



# IPA Action Group Rock glacier inventories and kinematics

Towards standard guidelines for inventorying rock glaciers

## **Baseline concepts**

*(Version 4.2.1)*



<https://www3.unifr.ch/geo/geomorphology/en/research/ipa-action-group-rock-glacier> (Action Group website)

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## Authors and contributions

The document has been edited by Reynald Delaloye and Thomas Echelard (University of Fribourg, Switzerland) with the contribution of the participants at the workshop held in Evolène (Switzerland) on 23 - 27 September 2019 as well as further members of the Action Group.

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*The purpose of this document is to serve as baseline for the practical establishment of standardized rock glacier inventories on a global scale.*

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Updated versions including the renewed approval list and possibly very small changes and edits could be released at any time during the lifetime of the Action Group and renamed by adding a third digit in the versioning (e.g. 4.0.x). The last version will always be the one hosted on the Action Group website. There will be no specific information sent to the Action Group subscribers.

If minor content changes appear to be necessary, they will be adopted by the dedicated committee named in Evolène in September 2019, including Xavier Bodin (France), Francesco Brardinoni (Italy), Reynald Delaloye (Switzerland), Christophe Lambiel (Switzerland), Shelley MacDonell (Chile), Line Rouyet (Norway) and Lucas Ruiz (Argentina). The second digit of the versioning will be changed (4.x) and an information will be sent to the Action Group subscribers.

If major changes are required, a thorough revision of the document must be undertaken and the community will be questioned.

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## Preamble

Rock glacier inventories have been set up for decades all around the world, yet without any real coordination, making their global assemblage and uniform completion impossible. In the meantime, quantitative information about kinematics has been made available for numerous rock glaciers, particularly with the development of remote sensing techniques. The IPA (International Permafrost Association) Action Group *Rock glacier inventories and kinematics* (2018–2023) aims at **exploring the feasibility of developing widely accepted standard guidelines for inventorying rock glaciers on a global scale, including information on their kinematics.**

Defining standard guidelines for inventorying rock glaciers constitutes Task 1 of the Action Group, which has been divided into three Sub-Tasks:

- 1.1: definition of the *main concepts and principles* (present document),
- 1.2: establishment of *practical inventorying guidelines*,
- 1.3: establishment of a *technical (operational) manual*, on how to implement a rock glacier inventory in an open-access database.

The present document intends to set the necessary **baseline concepts** for inventorying rock glaciers on a global scale (Sub-Task 1.1). Its content is the result of a preparatory workshop held in Chambéry (France) on 23 March 2019, comments received about the workshop wrap-up, further informal meetings and discussions between participants of the Chambéry meeting, [comments](#) received on [version 1.0](#) until 15 August 2019, the revision of [version 2.0](#) during the international workshop held in Evolène (Switzerland) on 23-27 September 2019 and [comments](#) received on [version 3.0](#) (post-workshop I). Version 4.0 has been released in January 2020, then slightly revised in May 2020 ([version 4.1](#)).

### What is new since version 4.1?

Version 4.2: The preparation of the *practical concepts* for inventorying rock glaciers (Sub-Task 1.2) has shown that some *baseline concepts* are difficult to implement and need some adaptation. It has essentially concerned the section 3b. The section 4 has also been shortened in order to avoid any repetition with the *practical concepts* document.

Version 4.2.1: Illustrations have been added in section 3. Numbers in brackets (e.g. [\(4\)](#)) are active links to them. Suggestions for further illustrations are welcome.

### Provisional timeline

- Illustrations provided in version 4.2.1 are open to [comment until 15.09.2021](#) using exclusively the dedicated boxes inserted at the end of each sub-section of concern.
- Version 4.3 is intended to be released until 31.12.2021



## 1. Purpose of standardized guidelines

Today, although many (published and unpublished) regional rock glacier inventories exist, they are not exhaustive worldwide. Existing rock glacier inventories have various ages and have been compiled using different methodologies, which mainly depend on the experience of the cartographer, review process and availability of appropriate source data (e.g. satellite imagery), as well on the varying objectives that motivated each single study. For these reasons, merging all existing inventories in a fully coherent way is presently not possible.

