



PermaCOST Training School

1. Introduction to RGIK

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permacost.eu & cost.eu/actions/CA24157

- Periglacial environments
- Rock glacier inventories (RoGIs): Range of applications
- Statement of the problem: The winding road to a consensus on rock glacier definition
- The RGIK methodological workflow: motivation and implementation
- Practical exercise aiming to: (i) RGIK training
(ii) draft a paper involving each of you as co-author



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PERIGLACIAL environments are defined as those in which **frost action** and/or **permafrost related processes** dominate (French 2000, French & Thorn 2006) → **Nothing to do with location with respect to glaciers.**

PROGLACIAL environments are defined as those which are located **close to** the ice front of a glacier, ice cap or ice sheet (Penck & Bruckner 1909).

PARAGLACIAL environments are defined in Church and Ryder (1972) as “**non-glacial environments conditioned by glaciation**” and this definition has been expanded by Ballantyne (2002) as follows:
all “**non-glacial earth surface processes, sediment accumulations, landforms, land systems and landscapes that are directly conditioned by glaciation and deglaciation**”.

PERIGLACIAL environments are defined as those in which **frost action** and/or **permafrost related processes** dominate (French 2000, French & Thorn 2006) → **Nothing to do with location with respect to glaciers.**



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(2002), as follows.

Environment	Criteria			
	Transitional in Space/Time	Location	Process	Form
Paraglacial	Degree of recovery from glaciation	Uplands	Non-glacial	No storage
		Major Valleys		Storage dominant
Proglacial		Ice-marginal	Glaci-fluvial	Erosional
			Glaci-lacustrine Glacimarine	Depositional
Periglacial			Freeze-thaw permafrost	Patterned ground Pingo

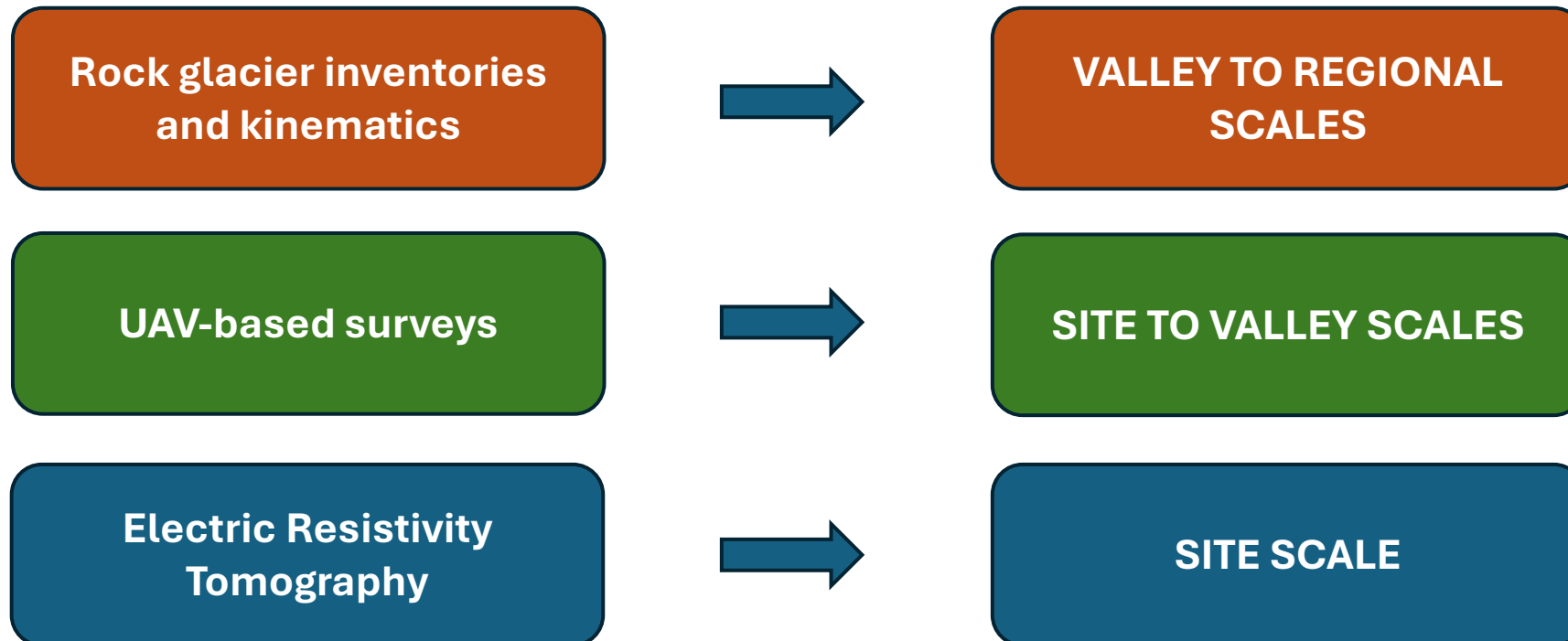
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From Slaymaker (2011)

Palsas
Rock glaciers

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How we detect permafrost and evaluate periglacial change - Tools covered in the school:

