Proposal for geomorphological mapping of debris-covered and rock glaciers and its application to Tröllaskagi Peninsula (Northern Iceland)

Luis M. Tanarro a, David Palacios a, José J. Zamorano b and Nuria Andrés a

aDepartment of Geography, Universidad Complutense de Madrid, Madrid, Spain; bDepartment of Physical Geography, Instituto de Geografía, Universidad Nacional Autónoma de México, México D.F., México

ABSTRACT
This work defends and applies a new proposal for mapping debris-covered glaciers and rock glaciers. This proposal combines highly accurate traditional methods, such as manual geomorphological photointerpretation, with novel digital techniques. The new methodological strategy applies rendering and lighting tools from Computer-Aided Design platforms and uses graphic design from Desktop Publishing Programs, to improve the geovisualization of geomorphological maps. This combination was applied to the debris-covered glacier and a set of rock glaciers located on the Tröllaskagi peninsula (northern Iceland). The result is a 1:4,500 scale geomorphological map of 16 km², which for the first time maps the features that differentiate the debris-covered glacier from rock glaciers, as well as genetically different units within each formation and a long series of landforms characteristic of different processes. This map thus becomes a very useful tool in the evolutionary study of these formations in relation to the impact of climate change.

1. Introduction

Three major types of ice masses have been differentiated within high mountain areas, according to the importance of the debris cover: debris-free glaciers (without major debris cover), debris-covered glaciers (with an almost continuous, thin debris cover), and rock glaciers (with a continuous, very thick debris cover, where the ice often only fills the interstices between blocks). Recent studies suggest that these three types are actually three evolutionary phases of the same glacier transformation process, as their surfaces are covered by debris because of high erosion rates from surrounding slopes and where decreasing ice content exposes additional englacial debris (Anderson, Armstrong, Rossi, & Crump, 2018; Berthling, 2011; Janke, Bellisario, & Ferrando, 2015; Monnier & Kinnard, 2015, 2017). Although the flow is very different in these three types of ice masses, their defining criteria are not fully established, especially the difference between debris-covered and rock glaciers (Berthling, 2011; Janke, Regmi, Giardino, & Vittek, 2013; Kirkbride, 2011; Monnier & Kinnard, 2015, 2017; Whalley, Matsuoka, Sik, Kereszturi, & Hargitai, 2015). This lack of a clear distinction between the two formations is a major shortcoming as some rock glaciers in fact derive from debris-covered glaciers (glacier-derived rock glaciers), but others derive from rock fall talus, where interstitial ice has formed between the blocks and the whole mass acquires a plastic character (talus-derived rock glaciers) with the existence of permafrost (Janke et al., 2015; Whalley et al., 2015).

One way to differentiate debris-covered and rock glaciers is by the amount of ice present in each formation. Thus, in debris-covered glaciers ice accounts for more than 70% of the mass and in rock glaciers the proportion of ice is significantly lower (Janke et al., 2015; Whalley et al., 2015). However, to calculate the amount of ice present within these formations requires the use of very complex techniques. A simple and easy way to distinguish debris-covered from rock glaciers is with the morphology adopted by the debris accumulation on the glacier surface. In both formations, the predominant landforms are those derived from the internal flow of the glacier, such as alternating furrows and ridges, but the ridges of debris-covered glaciers tend to be more longitudinal to the flow, and there are evident lateral and central moraines (Monnier & Kinnard, 2015, 2017). Thermokarst morphology is also common in debris-covered glaciers, favoring the development of depressions and lakes, and much more chaotic landforms such as hummocks, meandering furrows and ponds (Monnier & Kinnard, 2015, 2017). Rock glacier morphology is linked to a much slower, more viscous flow than in debris-covered glaciers (Janke et al., 2013). For this reason, in rock glaciers pronounced transverse ridges and furrows predominate, perpendicular to the flow direction.
originating in over-thrusting of internal shear planes, while lateral ridges and meandering furrows originating in resistance to flow are also common (Janke et al., 2015; Whalley et al., 2015). The lobes of rock glaciers are usually longer than they are wide, with a combination of transverse and lobate forms (Janke et al., 2015; Whalley et al., 2015).