The increasing emergence of open-access satellite imagery (e.g. optical, SAR) facilitates the development of new inventories and/or the update of existing ones. The growing availability of remotely sensed data (e.g. Sentinel-1 SAR images) makes also the systematic detection of rock glacier surface motion, and consequently, the integration of kinematic information in standardized rock glacier inventories potentially feasible.

Previous glacier-oriented initiatives, such as the World Glacier Inventory (WGI) or Global Land Ice Measurements from Space (GLIMS), tried to include rock glaciers but have not succeeded in being systematic and homogeneous. It has been particularly difficult to properly include rock glaciers due to the complexity of detecting them automatically by remote sensing (GLIMS methodology).

The development of widely accepted standard guidelines for inventorying rock glaciers, including kinematic information, is becoming an urgent task to be fulfilled by the scientific community of concern. It will serve the compilation of new regional inventories and the adaptation of existing ones, hence leading – as a final objective – to the merging of all inventories in a more homogeneous open-access worldwide database. Standard guidelines should also help to avoid, or at least minimize, potential discrepancies between various usages of rock glacier datasets.

Inventorying rock glaciers is a manual (visual) procedure, which cannot be automatized yet and requires geomorphological expertise by the operators. Identifying and characterizing rock glaciers has often led to various and sometimes controversial opinions due to the complexity of morphologies (e.g. multiple generations, coalescent landforms, heterogeneous dynamics, interaction with glaciers) and the diversity of environments in which rock glaciers have developed. In order to overcome any endless discussion, it must be accepted that subjectivity is part of the process of rock glacier mapping. Establishing standard guidelines aims at minimizing its impact. It could even be envisaged that an increasing number of manually identified rock glaciers based on a widely accepted standard would support the development of automatic techniques (e.g. deep learning) as a complementary tool to compile inventories.

## 2. Inventorying rock glaciers

Rock glaciers are characteristic landforms associated to mountain periglacial landscapes. They are prevalent periglacial items of the Earth's geomorphological heritage, whose identification (detection and delineation) can be nevertheless challenging. Motivations for producing rock glacier inventories and approaches to create them are various.

### *2a) Motivations for producing a rock glacier inventory*

Basic and applied scientific motivations for producing an exhaustive rock glacier inventory at various scales can be summarized as follows:



- **Geomorphological mapping:** rock glaciers are identified and mapped as functional<sup>1</sup> or inherited<sup>2</sup> (relict) landforms of the geomorphological landscape: they are part of the mountain sediment cascade and as such contribute to control the pace of periglacial mountain landscape evolution. Enhancing the value of geomorphological heritage could also be the main motivation to compile a rock glacier inventory.
- **Proxy for permafrost occurrence:** functional rock glaciers are geomorphological indicators of the occurrence of permafrost. Even if it is accepted that functional rock glaciers may export perennially frozen ground outside of a permafrost prone area, they can be used to approximate the regional lower limit of the mountain permafrost belt and to validate spatial models of permafrost extent. Conversely, inherited (relict) rock glaciers are discriminative landforms of currently permafrost-free areas. Although functional rock glaciers attest to the occurrence of permafrost at depth, it must be considered that given the ongoing climate change, these features may gradually no longer reflect surface conditions favorable to permafrost occurrence.
- **Paleo-permafrost studies:** inherited (relict) rock glaciers can be used as proxies for various paleo-permafrost extents. Discrimination between inherited and functional state is often difficult, making integration of inherited landforms in a global inventory indispensable.
- **Climate relevant variable:** rock glacier movement is particularly sensitive to changing permafrost temperature. Updating and comparing inventories of functional rock glaciers, which include temporally well-constrained kinematic information, can be used to assess the impact of ongoing climate change on the mountain periglacial environment over regions.
- **Hydrological significance:** functional rock glaciers are, by nature, ice (and water) storage features, which may play a prominent role in the hydrological regime of mountain catchments, especially in dry areas. Rock glacier inventories have been developed and/or used in particular for estimating their regional water-equivalent significance. In addition to being ice storage features, rock glaciers can affect water transit time and water chemistry in a catchment.
- **Geohazards:** functional rock glaciers may be the source of direct or indirect geohazards (e.g. destabilization, conveying of loose debris into a debris flow prone gully) that may pose risk to human activities and/or facilities (e.g. transport infrastructures, buildings, livelihoods). Rock glacier inventories and related kinematic data can be used to locate and assess some potential geohazards at local to regional scales. It must be noted that in the context of infrastructure construction/maintenance, using a rock glacier inventory will not be sufficient to fully understand the issues related to permafrost degradation. However, it may provide clues for assessing the occurrence (or absence) of permafrost in the study area.