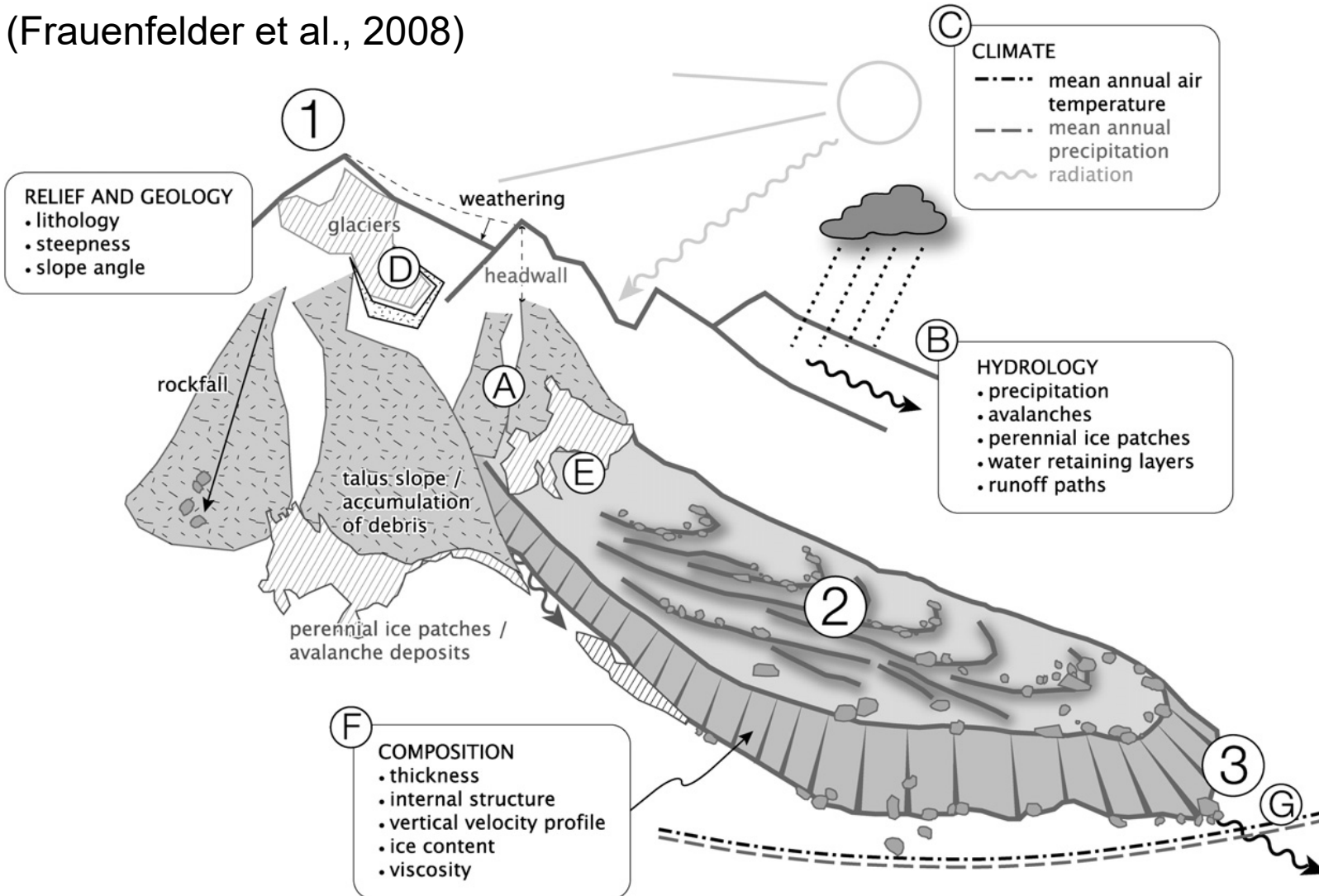


Rock glaciers: Complexity and debate



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(Frauenfelder et al., 2008)



Rock glaciers as complex flow-like landforms that develop:

- over **millennial time scales** (Quaternary geology)
- in **cold climates** and therefore respond to **climate change** (Physics, Climatology and Hydrology)
- through creep, which is also controlled by the deposit's **grain size distribution** and **internal stratigraphy** (Sedimentology and Geophysics)
- from **coarse unsorted mixtures** supplied by mass wasting and/or inherited by glaciers. Their formation requires **topographic relief** and **sediment supply** over time (Geomorphology)

Are rock glaciers really complex?



FROM CONSERVATIVE TO MORE “AGGRESSIVE” DEFINITIONS

Rock glaciers are characteristic **large-scale flow features of frozen material** in cold-climate high-relief regions (Humlum, 2000) → **no formative mechanism is implied**

Rockglaciers are **periglacial debris accumulations** produced, deposited, and deformed over time scales of **centuries to millennia** (Frauenfelder et al., 2008) → **emphasis on Quaternary scales of development**

Rock glaciers exhibit a variety of transitional features common to the alpine landscape; this makes it difficult to form a general standard definition. However, the majority of rock glaciers demonstrate lobate or tongue-shaped forms **resulting from a combination of glacial, nonglacial, and periglacial processes** (Janke et al. 2013)

→ **Conservative approach that does not exclude any formative mechanism**

→ Rock glaciers are debris landforms generated by the former or current creep of frozen ground (permafrost) (Haeberli et al., 2006; 2024) → **formative mechanism is associated with the deformation of permafrost. Following this logic, other mechanisms are ruled out and lead to other landforms i.e., debris-covered glaciers**

RoGIs have found a broad range of applications to:

- aid assessing the spatial distribution of **discontinuous permafrost** → **depending on RG definition**
- evaluate **water** storage/supply potential
- appraise **geohazard** potential associated with their **mobility** and **proximity to infrastructure**
- help constraining **post-LGM environmental conditions** that supported permafrost development and persistence
- etc.

