Review 2 (by Lukas U. Arenson)

Dear Lukas Arenson,
we thank you very much for your constructive and valuable suggestions and comments related to the content and editorial issues. We carefully addressed all of them and listed the changes in detail hereafter.

Philipp Mamot, on behalf of all co-authors

RC = Referee comment
AR = Author response

Lines 2-5:
RC: The referee suggested to

(1) write “rock types” instead of “rocks”
(2) delete “now”
(3) replace “experiments” with “laboratory tests”
(4) add a comma
(5) add “at temperatures” and “normal stress of”

AR: We adjusted the proposed changes in the revised manuscript as follows (lines 2-5 in the revised manuscript):
“To test the applicability to other rock types, we conducted laboratory tests with mica schist/gneiss, which provide the maximum expected deviation of lithological effects on the shear strength due to strong negative surface charges affecting the rock-ice interface. Retesting 120 samples at temperatures from −10 to −0.5 °C and normal stress of 100 to 400 kPa,…”

Line 8:
RC: The referee suggested to delete “the” and “of” and modify “change” to “changes”.
AR: Adjusted as proposed (line 8 in the revised manuscript).

Line 22:
RC: The referee asked for a reference to the Mohr-Coulomb failure criterion.
AR: We added the reference in the text and included the two citations in the reference list (line 22 in the revised manuscript):

"The failure criterion is based on Mohr-Coulomb (a combination of Coulomb (1776) and Mohr (1900)), and contains a temperature- and stress-dependent cohesion and friction which decrease upon warming."

Line 25:
RC: The referee replaced "for" with "by" and "the" with "their".
AR: We changed the wording as proposed (line 28 in the revised manuscript).

Line 26:
RC: "rock type" was added, "in" was modified by "with", "laboratory tests" was proposed for "experiments".
AR: Adjusted as proposed (line 29 in the revised manuscript).

Lines 27-28:
RC: "You mean the rock types in which failure occurred? Sentence unclear."
AR: We revised the sentence to clarify what we aimed to say (lines 29-31 in the revised manuscript):
"An inventory of rock slope failures in the central European Alps by Fischer et al. (2012) shows that the rock types, in which failure occurred and which potentially include the fracturing of ice-filled rock joints, are not only limestone but also gneiss and granite."

Line 29:
RC: The referee suggested to add "for the area".
AR: Adjusted as proposed (line 33 in the revised manuscript).

Line 33:
RC: The referee suggested to add "types".
AR: Changed as proposed (line 36 in the revised manuscript).

Line 44:
RC: The reviewer suggested to exchange "we" by "one would".
AR: Adjusted as proposed (lines 47-48 in the revised manuscript).

Caption Fig. 1:
RC: "Use same fonts and subscript as in Figure."
AR: We revised the caption as followed:

"…b), c) and d) Associated results of thin section analyses, where M refers to mica, Q to quartz, F to feldspar, C to calcite (C_F = fine grains; C_C = coarse grains) and O to others."

Line 61-62:
RC: The reviewer replaced "due to" with "for a" and the syntax of a sentence was changed.
AR: We realised the proposed changes in the following way (lines 71-72 in the revised manuscript):
"Two point-counter tracks of at least 100 points were indexed on each thin section. We estimated the mica content on sample surfaces via image histogram analysis."

Line 66:
RC: The reviewer added an "s" at the end of "piece".
AR: Modified as proposed (line 75 in the revised manuscript).

Line 70:
RC: The reviewer suggested to add "respectively".
AR: Adjusted as proposed (line 80 in the revised manuscript).

Line 83:
RC: The reviewer suggested to exchange "are" with "is".
AR: Adjusted as proposed (line 95 in the revised manuscript).

Line 88:
RC: The referee reminded to set "laboratory tests" instead of "experiments"
AR: We exchanged the wording as proposed by the reviewer (line 99).