Another important problem in studies of debris-covered and rock glaciers is to determine their flow type and intensity. In debris-covered glaciers, the flow responds to the reaction of the glacier to its mass balance; in rock glaciers the flow displays the deformation of ice/debris mixtures by long-term creep under permafrost conditions (Berthling, 2011). Flow analysis can be very useful to determine the origin of these formations and to establish their relationship with climate evolution (Janke et al., 2015; Monnier & Kinnard, 2015, 2017; Whalley et al., 2015). At present, this is proposed as the best method to study the origin and climatic significance of rock glaciers and debris-covered glaciers, to analyze their dynamics and their morphological changes over time (Bosson & Lambiel, 2016; Capt, Bosson, Fischer, Micheletti, & Lambiel, 2016; Emmer, Loarte, Klimes, & Vilimek, 2015).

For all the above reasons, geomorphological mapping is evidently of great importance in the study of debris-covered, rock glaciers and proglacial landforms (Benn, Kirkbride, Owen, & Brazier, 2003; Evans & Twigg, 2002). One problem of this cartography is the difficulty of representing complex landforms, where geomorphological features from different periods overlap in numerous flow units, as has been previously revealed in Iceland (Kjær, Korsgaard, & Schmacker, 2008; Schomacker, Benediktsson, & Ingólfssson, 2014; Bennett & Evans, 2012). All these complex landforms express the complex evolution of the whole. Despite the importance and considerable complexity of this mapping, previous studies tend to oversimplify and only delimit the main ridges and furrows, the glacier toes and some large collapse depressions (e.g. Kellerer-Pirkblauer & Kaufmann, 2012; Serrano, San José, & González-Trueba, 2010 Roer & Nyenhuis, 2007). Only more recent research delimits different flow units in geomorphological maps (Dusik et al., 2015; Emmer et al., 2015; Monnier, Kinnard, Surazakov, & Bossy, 2014).

This work aims to develop a geomorphological mapping proposal that can be used to define the morphologies of debris-covered glaciers and rock glaciers in as much detail as possible, so that they can be clearly differentiated. In addition, this mapping could be considered as evolutionary and be used to produce an adequate follow-up of future morphological changes in these formations to determine their origin, state and dynamics (Tanarro et al., 2019). To develop this proposal, the debris-covered glacier in the Hóladalsjökull cirque (65°42′ N; 18°57″ W) and a group of rock glaciers in the Fremri-Grjótárdalur cirque (65°43′ N; 19°W) have been selected, both located near the town of Hólar in the Viðinésdalur valley, on the Tröllaskagi peninsula (Northern Iceland) (Figure 1(A)).

### 2. Geographical, geological and climatic setting

The Tröllaskagi Peninsula is in the north of Iceland, at maximum latitude 66°12′N, and is limited by the Skagafljót fjord to the west, and Eyjafjörður to the east, between meridians 19°30′W and 18°10′W. The peninsula is formed by a semi-horizontal accumulation of Miocene basaltic lavas, with interleaved sedimentary layers of clay, or ‘red interbed layers’ (Saemundsson, Krisjansson, McDougall, & Watkins, 1980). This lava accumulation forms an extensive plateau, with summits between 1200 and 1500 m altitude, with deep, incised, flat-bottomed valleys. In the cirque-shaped headwaters of these valleys there are currently numerous glaciers, mostly not exceeding 2 km in length. A few are debris-free glaciers, and most are debris-covered and rock glaciers (Andrés, Palacios, Tanarro, & Fernández, 2016; Fernández, Andrés, Saemundsson, Brynjólfsson, & Palacios, 2017). Lilleøren et al. (2013) have identified 118 rock glaciers, of which 51 are talus-derived rock glaciers and 67 are glacier-derived rock glaciers.

To develop the geomorphological mapping proposal, the Hóladalsjökull debris-covered glacier and the rock glaciers of the Fremri-Grjótárdalur cirque were selected for this case study. The classifications of Hóladalsjökull as a debris-covered glacier, and the mix of debris and ice flows located in Fremri-Grjótárdalur cirque as rock glaciers, have been proposed and demonstrated by previous experimental studies (Kellerer-Pirkblauer, Wangenstein, Farbrot, & Etzelmüller, 2008; Tanarro et al., 2019) and are in agreement with those defined in previous publications (e.g. Kirkbride, 2011; Janke et al., 2015; Monnier & Kinnard, 2017; Anderson et al., 2018; Anderson & Anderson, 2018; Knight, Harrison, and Jones 2019). These formations are located on the northern slope of the Viðinésdalur valley, which flows into the Skagafljótur near the village of Hólar (65°42′N–65°44′N and 18°56′W–19°02′W, 160 m). Hóladalsjökull is in the easternmost cirque and Fremri-Grjótárdalur is more western, but both have a maximum altitude between 1200 and 1330 m and minimum altitude between 800 and 900 m (Figure 1(B and C)).

