.

16. Line 121. Describe them (what was used here ?).

Response. An explanatory sentence has been added.

17. Lines 166-167. Much of this is more appropriate in a discussion section dealing with implications and interpretations based on the results, rather than results itself.

Response. The old Results and Discussion section has been separated in two different sections, following the Referee's advice.

18. Lines 167-168. To me, this second part is essentially the results.

Response. Results and Discussion have been separated in two different sections in the new version of the manuscript, as previously exposed.

19. Lines 170-174. This belongs in the study area section - it is not Results.

Response. We agree with the Referee. The paragraph has been moved to Study area section.

20. Line 188. Meaning not clear.

Response. We agree with the Referee. The sentence has been rephrased.

21. Line 200. To me, some of the photos suggest that there might be some rotational movement (slumping).

Response. We have not identified evidence of slumping processes. The image in Figure 2c may be misleading in this regard. Actually, we think the block toppled due to the gap generated after the other block slid in front of it.

22. Line 211. Explain ?

Response. It has been specified that the sandstone appear in 1-10 m thickness layers. Moreover, we have done a new figure in which the stereographic projection of the family joints and a histogram of the joint spacing are shown.

23. Line 215. Do you mean exposure ?

Response. As the Referee suggests it refers to exposure. The word has been replaced.

24. Line 220. This is more appropriately Discussion rather than Results

Response. The sentence has been moved to the Discussion section.

25. Line 230. All of this section dealing with causes etc belongs in a Discussion section - they are interpretations based on the results but are not results per se.
Response. The mentioned section has been moved to the Discussion section.
26. Lines 239-241. Surely the development of such large fractures in the cliff top must indicate catastrophic failures or failures at some point in the future.
Response. Following the Referee suggestion, we have changed the phrase to avoid being speculative, focusing only on the behavior observed on the cliff during the two monitoring years.
27. Line 244. It's that part surely which constitutes the main part of the results - I would put this first rather than discussions of geology etc.
Response. The paragraph has been moved to the beginning of Results section.
28. Line 262. Given that the Holderness example is, I assume, in clay, the two locations are hardly comparable.
Response. We have specified that it is a measured retreat on a clay coast. On the other hand, the results have been discussed in comparison to other areas of the world.
29. Lines 269-272. This belongs in the figure caption.
Response. Following the Referee proposal, the indicated text has been removed from the manuscript text and partially added to the figure 6 caption.
30. Line 290. These are also periods when waves are highest - generating vibrations in the cliff face and/or undercutting and destabilizing the slope. Also high waves might remove talus which had been butressing the foot of the cliff.
Response. We agree with the Referee's idea. A clarifying phrase according to his reasoning has been added.
31. Lines 314-316. Water is likely to operate most effectively along joints and bedding planes rather than in the pores of rocks.

Lines 318-319. exactly !.
Response. The paragraph has been rewritten to indicate that the more effective infiltration is along joints and bedding planes. We think that the very opening of the cracks prevents surface runoff and favors infiltration. Moreover, we also pointed out the importance of the porosity water filling of the Lastres Fm. sandstone.
32. Lines 320-322. Depends what you mean by this. Slope moisture content may well trigger coastal mass movements but they are primarily the result of wave oversteeping of slopes. All the moisture does is help to determine when they occur - but why they occur is due to waves.
Response. We agree with the Referee's idea. We have rewritten the sentence to avoid misunderstandings.
33. Lines 322-324. This is faulty logic. As noted above it is the waves that cause the blocks to fall. The accumulation of the blocks is simply a measure of the rate of wave removal. Comparing them to the pebble, which is likely to be an essentially equilibrium form (amount is essentially stable) is not a valid comparison of coastal vs mass movement activity.
Response. We agree and we have totally changed the sentence according to the Referee's suggestion.
34. Lines 352-353. Does it ? The results are pretty predictable - the role of water etc. How will it help to develop predictive models - the relationships with geology are some speculative given that no deep drilling was performed and in any case the relationships are site-specific.

Response. Taking into account the Referee's suggestion, we have rewritten the sentence, pointing out that the results of this work represent an important contribution to the knowledge of how the cliff coast of the Cantabrian coast behaves, taking into account the scarcity of previous works.

35. FIGURE 1. Define the back squares in this map = what are they representing ?

Response. The black squares refer to feno survey markers installed in June 2018 (please, see Figure 1 legend).

36. FIGURE 2. Could there be any rotational movement here - the photos suggest possible slumping in paces and marls and other soft rocks are susceptible to this type of mass movement. Also have you clearly demonstrated that the subsidence is not due to black jet mining - that might explain which there is no long or repetative history of large mass movements (collapse over mine workings might only happen once.

Response. We have not identified evidence of slumping processes. The image in Figure 2c may be misleading in this regard. Actually, we think the block toppled due to the gap generated after the other block slid in front of it.

37. TABLE 3. Accumulated

Response. The mistake was corrected.