Lines 90-96:
RC: The referee suggested to

(1) add a comma
(2) write "close to" instead of "close around"
(3) delete "well"
(4) write "outside the valid temperature range proposed" instead of "outside of its proposed valid temperature range"
(5) relocate a part of the sentence to the end of it
(6) replace "visible" with "noted"
(7) add "the"

(8) extend “close to the melting point” with “of the ice”.

AR: Revised as proposed (lines 101-108 in the revised manuscript):

“Overall, the measured peak shear stresses of this study lie well within, or close to the range of the failure criterion (dark blue area in Fig. 2). Even the laboratory tests conducted at −10 ◦C fit mostly within the expected values of the same failure criterion, although they are outside the valid temperature range proposed. Nevertheless, the measured peak shear stresses tend to fall below the failure criterion for the same temperature and at a normal stress of 400 kPa. This pattern is also noted in the previous tests with limestone (grey triangles in Fig. 2) and in the concrete-ice shear experiments by Günzel (2008), possibly due to the beginning transition from brittle to ductile failure with higher rock overburden leading to a lower shear strength (Renshaw and Schulson, 2001). When approaching the melting point of the ice, above −2 ◦C, the measured peak shear stresses slightly exceed the calculated range of the failure criterion.”

Line 98 and 101:

RC: “I suggest to use ratio instead of proportion (also in the Figure). To me ratio sounds more natural.”

Further, the reviewer asked to add “of ice” behind “ the melting point”.

AR: Adjusted in the text (line 109 in the revised manuscript), in Fig. 3 and in the respective caption (see below), as proposed.

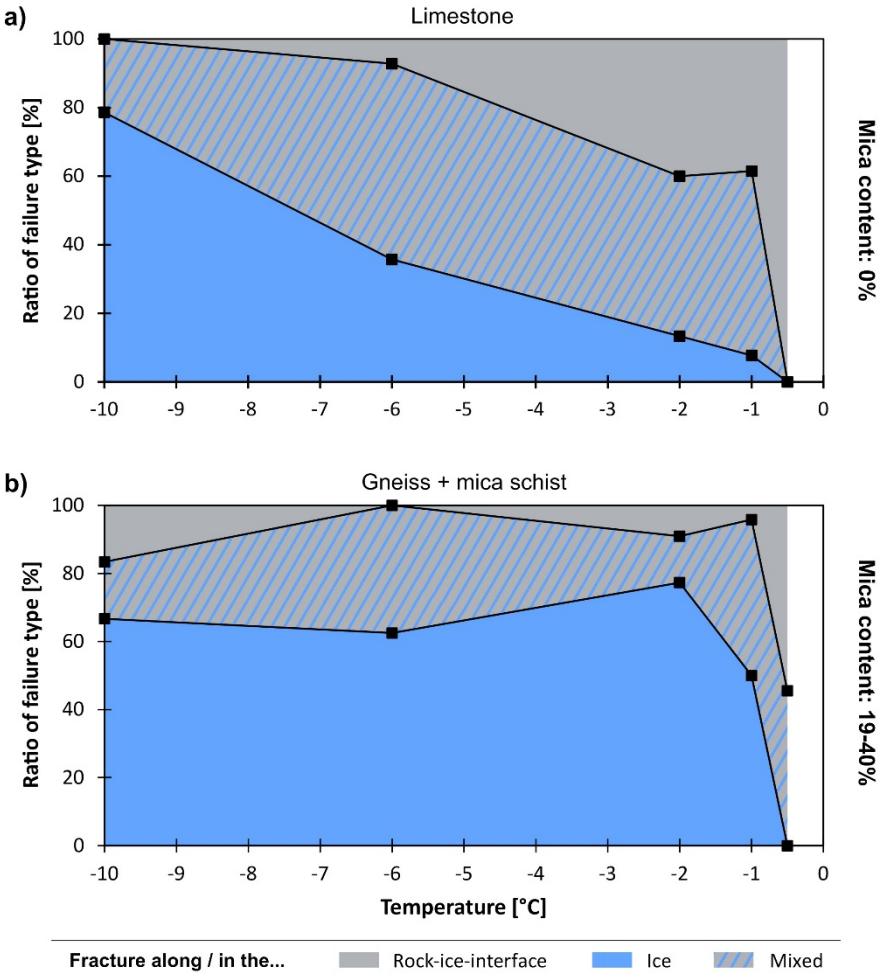


Figure 3. Ratios of failure types versus temperature for a) mica-free (0 %) and b) mica-rich (19-40 %) surfaces in ice-filled rock joints. […] in mica-free joints the proportion of ice fracturing decreases gradually when approaching the melting point of ice…"