At the Hólar weather station (160.0 m a.s.l.), the period 1961–1990 (Icelandic Meteorological Office) obtains a mean annual air temperature (MAAT) of 2.7°C and mean annual precipitation of 485 mm. Based on data extrapolation from the Hólar station and assuming an altitudinal thermal gradient of −0.65°C/100 m−1, Kellerer-Pirkblauer et al. (2008), estimate that the MAAT at the front of these glaciers
is between $-1.8^\circ$C and $-2.6^\circ$C. According to permafrost distribution models in the Trollaskagi mountains (Etzelmüller et al., 2007; Farbrot et al., 2007; Wangensteen et al., 2006), the lower permafrost limit is 850–950 m at the bottom of these cirques.

3. Methods and materials

The new proposal for mapping debris-covered and rock glaciers combines traditional, very accurate methods, such as manual geomorphological photointerpretation, and novel digital techniques, such as the application of rendering and lighting tools, available in Computer-Aided Design (CAD) platforms, which considerably improve the geomorphological map display. The new digital technologies speed up the work and improve its 2D and 3D geovisualization.

The topographic base map was obtained by manual photogrammetric restitution and the geomorphological information recognized was defined by traditional photointerpretation to produce a geomorphological flow units map and a geomorphological features map. With this detailed information, CAD Bentley MicroStation and a Desktop Publishing program (DTP CorelDraw) were combined to obtain high visual quality geomorphological mapping. To enable a better
understanding of the geomorphological meaning of the map, the landforms and features were also represented in different didactic transects.

3.1. Topographic base map

The topographic base map was obtained by manual photogrammetric restitution of 1980 overlapping stereo aerial photographs, using a digital photogrammetric workstation (Digi3D). The mean square error of the absolute orientation in x, y, z (RMSExyz) of each photographic stereo-pair was 0.153 m. Then, the manual digital photogrammetric restitution in 3D of the contour lines and of numerous points (spot elevation) was carried out. The result was a topographic map at scale 1: 2000 with a 2 m contour interval.

3.2. Geomorphological mapping

The geomorphological mapping process included the following stages:

3.2.1. Traditional photointerpretation and production of a manual geomorphological map

Photointerpretation of aerial-photo pairs from different years (1946, 1980, and 1994) was carried out with a Topcon mirror stereoscope. The geomorphological information recognized during the photointerpretation process in the above flights was delineated on the 2000 orthophoto. This information consists of the division of the debris-covered and rock glaciers surfaces into flow units (Figure 2(A)) and the definition within each flow unit of specific features such as ridges, furrows, depressions, etc. The result is a black and white geomorphological map with different linear symbols for each feature, represented at scale 1: 2000 (Figure 2(B)).

3.2.2. Georeferencing and digitizing the manual geomorphological maps

The flow units map (Figure 2(A)) and the individual geomorphological features map (Figure 2(B)) were scanned at high resolution to obtain raster images. These images were then georeferenced on a CAD platform, by identifying control point coordinates in the 2000 orthophoto. The flow units map was digitized with CAD software, which was also used to clean all the topological inconsistencies generated in the digitization process. Finally, the topology was created by defining the centroid and polygon of each flow unit. On the other hand, the individual features map was transformed into a transparent black and white raster image, using a desktop publishing program.

Figure 2. Cartography: (A) Map of the geomorphological flow units; (B) Map of geomorphological features; (C) Topographic base map; (D) Digital Elevation Model.
3.2.3. Symbolization and design of the final map
DTP CorelDraw was used for the digital symbolization and graphic design of the Main Map. Flow units were represented by applying colors to the polygons, following the classic proposals for geomorphological map legends (Lambiel et al., 2012; Peña Monné, Pellicer Corellano, Chueca Cía, & Julián Andrés, 1997; Tricart, 1976). Various tones of purple are used to differentiate units from different periods in the debris-covered and rock glaciers. Various tones of green are used to differentiate flow units with predominantly longitudinal crests and furrows on debris-covered glacier surface. Light blue is used to show debris-free ice. The initial black and white features map is used as a transparent layer, respecting the initial symbols and patterns of each landform, to represent the different landforms within each flow unit. Thus, each symbolic pattern is not merely an automatic repetition, but instead represents the exact position of the different landforms. The final geomorphological map is the result of combining colors representing the areas of each unit of flow, and patterns and symbols representing the individual landforms.