It is very important to note that the original motivation for producing a rock glacier inventory may differ from that of a subsequent third-party user. Therefore, standardized guidelines should help to avoid, or at least minimize, potential discrepancies.

## 2b) Inventory compilation

Two main approaches have been commonly used for compiling a rock glacier inventory:

- **Geomorphological approach:** rock glaciers are recognized by a systematic visual inspection of the (imaged) landscape and DEM-derived products. To this purpose, surface texture and morphometric analysis could also be used. LiDAR DEM surveys, when available, facilitate also the identification of

<sup>1</sup> In a geomorphological slope sequence, a functional rock glacier is a landform, which is currently conveying sediments from a rooting zone towards its front.

<sup>2</sup> In a geomorphological slope sequence, an inherited rock glacier is a landform, which today no longer conveys sediments from a rooting zone towards its front, due to permafrost exhaustion.



rock glaciers in forested areas. This is the classical approach, locally complemented by field visits. It allows the production of exhaustive inventories of presumed moving and non-moving landforms, whose discrimination (activity classes) is primarily based on geomorphological characteristics. Development in deep-learning techniques could also serve this approach.

- **Kinematic approach:** moving areas, which may be temporally and spatially heterogeneous, are detected and characterized using multi-temporal remotely sensed data (e.g. SAR-derived products, multi-temporal airborne LiDAR, high resolution optical satellite and aerial images). The association of a moving area to a rock glacier is then mainly performed by the geomorphological assessment of optical images (geomorphological approach). This approach is limited to the non-exhaustive identification and delimitation of moving areas on rock glaciers, whereas non-moving rock glaciers, for instance, are missed. It provides quantitative data for evaluating the motion rate of rock glaciers. It also allows the identification of moving areas, which cannot be geomorphologically related to rock glaciers.

Whereas the two approaches are complementary and can be used in an integrated and iterative process, a rock glacier inventory is by definition a geomorphological inventory.

### 3. Rock glaciers

The following section defines rock glaciers in the perspective of generating a standardized inventory and details various significant aspects related to their characterization.

#### *3a) Technical definition of rock glaciers*

The present technical definition (also called operational definition) is exclusively addressed to frame rock glacier inventorying and lies beyond any outstanding controversy, for example about rock glacier genesis and ice origin. It relies on the most common geomorphological evidences allowing the identification of rock glaciers in the landscape:

**Rock glaciers are debris landforms generated by the former or current creep of frozen ground (permafrost)<sup>3</sup>, detectable in the landscape with the following morphologies: front lateral margins and optionally ridge-and-furrow surface topography.** In a geomorphological slope sequence, rock glaciers are landforms conveying (or having conveyed) debris from an upslope area (source area or rooting zone) towards their front (3). The debris grain size is not specified.

Geomorphological criteria:

- **Front** (mandatory criterion): a discernable talus delimiting the terminal part of a (former) moving area overriding a non- or less-moving terrain and, when non-eroded, drawing a convex morphology perpendicular to the principal (former) flow direction. For a rock glacier developing on a steep slope, the front may be difficult to recognize.
- **Lateral margins** (criterion): discernible lateral continuation of the front. Lateral margins may nevertheless be absent in particular in the upper part of the landform.
- **Ridge-and-furrow topography** (optional criterion): pronounced convex downslope or longitudinal surface undulations associated with current or former compressive flow.