Lines 105-109:

RC: The referee suggested to

(1) relocate the word "other" behind "rock types"
(2) write "demonstrated" instead of "showed"
(3) replace "involved in rock slope failures within the Alpine mountain permafrost belt" with "involved in permafrost rock slope failures"
(4) write "for those rock types" instead of "to these rocks"
(5) exchange "as" by "since"
(6) write "below" instead of "to".

AR: Adjusted as proposed (lines 116-120 in the revised manuscript).

Lines 110-117:

RC: The referee suggested to

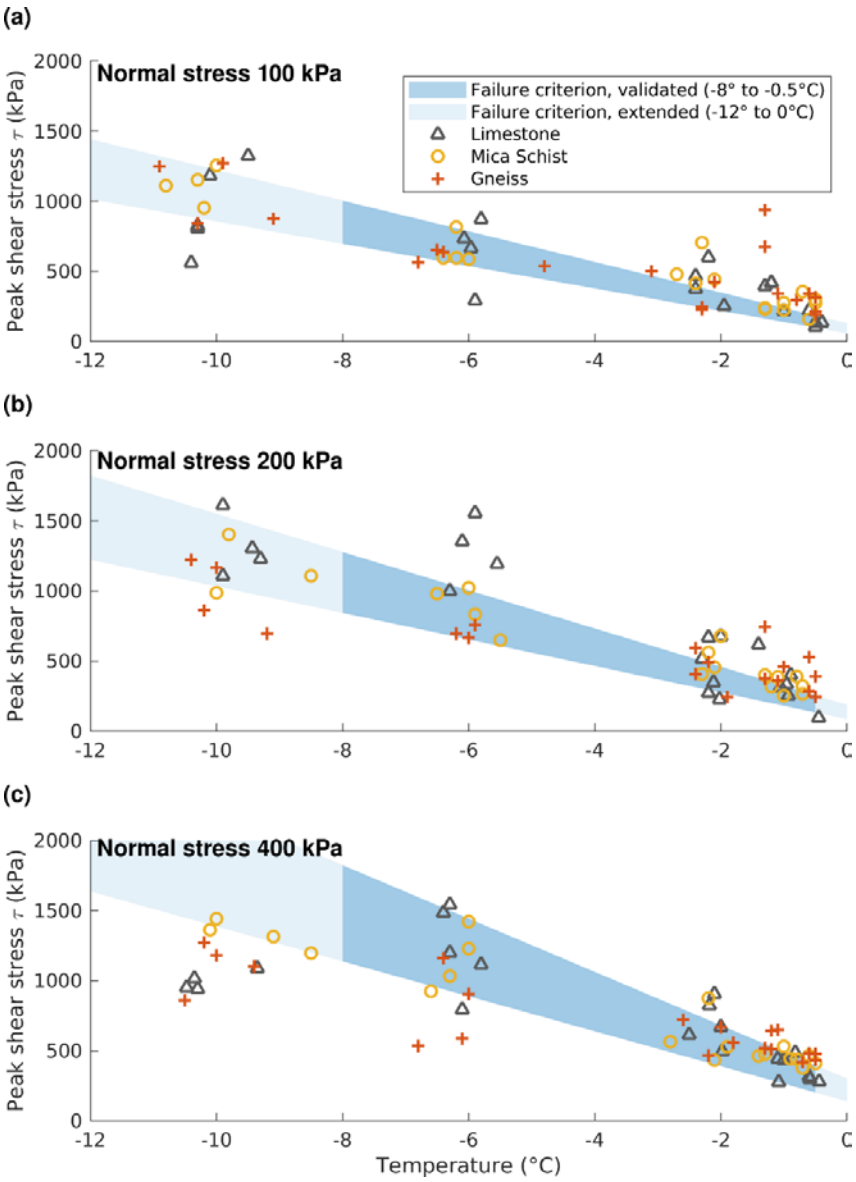
(1) add a comma
(2) write “seems to be” instead of “is rather”
(3) exchange “below” by “to”
(4) extend “close to the melting point” with “of the ice”
(5) delete a reference to Section 1
(6) write “strengthening” instead of “stabilising”.