IMPORTANT: inventories (of any kind) are by definition spatially distributed databases. We are not dealing with a handful of landforms, but typically with 10^2 to 10^5 number of observations across valleys and/or regions.

→ **In-situ field-based information** and **monitoring** (due to logistics, costs and time) are **restricted** to a limited subset of landforms

→ To **upscale** from sites to regions we have to rely on **remote sensing data**

Does permafrost occur on both valleys? PermaCOST



Rock glaciers: A winding history

A winding road filled with obstacles, including international **LACK OF CONSENSUS** on:

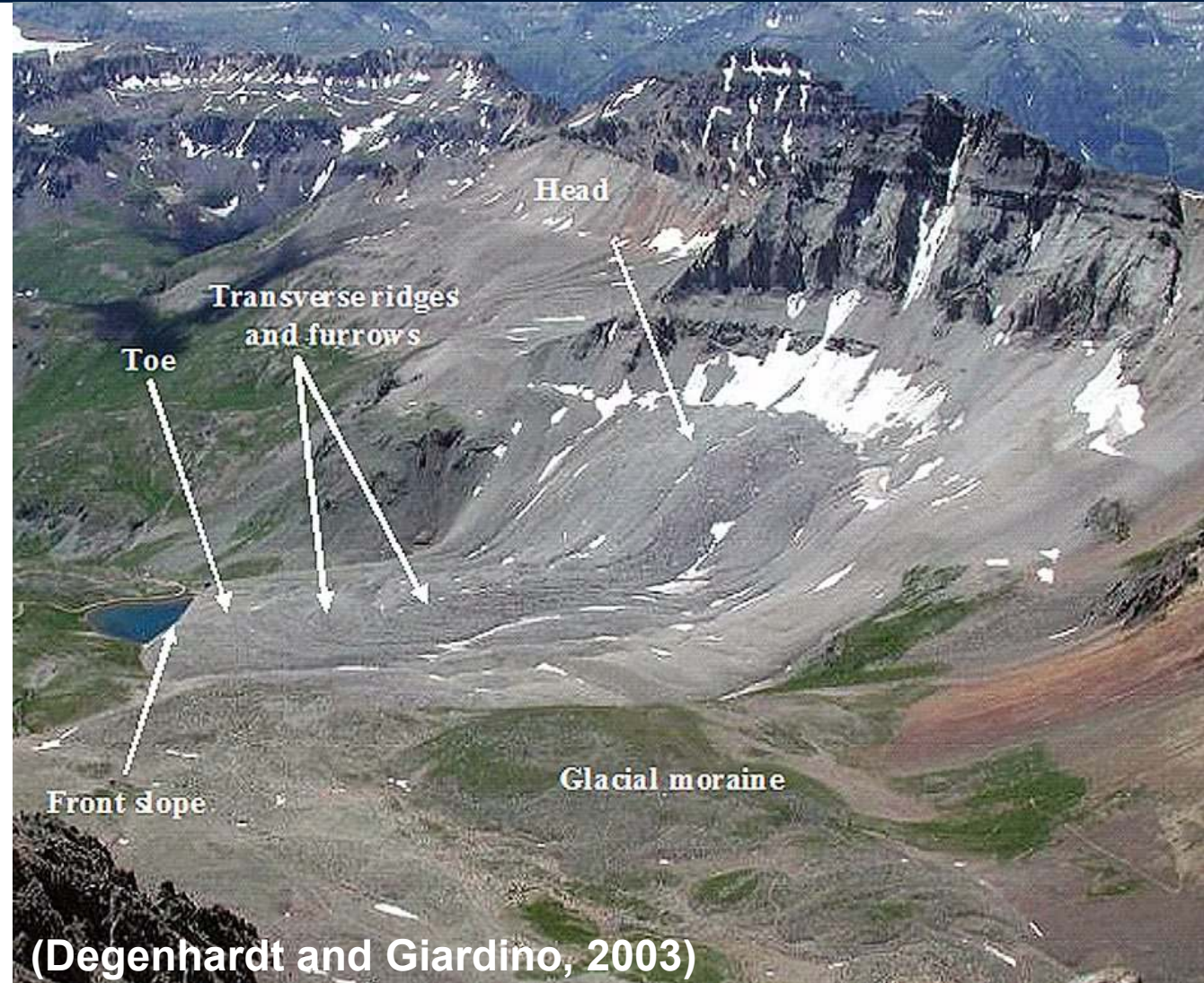
1. Rock glacier origin:

- (i) Permafrost derived - deformation of permafrost-bearing debris
- (ii) Glacier derived - deformation of debris bearing inherited glacier ice
- (iii) Glacier-rock glacier continuum - both formative mechanisms are possible depending on landscape history and local conditions

2. Geomorph definition of rock glacier

3. Geomorph classification & characterization

4. Mapping (outline delineation)



(Degenhardt and Giardino, 2003)

