Comment on tc-2021-88

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Community comment on "Comment on "Ice content and interannual water storage changes of an active rock glacier in the dry Andes of Argentina" by Halla et al. (2021)" by W. Brian Whalley, The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-88-CC2, 2021

Response from the authors of Halla et al. 2021 to the comment on tc-2021-88

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First, in contrast to what Whalley states in line 13 of his comment, we want to clarify that our case study (Halla et al. 2021) on the Dos Lenguas rock glacier (DL) examines a single rock glacier located east of the Andean water divide in Argentina, not multiple rock glaciers located west of the water divide on the Chilean side – this information is contained in the title of our work.

Second, neither discussing the origin of ice nor pinpointing the origin of rock material of the DL rock glacier has been the focus of our case study since it is not relevant for the estimation of ice and water content. Therefore, in our work, we merely classified DL as an active rock glacier and refrained from exclusively classifying DL neither as a talus rock glacier nor as a morainic-derived debris rock glacier (Barsch, 1996). It is purely speculative to classify a rock glacier according to its type of ground ice without direct subsurface observations. In contrast, the surface texture, the geomorphological characteristics and spatial connection of the rock glacier to the upslope are recommended proxies for visual observations (cf. standard guide lines for inventorying rock glaciers from the IPA Action "Group Rock glacier inventories and kinematics", 2018-2022, https://bigweb.unifr.ch/Science/Geosciences/Geomorphology/Pub/Website/IPA/Guidelines/V4/200507_Baseline_Concepts_Inventorying_Rock_Glaciers_V4.1.pdf).

Third, it is our scientific opinion that the assessment and discussion of the origin of a distinct rock glacier or landform should be based on on-site specific geomorphological characteristics (form, process, and material) of the landform. Therefore, we strongly disagree with the author's opinion that the simplest explanation using the glacier ice core model ('glacigenic hypothesis') applies to DL (Line 18) and to all rock glaciers in the region (Line 32) simply by assumption, without any field-based evidences or proxies. Accordingly, only arguments based on site-specific observations and measurements at the DL will be discussed below and opposed to Whalleys claims related to DL and the case

study of Halla et al. 2021.

In line 17, Whalley states that the DL "*shows no rock glacier formation in or from the extensive local talus*". However, well-defined talus slopes and cones are clearly visible even in Google Earth images, which smoothly transition into the root zone of the DL forming longitudinal ridges and furrows (Fig. 1). Further, the author claims in line 20/21, again without providing any field evidence, that *"At DL, a small glacier formed in a south-facing hollow then covered by insulating weathered rock debris."* However, this statement contradicts our geomorphological observations and measurements. Due to the geological fault crossing the upper Agua Negra valley at the study site, the heavily dissected bedrock in the contribution area above DL shows ongoing rock fall activity to the taluses that grade into the root zone of DL. The contributing area shows neither micro scale features of former glaciation like striation at bedrock outcrops nor the meso-scale morphometry of a cirque formation. No surface ice or perennial snowfield are present in the contributing area of DL, because the climatic conditions are too dry to form surface ice. The debris layer of the entire DL including the root zone shows sorted and structured material both at the surface and at outcrops (front and lateral slopes, crevasses, front of transverse ridges). The material has therefore been most likely produced by frost weathering, rock fall processes and cumulative viscous creep in frozen condition. No unsorted glacial deposits, like moraines, or any other geomorphological remains/traces of a former glacier were observed on the surface during the field campaign. The surface morphology of the entire rock glaciers is well structured by distinct ridge and furrow morphology (Fig.1). There is no 'hummocky terrain' indicating meltout of glacial ice at the DL. The thermokarst lakes at DL are located in furrows (cf. Fig. 2 and Fig. 9 in Halla et al. 2021) and their bottom and surroundings consist of sediments that show pore ice building up during freezing periods. Therefore, thermokarst lakes on DL are not comparable to supraglacial lakes on debris-covered glaciers that melt into a glacial ice core.

Further, the geophysical measurements at DL indicate rather ice-rich permafrost conditions than a buried glacial ice core. The measured characteristic electrical resistivities are predominantly in the medium-to-high kΩm range, typical for ice-rich permafrost (cf. Fig. 5 in Halla et al. 2021). Thus, the resistivities measured on DL are a magnitude smaller than for glacial ice and buried glacial ice cores, which typically have resistivities of in the range of MΩm (Haeberli, W. and Vonder Mühll, D, 1996). Even the highest resistivities of the ERT-profile L1 in the root zone (cf. Fig. 5a in Halla et al. 2021) are significantly lower than what would be expected for glacial ice. In summary, ERT-derived data, serving as a proxy for the internal structure of DL here, rather indicates the presence of ice-rich permafrost than buried glacial ice.

Also the seismic p-wave velocities results at DL show a broad range of p-wave velocity from 1500 to 4500 m s^{-1} (cf. Fig. 6 in Halla et al. 2021), which is characteristic for permafrost with varying ice content in rock glaciers (Draebing, 2016, Hauck and Kneisel, 2008). A narrow range of P-wave velocities around ~3500 m s^{-1} would be expected for pure ice (Timur, 1968, Hauck et al. 2011). We will here not go into the details of the necessary geophysical data processing for being able to differentiate between glacial ice and ice-rich permafrost occurrences, as this was neither the aim nor the topic of our paper, but it can be stated that we see no evidence for the presence of glacial ice in our geophysical data.

In summary, based on our data-supported on-site investigations, the DL should rather be considered as a talus rock glacier, since we find no indications nor proxies that would suggest a 'glacigenic' origin of DL.

Figure 1. Dos Lenguas rock glacier in the dry Andes of Argentina. The source area of the active rock glacier shows talus slopes and talus cones that transition into a distinct ridge and furrow topography. Source: Google Earth image © CNES / Airbus (image date: April 2019).

References:

Barsch, D.: Rockglaciers: indicators for the present and former geoecology in high mountain environments, Springer, Berlin, 331 pp., 1996.

Draebing, D.: Application of refraction seismics in alpine permafrost studies: A review, Earth-Sci. Rev., 155, 136–152, https://doi.org/10.1016/j.earscirev.2016.02.006, 2016.

Haeberli, W. and Vonder Mühll, D.: On the characteristics and possible origins of ice in rock glacier permafrost. Zeitschrift für Geomorphologie N.F. 104, 43-57, 1996.

Halla, C., Blöthe, J. H., Tapia Baldis, C., Trombotto Liaudat, D., Hilbich, C., Hauck, C., and Schrott, L.: Ice content and interannual water storage changes of an active rock glacier in the dry Andes of Argentina, The Cryosphere 15, 1187-1213, doi.org/10.5194/tc-15-1187-2021, 2021.

Hauck, C. and Kneisel, C.: Applied Geophysics in Periglacial Environments, Cambridge University Press, Cambridge, UK, 256 pp., 2008.

Hauck, C., Böttcher, M., and Maurer, H.: A new model for estimating subsurface ice content based on combined electrical and seismic data sets, The Cryosphere, 5, 453–468, https://doi.org/10.5194/tc-5-453-2011, 2011.

Timur, A.: Velocity of Compressional Waves in Porous Media at Permafrost Temperatures, Geophysics, 33, 584, https://doi.org/10.1190/1.1439954, 1968.