In coherence with global glacier inventories standards, and given the technical limitations (that may evolve in the future), it is recommended that the minimum rock glacier size applied for an inventory

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<sup>3</sup> Rock glacier (or permafrost) creep has to be understood here as a generic term referring to the variable combination of both internal deformation within the crystalline structure of the frozen ground (creep stricto sensu) and shearing in one or several discrete layers at depth.





to be included into a global compilation should be 0.01 km<sup>2</sup>. Nevertheless, inventories at higher resolution are encouraged.

### ***Discriminating rock glaciers from other landforms***

Without the knowledge of the environmental context and/or limited mapping experience, some landforms may express rock glacier-like morphology (e.g. solifluction lobe, earth flow, and lava flow) leading to inconsistent mapping.

Permafrost creeping areas that can be detected as moving in a kinematic approach but that do not express the morphology typical of a rock glacier (as it is for many push-moraines and for frozen debris lobes) are also excluded from this definition. Therefore, a rock glacier inventory is an inventory of rock glaciers only, but is neither an inventory of any ground ice occurrences, nor of any other mountain permafrost-related landforms.

Rock glaciers, as landforms resulting from a permafrost creep process, should also not be confused with debris-covered glaciers, which are glaciers partially or completely covered by supraglacial debris. Typically, there are two main examples of misrecognition: either the entire glacier is confused with a rock glacier (or the reverse), or the rock glacier is located in front of a glacier in a “debris-covered glacier to rock glacier” sequence (c.f. Section 3.c, glacier-connected) and is difficult to be recognized/delineated unambiguously in the absence of direct observation at depth. An arbitrary separation between rock glacier and debris-covered glacier or between the debris-covered glacier and the rock glacier section in continuous sequence can be based on morphological and textural criteria. A “checklist table” will be provided in the *practical inventorying guidelines* helping the distinction.

Do you have any comment about the proposed illustration(s) in the previous section? Please use the following link to submit it.

If you would like to propose any other illustration, provide both location (e.g. 42.8319°N, 43.8993°E) and accompanying explanations. Also add your name, so we can contact you back if necessary.

[Comment box 3a](#)

### ***3b) Rock glacier morphological system and units***

Rock glaciers with a complex morphology (e.g. multiple generations, multiple lobes, coalescent lobes and heterogeneous dynamics) are common and difficult to characterize unequivocally. The scale of discrimination depends on the study motivations, the operator, the available data and the complexity of the landform.

To address this issue, the following hierarchical **classification scheme** is adopted.

- **Level 1 – Rock glacier unit:** a single rock glacier landform that can be unambiguously discerned according to the technical definition provided in section 3a and, in case of a spatial connection, can be differentiated from other (adjacent or overlapping) rock glacier units according to any of the following criteria:
  - Morphological expression and/or land cover suggest a distinct timing of formation (e.g. overlapping lobes).
  - Connection to the upslope unit can be discriminated (cf. section 3c).
  - Activity is clearly different (cf. section 3d).

Rock glacier units are classified as **simple** or **complex**. A simple rock glacier unit shows homogeneous attributes corresponding to the criteria listed above (4). A complex unit shows some





spatial variability within these attributes, but does not include sufficient evidence to unambiguously separate units ([5](#), [8](#), [7](#), [65](#)).

- **Level 2 – Rock glacier system:** any landform composed either of a single rock glacier unit or of multiple units that are spatially connected, either in a topo-sequence or through coalescence. A rock glacier system including only one unit is classified as a **mono-unit** system ([4](#), [5](#), [8](#)), else it is a **composite** system ([6](#), [9](#), [7](#), [10](#), [69](#)).

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### *3c) Spatial connection of the rock glacier to the upslope unit*

The geomorphological unit located directly upslope of a rock glacier unit or system can hold implications for the characterization of the latter (e.g. internal structure and composition, ice origin, ice content), the designation of attributes (e.g. landform outlining, definition of the rooting zone) as well as the analysis of the kinematic behavior. The focus is set on the spatial (structural) connection because it is generally discernable in optical images. The spatial connection of the rock glacier to an upslope unit does not necessarily mean that there is a dynamic and/or genetic connection. The term “derived” is not used because it implies an interpretation of the origin of both debris and/or ice.

