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The Cryosphere Discussions

Interactive comment on "Fracture dynamics in an unstable, deglaciating headwall, Kitzsteinhorn, Austria" *by* A. Ewald et al.

Anonymous Referee #2

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Dear Editor,

I have reviewed the paper "Fracture dynamics in an unstable, deglaciating headwall, Kitzsteinhorn, Austria" with great interest. The authors present a new dataset consisting of fracture displacement and temperature measurements over 2.5 years. This study observes reversible fracture displacement due to thermo-elastic strain of the rock mass, concludes that the percolation of water into fractures can result in irreversible fracture displacement and thereby supports the findings of a series of other studies in bedrock permafrost (e.g. Blikra & Christiansen, 2014, Weber et al., 2017, Draebing et al., 2017).

For me this manuscript presents an interesting study based on a new dataset, but it needs to clarify the methods used and increase the novelty in interpreting/discussing

the results before it can be published in The Cryosphere.

MAJOR POINTS

1) How does steep rock slopes differ from deglaciated headwalls? Without a direct comparison, it is difficult/critical to assign processes to deglaciation.

2) I find the term deformation for discontinuities or fractures/cracks confusing or problematic. I associate 'deformation' in rock mechanical contexts with a continuum, so a deforming fracture would be one that changes for instance shape from being planar to being curved. You are referring to movement of one side of the fracture with respect to the other one, while the fracture itself remains undeformed. I suggest using to use the term 'dislocation' for fractures (i.e. infinite deformation along a nominally flat fracture with very small aperture), and leave the term deformation for intact rock.

3) You focus on steep rock slope but gravitation is totally missing in interpretation and discussion.

4) You often mix results and discussion. I would suggest to clearly distinguish them.

5) Figure quality could overall be improved.

6) For me, the installation setup is not fully clear. I do not understand for certain what the two different crackmeters exactly measure. Therefore, it is difficult to fully review the results and discussion. Please also clarify the methods used.

7) Think about to refine the research questions including some novel idea/thoughts. The first two questions are mainly answered by several studies for the third one you do not have any evidence!

8) You often relativize your findings by statements like "... not be detected with the current measurement setup.", "... not been observed in this study." or similar.

MINOR POINTS P1L7f: The first sentence is hard to read. P1L19f: "Lower magnitude horizontal deformation occurs in autumn and early winter due to ice segregation."

is contradictory to the sentence on P10L25f P1L20: You state that "Irreversible fracture opening was not observed...". How do you know that cryogenic processes occur? Please take care on clearly formulated statements. P1L28: Add reference after "... at glacier cirques." P1L28: "Here, ..." - in general? Or where? P2L1f: "... rendering deglaciating headwalls particularly prone to rock slope failure." - is this link investigated? P2L3: Is this statement valid only for deglaciation triggered rock-slope instability or for rock-slope instability in general? P2L12: "... in rock slopes." - in general or deglaciated? P3L4ff: In this paragraph you mainly focus on monitoring but your intention is not to reduce your paper to a data set. P3L10-12: Are these research questions site specific or in general? P3L13ff: This paragraph shows the result. I would not put it in the introduction. P3L18: This section is much too short. I would extend it! And why Kitzsteinhorn? Is it representative? What are the coordinates and what is the elevation of the study site? P3L21f: Is the headwall now vertical or is the slope "only" 45°

Fig. 1: Where do you measure CTT? Where is the borehole (for the temperature measurements) located? Where is the weather station installed? (a) Scale not readable. North arrow not really readable. Coordinates would be nice. (c+d) Where are the crackmeters installed? (e+f) Where is top? Where are K1 and K2? P4L2: "... undergoing rapid deglaciation." - all slopes? Were all rock slopes at the Kitzsteinhorn glaciated in the near past?

P4L8: Which logger did you use? P4L11: Why do CDH and CDV not have the same resolution? Do you really mean resolution? Or accuracy? P4L17: "Temperature readings are taken every 10 minutes." ... and for the crackmeters? P4L19 "... and corrected for temperature variations." How? P4L21: Haberkorn adapted the method by Schmid to steep rock-slopes. Mention this! P4L21: And Haberkorn used this method based on near surface rock temperature. You are using air temperature. Can the method anyway be applied? P4L21: "... standard deviation of ..." over which period? 1 hour? 1 day? 1 week? P4L28f: You assume that all displacement occurs between the two blocks. What's happening at the outer ending of the blocks? No expansion there?

P4L30: There are four L's in Fig. 2. Please use L1, L2, H1 and H2. Eq. 2: L should be (H1-H2), or not? (H1 = height of Block 1; H2 = height of Block 2) P5L4: How many days a year do you stay at this condition? P5L4f: I can't follow this assumption. Why can you exclude ice segregation based on CTT data? At 2m depth, which is not below the block, the minimum temperature is >-8°C...

Fig. 2: What is below the blocks? What's at the interface below the blocks? You never mention gravitation, which is important in steep rock slopes. If you had a block with only friction on a slope, thermo-elastic strain would cause irreversible displacement. If cryostatic pressure opens a fracture, why would it close again?