3.3. Geovisualization of the geomorphological map in 3D
To show the relief sensation of geomorphological maps, the most common solution, when using GIS or DTP software, is generally to apply a simple transparency to the geomorphology layer on the Digital Elevation Model (DEM). Conversely, CAD platforms have the advantage of providing specific rendering and lighting tools that can be applied to geomorphological coverage, to obtain a more expressive and realistic map, both for 2D and 3D geovisualization. For this reason, this proposal applies the tools offered by CAD to map complex landforms for the first time. The cartography obtained offers a more realistic appearance in 3D, after combining the DEM with the geomorphological map into a CAD platform.

3.3.1. Creation of the digital elevation model
The DEM was created with GIS Global Mapper program from the topographic base (Figure 2(C)). The result was a map in raster format with pixel size 2 m (Figure 2(D)). The DEM data were exported to a XYZ Grid format (*.xyz) to be processed in CAD.

3.3.2. Creation of mesh structure and generation of 3D model
The XYZ Grid file was imported into the MicroStation CAD platform to create a mesh structure which can be represented by applying different visualization styles and assigning textures in a 3D model. In this case, the geomorphological map previously exported as an image was draped on the mesh structure. Rendering tools were also used to define the 3D model lighting properties according to the pre-defined solar position, by specifying the geographical coordinates, day, time, and sun height. The final result can be exported to a file in Adobe Acrobat format (*.pdf) in 3D.

4. Description of geomorphological landforms
The final geomorphological map (Main Map) defines the most important units of the Hóladalsjökull debris-covered glacier and the Fremri-Grjótárdalur rock glaciers, and the internal features within each unit. The differentiation between active and relict rock glaciers agrees with criteria specified in previous publications (Andrés et al., 2016; Farbrot et al., 2007; Kellerer-Pirklbauer et al., 2008; Tanarro et al., 2019).

4.1. Units and features related to glacial processes
4.1.1. Present debris-free glaciers
In both cirques there is debris-free glacial ice at the glacier headwalls. This sector is about 1.6 km² in Hóladalsjökull, located under the cirque wall and divided into three different tongues. In each tongue, an upper part can be differentiated with a steep slope, and a lower part where the ice tends to form a depression, with a sharp borderline between them shown on the map. The debris-free glacial ice of the Fremri-Grjótárdalur cirque occupies three very small, isolated, depressed areas.

4.1.2. Spoon-shaped depressions
As indicated above, spoon-shaped depressions can form at the head of these glaciers. In Hóladalsjökull, there are three of these depressions in an area of around 2.5 km², of which approximately 66.6% is occupied by debris-free glacial ice. Debris ridges and hummocks appear at the bottom of the depressions. These depressions are surrounded in their lower sector by sharp lateral and frontal crests, located at 1.4–1.6 km from the glacier head, at altitudes 1020–1038 m, and reach 17–20 m above the bottom of the depressions. In the Fremri-Grjótárdalur cirque, smaller depressions have also been formed.

4.1.3. Old moraines and erratic boulders
Outside the current glaciers, morainic ridges have been located in the Fremri-Grjótárdalur cirque and erratic boulders in the Hóladalsjökull cirque, deposited by previous glaciers around 14 ka ago (Andrés et al., 2016).
4.2. Units and features related to the debris-covered glacier

From the crests that surround the spoon-shaped depressions, the Hóladalsjökull debris-covered glacier extends to a length of about 2 km, at altitude around 900 m, and with maximum width 1.3 km, covering an area of 2.21 km². Its culminating surface has a gentle slope of less than 5°. Its front forms an abrupt wall more than 30 m high, with a 30° slope (Figure 3(A–C)). The whole surface is covered with boulders with a clay matrix. The maximum diameter of these boulders may exceed 3.5 m. On this surface, the following units have been differentiated:

4.2.1. Longitudinal ridges and furrows

The longitudinal ridges and furrows may be more than 1.5 km long. The furrows sometimes display a meandering path and remain snow-covered throughout the year (Figure 4(A–C)).