- **Talus-connected (TC):** The rock glacier is part of a downslope sequence including headwall – talus slope – rock glacier (sometimes the talus slope is almost lacking) ([12](#), [70](#)). The rock glacier unit is subjacent and connected to a talus slope unit, which is dominantly fed by rock fall activity, but may also be fed by surface runoff, debris flow and/or avalanche events from the headwall unit. Sediment transfer across the talus slope unit can be operated by a number of interrelated processes. The area connecting the talus slope to the rock glacier is often characterized by a concave morphology, where, considering the landform history, the episodic to frequent development of long-lasting avalanche cones, snow/ice patches or even small glaciers (relative to the rock glacier size) may occur. In the latter case, although the episodic disappearance of the glacier implies a lack of efficient sedimentary connection with the relevant upslope unit, the rock glacier is still classified as talus-connected ([14](#), [70](#), [13](#)).

Protales ramparts are included in this category as “embryonic” rock glaciers if they are related to permafrost creep ([66](#)). They should not be confused with protalus-looking landforms related to (former or present) snow accumulation (i.e. pronival ramparts).

- **Debris-mantled slope-connected (DC):** The rock glacier lacks of any (significant) headwall. The debris is dominantly produced by in-situ bedrock weathering (debris mantle) and gradually put into motion by shallow, surficial mass movement processes (e.g. solifluction) before developing into a rock glacier feature ([16](#), [72](#), [17](#)).
- **Landslide-connected (LC):** The rock glacier is located in direct downslope spatial connection to a landslide (i.e. rock or debris slide) ([19](#)) or lies on a large and active deep-seated gravitational slope deformation. In these situations, where the talus slope unit is usually lacking, the identification of the rock glacier can be ambiguous.
- **Glacier-connected (GC):** There is a continuity from a (debris-covered) glacier or ice patch to a rock glacier feature (“debris-covered glacier to rock glacier” transition) ([22](#), [23](#), [73](#)). Delimitation between the glacier or the ice patch section and the rock glacier section is not feasible without



further direct or geophysical prospection. Embedded glacier ice within the rock glacier is likely to occur. Geomorphological indices evidencing the presence of a debris-covered glacier upslope of the apparent rock glacier feature may be observed (e.g. crevasses, thermokarst, meltwater channels).

- **Glacier forefield-connected (GFC):** The rock glacier develops within or from a (formerly) glaciated area. Interaction between the glacier or ice patch and the rock glacier feature is prevalent, but essentially restricted to phases of glacier advance (e.g. Little Ice Age). Embedded glacier ice within the rock glacier is possible. When receding, which is a common pattern nowadays, the glacier has disconnected from the rock glacier or may have completely disappeared. This category includes till-derived rock glaciers, which correspond to the classical debris rock glacier definition and some push-moraines (glacitectonized frozen sediments) ([24](#), [25](#), [27](#), [26](#)) .
- **Poly-connected (PC):** Two or more upslope connections (e.g. talus- and glacier-connected). The use of poly-connected should be restricted to cases where there is no large dominance of one type of upslope connection.
- **Other:** Other type of geomorphological sequence related to a rock glacier landform.

An attribute defining whether the rock glacier is currently connected to the upslope unit or not must be added.

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[Comment box 3c](#)

### 3d) Rock glacier activity

#### Background

The activity of rock glaciers was conceptually and classically categorized regarding the presumed flow behavior and, in relation to this, the ice occurrence. Primarily based on the observation of geomorphological (e.g. front slope angle) and vegetation-related indicators, which differ locally and regionally due to lithological and climatic settings, rock glaciers have been most commonly classified into the following categories of activity:

- **Intact:**
  - Active: rock glaciers bearing excessive ice that are in effective motion.
  - Inactive: rock glaciers that remain (almost) motionless yet still contain ice.
- **Relict:** rock glaciers that have stopped moving, often several hundreds to thousands of years ago, due to the loss of (almost) all their ice.

Historically, regional inventories of rock glaciers have been based on a *geomorphological approach*. In-situ or remotely sensed kinematic data as well as field visualizations have remained occasional. Activity attribution based on geomorphological indicators is a highly subjective task depending on the operators' skills. As a result of the continuous development of remote sensing techniques (e.g. photogrammetry, satellite-borne InSAR), kinematic information on surface motion can henceforth be obtained for a large majority of rock glaciers. This could allow the refinement of rock glacier activity categories.