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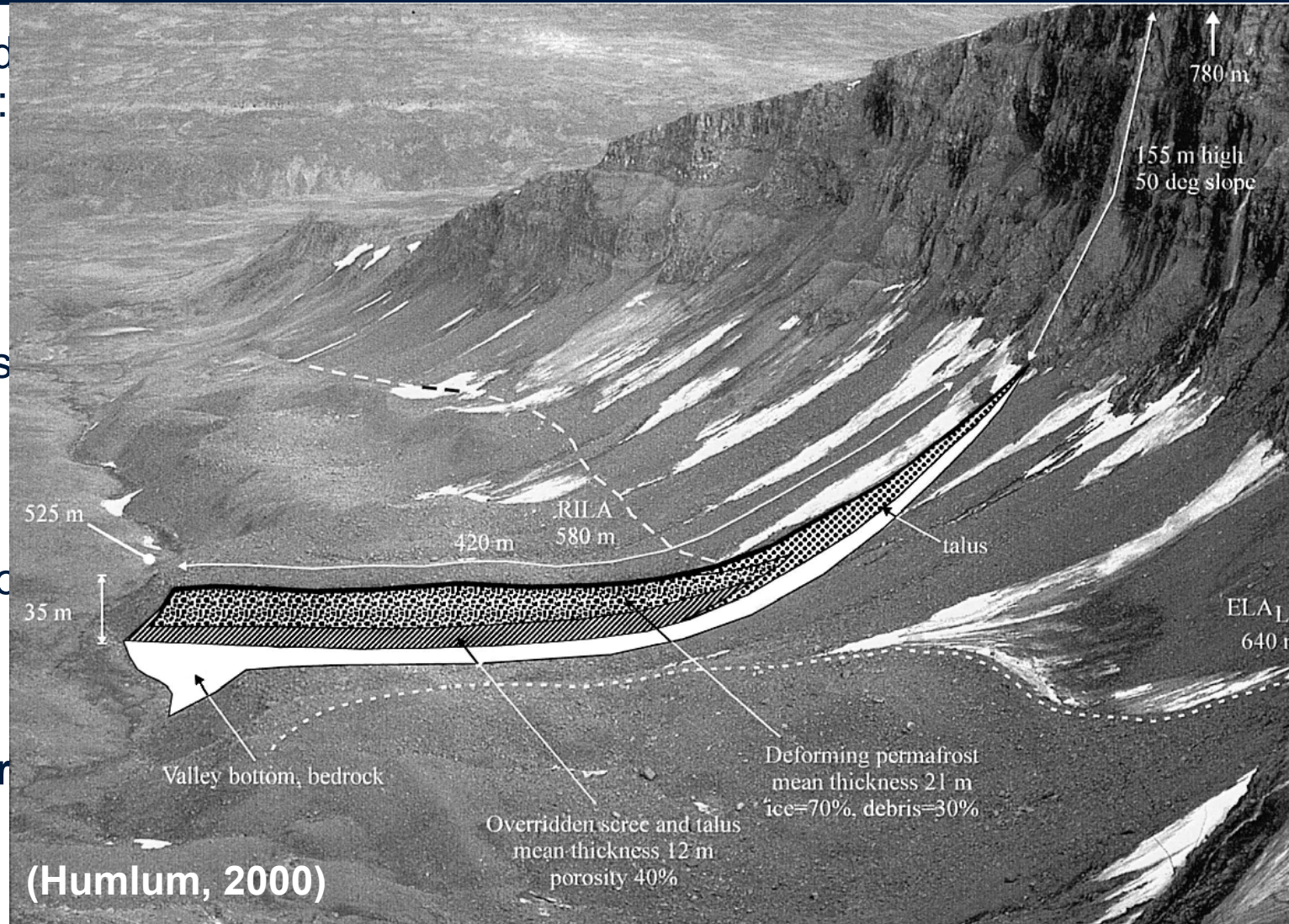
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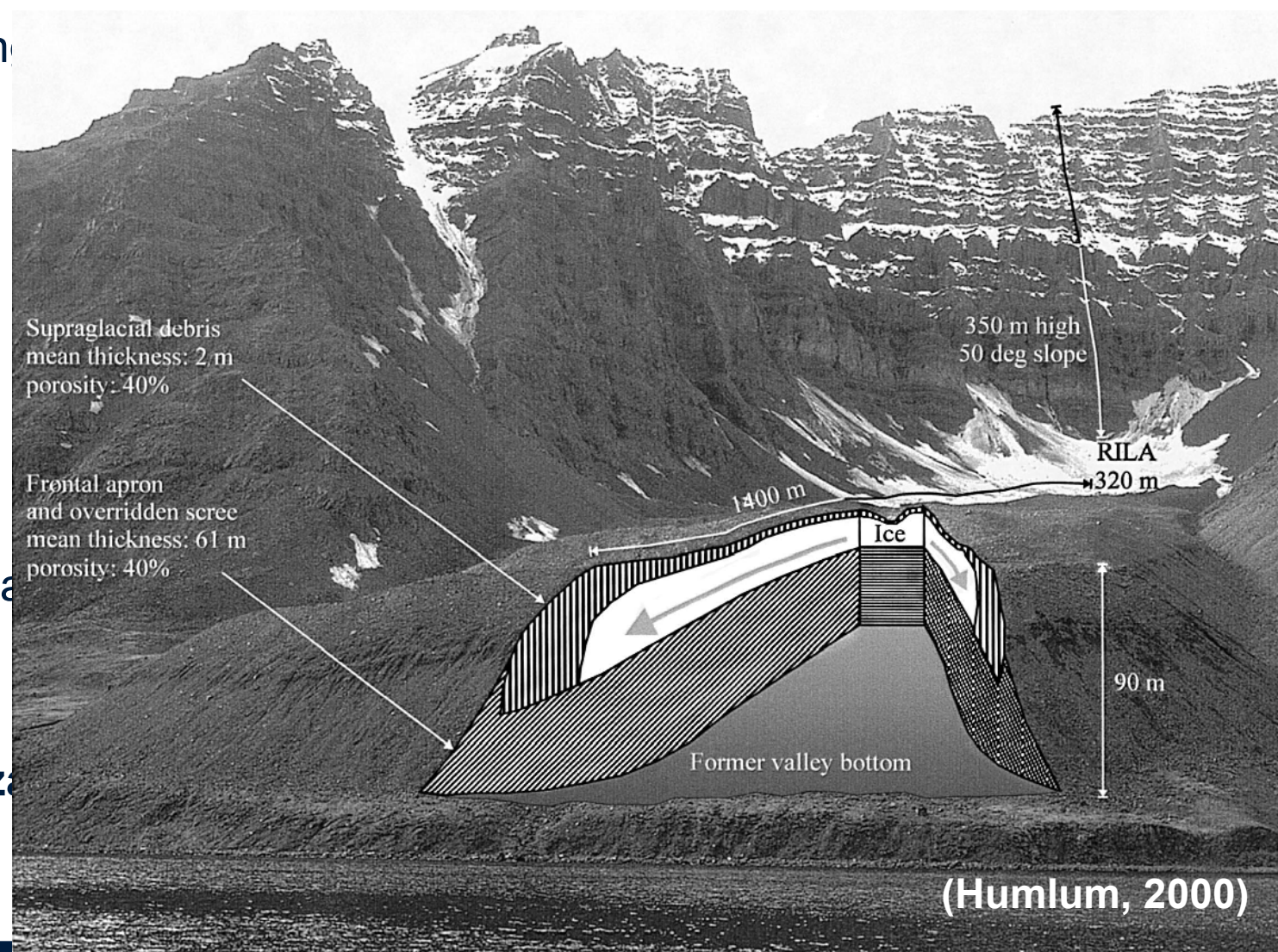