4.2.2. Central sector of the debris-covered glacier

The central sector of the debris-covered glacier is divided into two parts. The morphology of the upper part is complex, displaying longitudinal ridges, depressed areas with permanent snow cover and a succession of ridges and ogival transverse furrows. The lower part does not display clearly defined flow

Figure 3. Different views of the debris-covered glacier of Hóladalsjökull: (A) General view of the extent of the debris-covered glacier of Hóladalsjökull, from the summit plateau, showing its front, and the rock glacier at the bottom. (B) The eastern lateral of the debris-covered glacier, where the alternation of longitudinal ridges and furrows is observed. Large debris mounds derived from downwasting processes are also observed. (C) View of the western sector of the cirque which sheltered the glacier inside a spoon depression, limited by ridges.
structures (Figure 4(D)). Numerous depressions and drainage incisions develop, mainly running W-E and SSW-ENE following the slope direction, revealing internal water flow channels (Janke et al., 2013; Monnier & Kinnard, 2017).

4.2.3. Lower sector of the debris-covered glacier
The lower sector of the debris-covered glacier, to the glacier front, is characterized by the existence of furrows and transverse ridges with gentle slopes.

4.2.4. Thermokarst depressions
Collapse depressions caused by melting ice are frequently found, distributed throughout the debris-covered glacier, although they are more frequent in the central sector (Figure 5(A–D)). The debris layer is 2–3 m thick, as could be observed in the interior of these depressions during fieldwork (Figure 5(E and F)).

4.3. Rock glaciers: units and features
The rock glaciers are mainly found in the Fremri-Grjóttárdalur cirque, where two small monomorphic talus-derived rock glaciers have been identified, with two larger rock glaciers extending beneath them (Figures 6 and 7). Field observations and recent studies show that the surface debris layer rests on solid ice (Farbrot et al., 2007; Kellerer-Pirklbauer et al., 2008). All the rock glaciers of this cirque occupy an area of 0.96 km². In the western sector of the Hóladalsjökull cirque a small rock glacier has formed, covering an area of 0.29 km² with its front descending to altitude 904 m. The rock glaciers have been divided into different units in terms of their morphology, altitudinal position, and dynamics (Andrés et al., 2016; Kellerer-Pirklbauer et al., 2008; Tanarro et al., 2019; Wangensteen et al., 2006).

4.3.1. Rock glaciers in the eastern sector of the Fremri-Grjóttárdalur cirque
The eastern rock glacier is tongue-shaped, 400 m long and 300 m wide and descends to altitude 980 m. This tongue is divided into two lobes (Figure 6(E)). The upper lobe is 190 m long, 270 m wide and descends to 1002 m a.s.l. Still with ice remaining inside, it is formed by several crests and transverse furrows and has a pronounced front. The lower lobe, 250 m long, 280 m wide, extends below this front, ending at 978 m a.s.l. The morphology of this lower lobe is more chaotic, with a depressed area predominating at its center. This fossil lobe is considered free of interior ice (Figure 6(E and F)). At the western edge of this rock glacier there is a small talus-derived rock glacier, originating under three rock-fall cones.

4.3.2. Rock glaciers in the central sector of the Fremri-Grjóttárdalur cirque
In this sector, rock glaciers from two different periods have been formed, with significant
longitudinal development and clear SSE-NNW direction. The upper rock glacier is 800 m long and close to 400 m wide and its front ends between altitude 896 and 922 m. Its eastern boundary forms a steep front, while the western boundary is a deep longitudinal channel connecting with the rock glaciers in the western sector of the cirque. The upper part is characterized by a relatively flat block surface, and in the lower part there are abrupt ridges and furrows transverse to the flow (Figure 6(A–C)). The rock glacier ends in a steep slope front, with occasional block falls (Figure 6(D)). Just below this front there is a fossil rock glacier which displays a chaotic morphology and extends a further 500 m, down to altitude 850 m.

4.3.3. Rock glaciers in the western sector of the Fremri-Grjótárdalur cirque
In the western sector of the cirque, there is a rock glacier running NNE, close to 600 m wide, and 300–400 m long, ending in an abrupt front at altitude 950–940 m a.s.l. The surface morphology of this rock glacier is very complex, modeling a series of depressed, elongated areas in the direction of flow, with irregular, sinuous edges and some crests and transverse furrows (Figure 7(A–C)). At the boundary between the central and western rock glaciers there is a small talus-derived rock glacier attached to the cirque wall, with a steep slope at its front.