Whereas the classical categorization may have considered the activity of rock glaciers as almost constant over time at a scale of decades to centuries, observations of rock glacier kinematic behavior, in particular in the European Alps, show that an acceleration by a factor 2 to 10 of the surface velocities between the 1980s and 2010s has been a common feature, probably in response to increased permafrost temperature resulting from warmer air temperature. Some single features manifest singular behaviors (e.g. reactivation, rapid acceleration, destabilization or decrease in velocity). In cold permafrost regions (e.g. Arctic or high altitude Andes), rock glaciers, which are almost stationary or moving only very slowly, may accelerate in response to warming. These observations reveal the need of refining and/or redefining the categorization of rock glacier activity.

### ***Updated categorization of activity***

The following conceptual categorization of rock glacier activity refers exclusively to the efficiency of the sediment conveying (expressed by the surface movement) at the time of observation, and should not be used to infer any ground ice content. The categories are still based on geomorphological indicators, which have to be adapted regionally or contextually. If areal or point kinematic data are available, they should be integrated as a supplementary attribute and must be considered in order to assign the category of activity, which is defined as:

- **Active:** rock glacier moving downslope over most of its surface.
  - If no kinematic data is available: an active rock glacier shows geomorphological evidence of downslope movement such as a steep front (steeper than the angle of repose) and possibly lateral margins with freshly exposed material on top. ([28](#), [30](#))
  - If adequate kinematic data is available: an active rock glacier shows coherent downslope movement over most of its surface. As an indication, the displacement rate can range from a decimeter to several meters per year. ([71](#))
- **Transitional:** rock glacier with low movement only detectable by measurement and/or restricted to areas of non-dominant extent. According to the topographic and/or climatic context, transitional rock glaciers can either evolve towards a relict (degraded) or an active state.
  - If no kinematic data is available: a transitional rock glacier has less distinct geomorphological evidences of current downslope movement than active rock glaciers in the same regional context. ([31](#), [33](#), [32](#))
  - If adequate kinematic data is available: a transitional rock glacier shows little to no downslope movement over most of its surface. As an indication, the average displacement rate is less than a decimeter per year in an annual mean over most of the rock glacier. Downslope movement must not be confused with subsidence.
- **Relict:** rock glacier with no detectable movement and no geomorphological evidence of recent movement
  - If no kinematic data is available: a relict rock glacier shows no geomorphological evidence of recent movement. The relict state could be indicated by subdued topography and smoothed lateral and frontal slopes/margins, and also by vegetation and soil cover (e.g. lichen, grass, forest). Relict rock glaciers are generally found at lower elevations than the active ones. ([34](#), [35](#), [67](#), [92](#)).
  - If adequate kinematic data is available: a relict rock glacier shows no detectable downslope movement over most of its surface and the geomorphological characteristics are as described above.



Any activity assessment must be defined (i.e. based on geomorphological identifiers only or supported by kinematic data) and dated.

The principles about the use of kinematic data in a standardized inventory are developed in a separated document ([Kinematics as an optional attribute in standardized rock glacier inventories](#)), which provides also concepts for refining the activity (see above) into more classes.

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[Comment box 3d](#)

### 3e) Rock glacier destabilization

The motion rate of some rock glaciers may be characterized by a drastic acceleration that can lead the landform, or a part of it, to behave abnormally fast (i.e. no longer following the regional trend) for a minimum of several years. The term **destabilization** has been progressively used since the 2000s to refer to rock glaciers with obvious signals of abnormally fast displacement, often matched by the opening of large mostly transversal cracks and/or scarps ([36](#), [37](#), [29](#)).

Destabilized rock glaciers generally display an initial acceleration phase, followed by a high velocity phase and finally a deceleration phase. The morphology of destabilized rock glaciers can be preserved for a long time after the high-velocity phase has ended. Whereas this surface expression can be documented in an inventory as evidence of a current or past destabilization phase, an actual state of destabilization can only rely on kinematic data. Multiannual time series showing displacement rates of several meters per year and departing from the regional trend (if known) attest to the actual destabilization phase. Rock glaciers experiencing an ongoing destabilization phase constitute a sub-category of active rock glaciers and must be inventoried as such.