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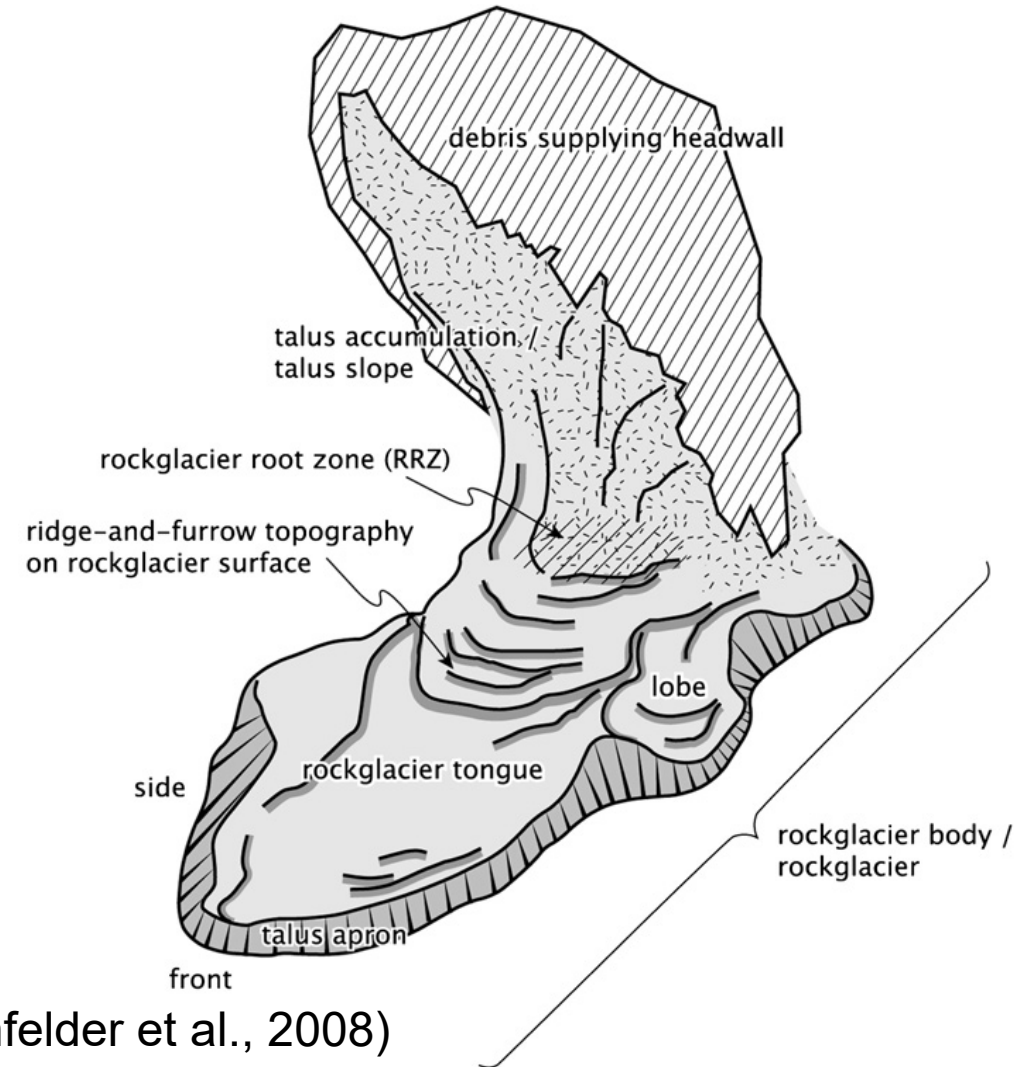
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(Frauenfelder et al., 2008)