Fig. 3: In this figure, it is not obvious how you get the zero curtain and snow cover periods as air temperature is fluctuating strongly. Probably from CTT in Fig. 4? If yes, why do you show air temperature in this figure? The precipitation is visualized for which periods (mm/hour or mm/day)? a) Why are there so many small gaps in precipitation and air temperature? a)+b) Add ticks for months. b) It's difficult to see the orange line on the gray area, e.g. the peak indicated with the black arrow. P5L32: "... indicating water percolation in the joint system." This is rather interpretation/discussion than result...

P6L3f: "... exceeded the contraction limit of the crackmeter so only minimum values for CDV were established." I do not understand. P6L4: "For most of the time, ..." And otherwise? When not? P6L5: "... negative correlation ..." Where? Have you done any correlation analysis? P6L9: Are these 0.2mm due to the thermo-elastic strain of the rock or a sensor artefact? P6L11f: Why? Is ice formation unlikely? P6L13: I don't understand. Fig. 6 shows the opposite! P6L16: Remove one "the". P6L16: Check the correct date format of copernicus. P6L17f: Very interesting!

Fig. 4: CTT in a) and b) the same? Why is the zero curtain not at 0°C? For better readability, I suggest having 3 subplots (1 temperature, 1 CDH, 1CDV) and may be combine with Fig. 7 (model output). In addition, I would a figure showing the temperature-

displacement relation: Once measured data and once modelled data. Like this you see if you remove the reversible component due to thermo-elastic strain.

Fig. 5: It's hard to compare the subplots as a)-c) have different ranges for the y-axes (e.g. for temperature, a = 15°, b=20°, c=10+). Is the weather station representative (close enough)? Topography is relevant: gully vs. spur like feature.

Fig. 6: It took me a long time to realize what * and ** are indicating. Was the rock-slope already covered by snow in September 2017? It looks like in b) but Fig. 4 says no? It is rather difficult to track the lines/points over time and to link a) and b).

P7L16: Why? How do you know? Fig. 8 shows a big range of alpha below -10°C.. P7L19: "... good agreement ..." correlation analysis is needed! P7L22: Pleas show the residual displacement!

Fig. 7: I would like to see the residual displacement. a) Your model shows a fracture closing in winter 2017/2018, but your data not... What's the horizontal yellow line in July 2017? b) You have less than 0.5 summer with vertical displacement data and there is almost no agreement with the model even in winter (2016/2017). Are the results still representative? a)+b) add ticks.

P8L2: "Data Quality ..." is not explained. P8L3-L11: This paragraph rather describes assumptions and limitations. P8L13: "... significant negative correlation ..." I haven't seen any correlation analysis! P8L13f: Only for certain time periods... P8L17: Give numbers! Yours in comparison to others. P8L20: "... not show significant ..." Analysis? P8L21f: Why are the boundaries exact at 0? The upper boundary in Fig. 8b is marked wrongly, it does not go up to 5E-5.

Fig. 8: Autumn cooling and spring warming can't be distinguished. Could you indicate these periods with different colors? Why is ice segregation in a) and b) indicated differently?

P9L10: "... causing the observed rapid contraction at the end of the zero curtain pe-

riod." I do not understand this statement. P9L14f: Do you have any evidence in the data? Or is it a conceptual thought? P9L17: "... no ... mechanical reaction ..." Why? And again significant... P9L20ff: This statement/interpretation is rather vague... P9L24: "... freezing of rainwater ..." Is this scenario often the case? P10L2ff: Hard to follow. P10L8ff: Temperature in Fig. 8 refers to 10day-means. However, in reality there is much more fluctuation and the temperature does not stay in the range mentioned... P10L22: You totally ignore the influence of gravity! P10L25: "... growth on a seasonal scale." Fracture is NOT growing/opening (see your figures), it closes again! P10L25f: Are you really able to observe ice segregation? What's the evidence? If yes, how do you know the depth? P11L1: ... or CTT is just not representative?! P11L9ff: This is rather a "review" and not really based on or linked to your observations. P11L24: "... low magnitude rock detachments." Have you monitored/observed them? P11L24: "The contribution of an individual fracture to the stability of the entire headwall may thus seem negligible." Assumption? Result? Interpretation? P11L28: "... than a centimeter." You don't show any data supporting this! P11L29f: You don't show this in Fig. 2. Why? P11L31: What's about gravity? P11L32f: "Our data shows that temperature in combination with moisture availability is the critical factor determining enhanced fracture deformation on diurnal to seasonal scales (Matsuoka, 2008)." Does your data or Matsuoka (2008) show it? P12L3: Repetition... P12L12-14: "A related ... in preparation)." I would move this to the introduction/motivation. P12L15: Really? Does it? You do not show/compare fracture that was exposed longer time. Without such a comparison, your statement has no evidence is therefore rather critical. P12L28: In my opinion, you can't conclude this statement...

I hope that these comments help for improving the presentation of this work.

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