It is worth noting that destabilization is not used here in a geotechnical, slope stability context, but solely to describe the above described temporal variability in rock glacier deformation.

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[Comment box 3e](#)

### 3f) Rock glacier outline

Technically defining a rock glacier as a landform implies setting a distinct outline, and for various practical issues (e.g. area calculation) this outline has to be a polygon. Mapping an outline retains some degree of subjectivity, i.e. it is dependent on the “operator”. It has been shown that the operators’ mapping styles may highly differ and significantly impact the exploitation of any rock glacier inventory data. For example, a rock glacier specific area directly affects a first-order assessment of inherent water content, or maximum and minimum rock glacier elevations directly influence altitudinal thresholds derived for modelling past or present occurrence of mountain permafrost. Therefore, “outlining rules” must be clearly defined in order to minimize subjectivity as much as possible. Nevertheless, if boundaries are uncertain, this uncertainty should be specified and highlighted in the database.



In order to address all inventorying motivations (*cf.* Section 2a), two ways of delineating rock glacier boundaries are recommended to be included as standards: the ***extended*** and the ***restricted geomorphological footprints***. If only one footprint is chosen, it must be clearly specified.

- **Extended geomorphological footprint:** the outline embeds the entire rock glacier up to the rooting zone and includes the external parts (front and lateral margins).
- **Restricted geomorphological footprint:** the outline embeds the entire rock glacier up to the rooting zone and excludes the external parts (front and lateral margins).

The delineation of the upper part of the rock glacier footprint and the definition of the rooting zone depend on the spatial connection of the rock glacier to the upslope unit (*cf.* Section 3c). The details of this procedure are described in the practical inventorying concepts (*cf.* [RGI PC](#) section 5d).

## 4. Inventorying strategy

The development of rock glacier inventories is driven by numerous motivations (*cf.* section 2a) and is thus highly dependent on both the aim and experience of the related operator. To minimize this subjectivity, a strategy to standardize the rock glacier inventories and make them comparable is summarized hereafter.

The inventorying strategy follows four consecutive steps, which are based on a combination of both geomorphological and kinematic approaches (*cf.* section 2b) and may be iteratively refined depending on (newly) available data:

- *Detecting rock glaciers:* recognition of relevant landforms (system/unit) to be inventoried in accordance to the technical definition of rock glaciers (*cf.* section 3a).
- *Locating rock glaciers:* attribution of a unique point identifier defining (ID attribution and georeferencing) any rock glacier system and unit.
- *Characterizing rock glaciers:* attribution of essential characteristics (attributes), including a kinematic attribute if adequate data is available.
- *Delineating rock glaciers:* outlining rock glacier units.

The two first steps (detecting and locating rock glaciers) are mandatory. For most identified rock glaciers systems and units, they should be definitive. The two other steps (characterizing and delineating rock glaciers) are conversely assessments of variables, which may depend on the availability of adequate source data and/or may change over time alongside the rock glacier evolution.

Finally, a *consolidation step* is recommended for any set of inventoried rock glaciers or updated variables. The consolidation is basically the systematic control and validation of the data by at least one, preferably several further operators.

*Practical concepts* for inventorying rock glaciers are detailed in a specifically related document ([RGI PC](#)).



## Acronyms

<b>DEM</b>	Digital Elevation Model
<b>ESA CCI+</b>	European Space Agency, Climate Change Initiative <a href="#">(link)</a>
<b>GLIMS</b>	Global Land Ice Measurements from Space <a href="#">(link)</a>
<b>InSAR</b>	Interferometric Synthetic Aperture Radar
<b>IPA</b>	International Permafrost Association <a href="#">(link)</a>
<b>LIDAR</b>	Light Detection And Ranging
<b>RGI-PC</b>	Towards standard guidelines for inventorying rock glaciers : practical concepts <a href="#">(link)</a>
<b>SAR</b>	Synthetic Aperture Radar
<b>WGI</b>	World Glacier Inventory <a href="#">(link)</a>