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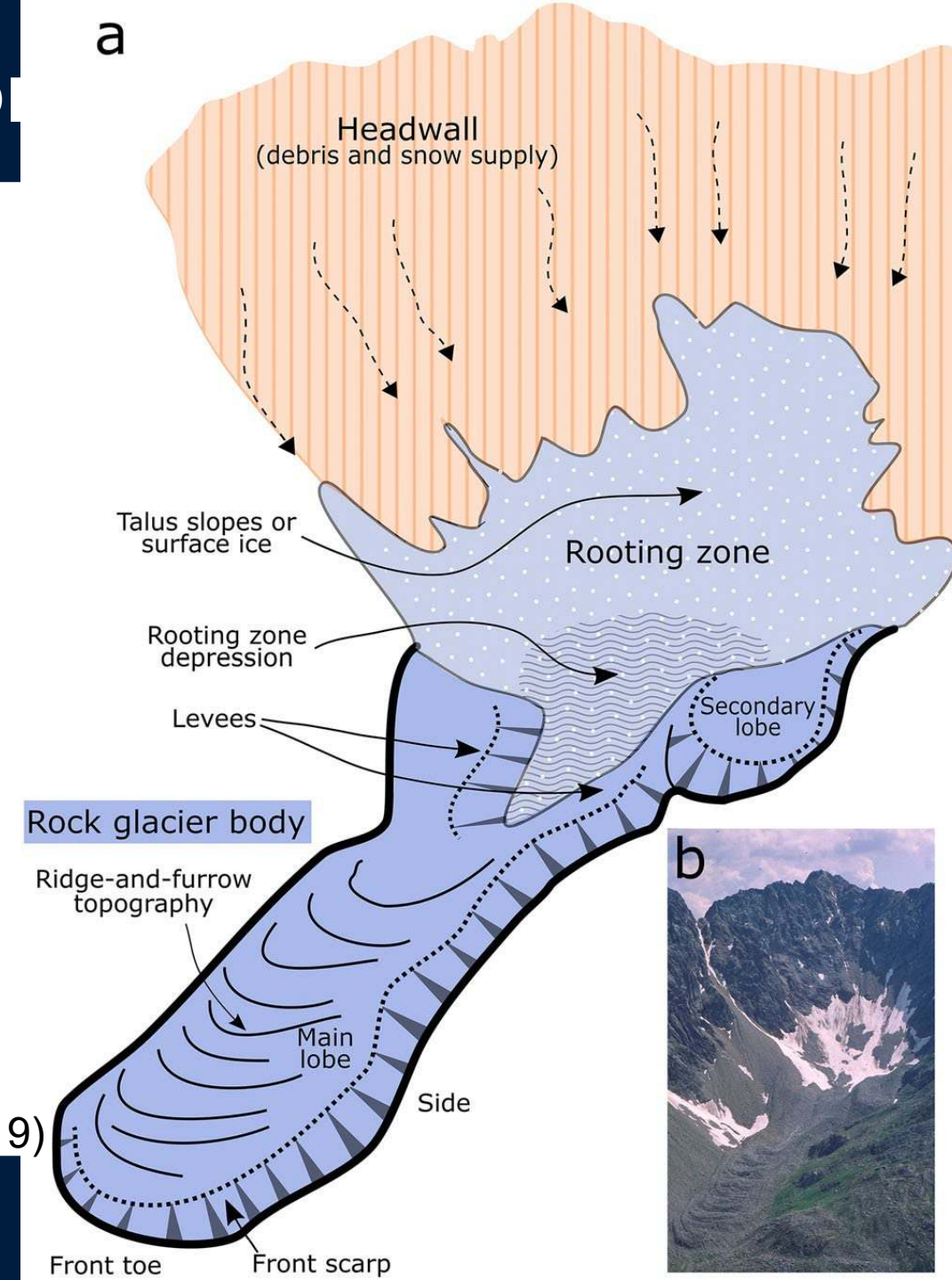
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(Brardinoni et al., 2019)