4.3.4. Rock glaciers in the western sector of the Hóladalsjökull cirque
There is a small active rock glacier to the east of the debris-covered glacier (Figure 3(A)), 300–450 m wide, which extends for some 580 m, and with a terminal front at altitude 922–928 m. Overlapped by this active rock glacier, a fossil rock glacier extends to altitude 904–906 m.

4.4. Other units
4.4.1. Glacier cirque and scarps
The map also defines the landforms surrounding the glaciers studied in the cirques. The contact between the culminating plateau and the cirques is an almost vertical wall 100–170 m high, where a succession of
basaltic lavas can be observed with interbedded reddish sedimentary levels (Figure 8(A)). These walls are eroding rapidly, with constant rock falls onto the surface of the glaciers (Figure 3(A)). The cirques where the Hóladalsjökull and Fremri-Grjótárdalur glaciers are located are 2.8 km and 2.3 km wide, respectively, while the cirque that hosts the small Hóladalsjökull rock glacier is less than 900 m wide.

4.4.2. Scree slopes and rock fall talus
Under the walls surrounding the cirques there are continuous scree slopes and rockfall talus, resulting from the intense erosive activity.

4.4.3. Patterned ground features
The high plateau, with altitudes 1200–1330 m a.s.l., borders the glacial cirques. On its surface, periglacial
activity and the existence of permafrost have modeled an extensive blockfield and patterned ground features (Figure 8(B)).

5. Conclusions

The combination of traditional techniques and new digital technologies has allowed us to obtain a geomorphological map that, for the first time, shows the morphology of the Hóladalsjökull debris-covered glacier, and of various rock glaciers in Fremri-Grjótárdalur cirque with greatly enhanced graphic expressivity.

The final map shows the result of combining the application of tools from different cartography software (CAD, GIS or DTP) and shows that they are complementary and can achieve a higher visual quality. In particular, CAD platforms have more efficient tools for digitalization tasks, especially in the most realistic visualization of maps. The 3D geovisualization of the final map enables the clear differentiation between

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Figure 7. Fremri-Grjótárdalur rock glaciers: (A) Front of the western rock glacier, with a succession of abrupt ridges and furrows, overlapping a lower fossil rock glacier; (B) Detail of a deep longitudinal furrow; (C) Detail of stepped ridge and furrow succession.

Figure 8. Landforms external to glaciers: (A) Cirque headwalls, showing the alternation of lava flows and clayey sediment levels. (B) Summit plateau with pattern ground landforms.
the geomorphological units and facilitates the interpretation of the landforms according to their origin, evolution, and disposition.

Observing the plan view of the geomorphological map and the 3D isometric view enables the interpretation of the significant differences between the characteristics of the Hóladalsjökull debris-covered glacier and the rock glaciers in the Fremri-Gjóttardalur cirque, thus clearly achieving one of the aims of our research.

The debris-covered glacier displays the presence of ridges and well-developed longitudinal furrows. In addition, as is typical of these formations, there are abundant collapse depressions due to melting ice. On the other hand, in the Fremri-Gjóttardalur cirque, multiple rock glaciers are identified with clear geomorphological differences. The rock glaciers of the central and western sector end in a succession of steps, formed by crests and abrupt fronts. These active rock glaciers cover a fossil rock glacier. The most remarkable characteristic of the different lobes is the morphological transformation from its root, modeled in less pronounced furrows and ridges, towards its front, where there is a sequence of steps formed by ridges with steep slopes and deep transversal furrows. In contrast, the rock glacier in the eastern sector forms a tongue divided into two superimposed lobes.

All the features highlighted by the geomorphological mapping carried out in this research may lead to a correct interpretation of the origin and evolutionary sequence of these debris-covered and rock glaciers. In the future, the periodic repetition of this type of geomorphological mapping may also be used to determine the dynamics of debris-covered and rock glaciers and their relationship with the impact of climate change.

Software

We used CAD Bentley MicroStation v8i to georeference and digitize the geomorphological outlines and to create the 3D geovisualization of the map. We produced the composition and final graphic design of the geomorphological map using CorelDraw X17. In addition, we stereo-plotted the topographic base map with the Digi3D digital photogrammetric workstation and obtained the DEM with Global Mapper v17.

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ORCID

Luis M. Tanarro https://orcid.org/0000-0003-0871-7711
David Palacios https://orcid.org/0000-0002-8289-0398
José J. Zamorano https://orcid.org/0000-0002-9575-5734
Nuria Andrés https://orcid.org/0000-0002-4362-1195

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