AR: Revised as suggested by the referee (lines 121-127 in the revised manuscript).

Fig. 2:

RC: The reviewer asked to change the three sub-headings from “normal load” to “normal stress”.

AR: Adjusted as proposed (see below):



Caption of Fig. 2:
RC: “But also an extension from -0.5 °C to 0 °C?”
AR: We added the information that the extended section also refers to temperatures between -0.5 and 0 °C:

“…The validated range of the failure criterion by Mamot et al. (2018) is marked in dark blue while an extended section to −12 ◦C and to 0 ◦C is displayed in light blue.”

Lines 118-119:
RC: “Just be consistent to talk about interface, not contact”
Further, the referee suggested to change the sentence to “…gains in importance at temperatures warmer than -6 °C”
AR: Adjusted as proposed (lines 129-130 in the revised manuscript).

Line 127:
RC: The reviewer added “in the Alps”.
AR: Adjusted as proposed (line 138 in the revised manuscript).

Caption of Fig. 3:
RC: The reviewer added “of ice” to “the melting point”.
AR: Adjusted as proposed.

Line 129:
RC: The referee added “rock types”.
AR: Adjusted as proposed (line 140 in the revised manuscript).

Line 132:
RC: “More out of curiosity and for reference to put this into perspective, what is the shear strength (or if not available he UCS) of the unfrozen rocks?”
AR: We provided two sentences on the shear strength of unfrozen joint surfaces to Section 1 (lines 23-26 in the revised manuscript). The presented unfrozen values by Krautblatter et al. (2013) are based on the same normal stresses (100-400 kPa) and on the same rock type (Wetterstein limestone) which were used in the laboratory tests by Mamot et al. (2018). The surface roughness of the unfrozen samples (grit of 24 grains per inch) differed only slightly from the one of the ice-filled samples (grit of 80 grains per inch). Shear strength values of

unfrozen gneiss or mica schist surfaces were not available and, hence, could not be presented. The new information in the article is as follows:

"When warming from -1 or -0.5 °C leads to thawing and a subsequent loss of the ice infill, the shear strength of unfrozen joints reduces slightly by approximately 100 kPa (Krautblatter et al., 2013; Mamot et al., 2018). However, the unfrozen shear strength is 400-1000 kPa lower when compared with the one of ice-filled joints at temperatures between -2 and -10 °C."

Lines 134-140:

RC: The referee proposed to

(1) change "performed" into "carried out"
(2) write "laboratory tests" instead of "experiments"
(3) replace "of" by "in", "existence" by "presence" and "lie" by "correspond"
(4) add "introduced by"
(5) replace "mostly all rock types" by "wide variety of rock types"
(6) add "in the Alps" at the end of the sentence

AR: Adjusted as proposed (lines 156-162 in the revised manuscript):

"In this study, we carried out 120 constant strain rate shear tests on ice-filled joints in gneiss and mica schist to investigate a potential influence of metamorphic foliated rocks with high amount of mica on the shear resistance of ice-filled discontinuities. Based on the laboratory tests, we could demonstrate a slight increase in peak shear strength at temperatures close to 0 °C, which is most likely caused by the presence of mica. However, overall our data correspond well with the failure criterion for ice-filled rock joints introduced by Mamot et al. (2018). As the tested mica-rich rocks represent the expected maximum deviation of potential lithological effects on the shear strength, we conclude that the failure criterion is transferable to a wide variety of rock types relevant for permafrost rock slope failures in the Alps.