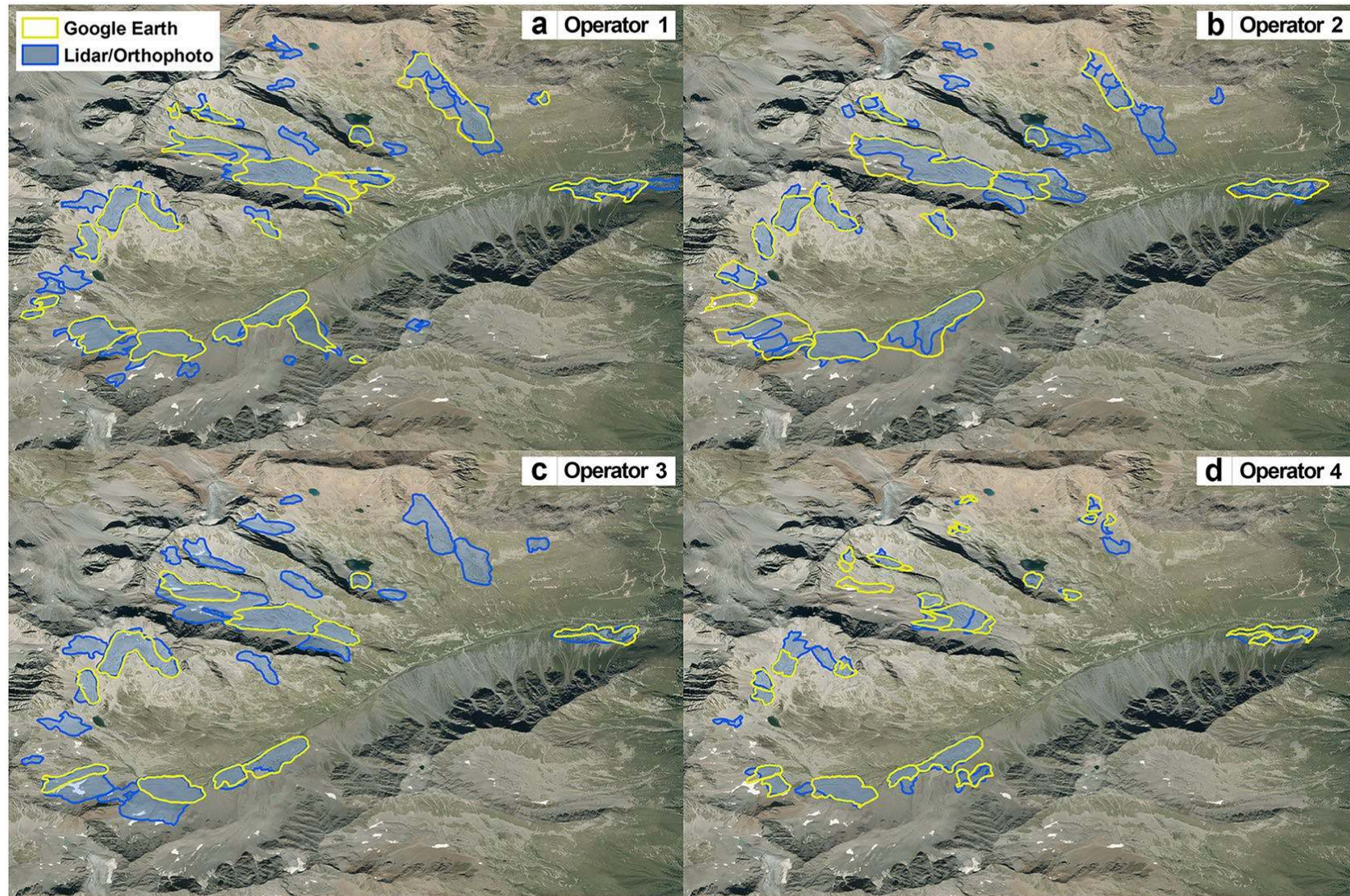


Lack of consensus: Effects on detection

An inventorying exercise conducted in 2018 and involving rock glacier international experts showed:

- heterogeneity in **RG detection**
from 12 to 33 RGs (GE imagery)
from 22 to 40 RGs (orthoph + Lidar)

(Brardinoni et al., 2019)



Lack of consensus: Effects on delineation

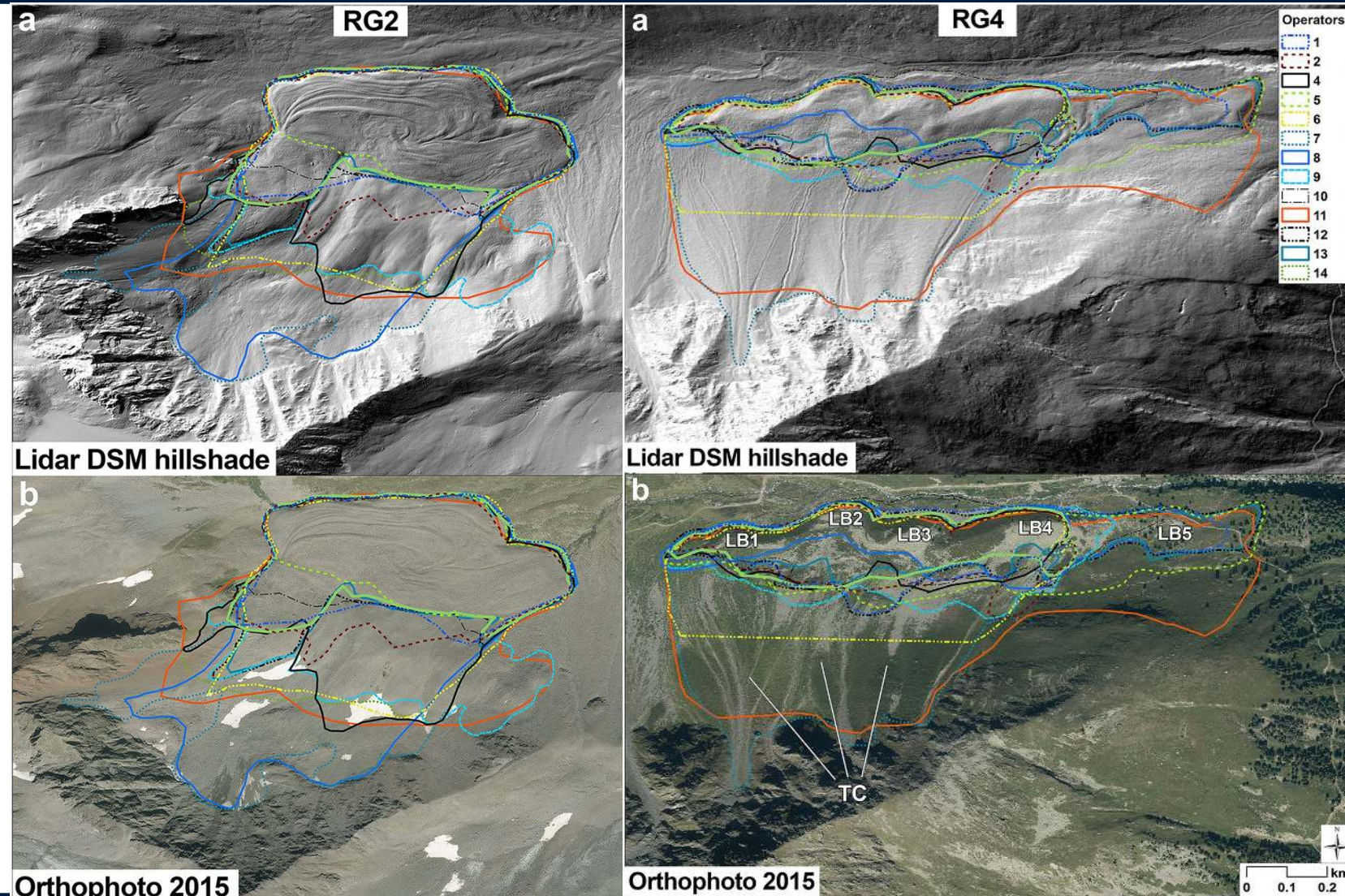


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An inventorying exercise conducted in 2018 and involving rock glacier international experts showed:

- heterogeneity in **RG detection**
- heterogeneity in **RG delineation**
from 0.78 to 2.61 km² (GE imagery)
from 0.89 to 2.69 km² (oph + Lidar)

(Brardinoni et al., 2019)



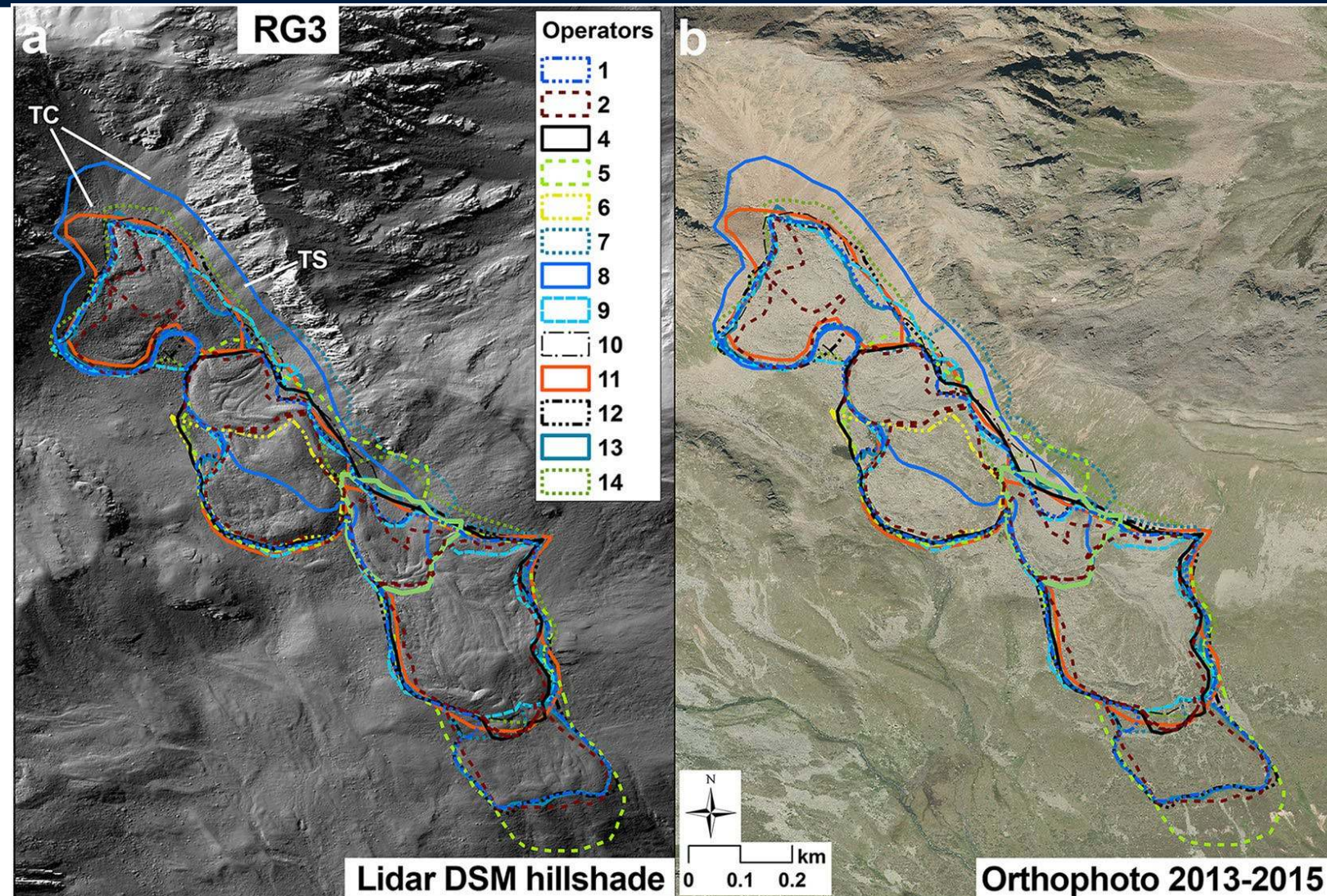
Lack of consensus: Effects on delineation

An inventorying exercise conducted in 2018 and involving rock glacier international experts showed:

- heterogeneity in **RG detection**
- heterogeneity in **RG delineation**

→ **A complex RG or many adjacent simple RGs? How many?**

(Brardinoni et al., 2019)

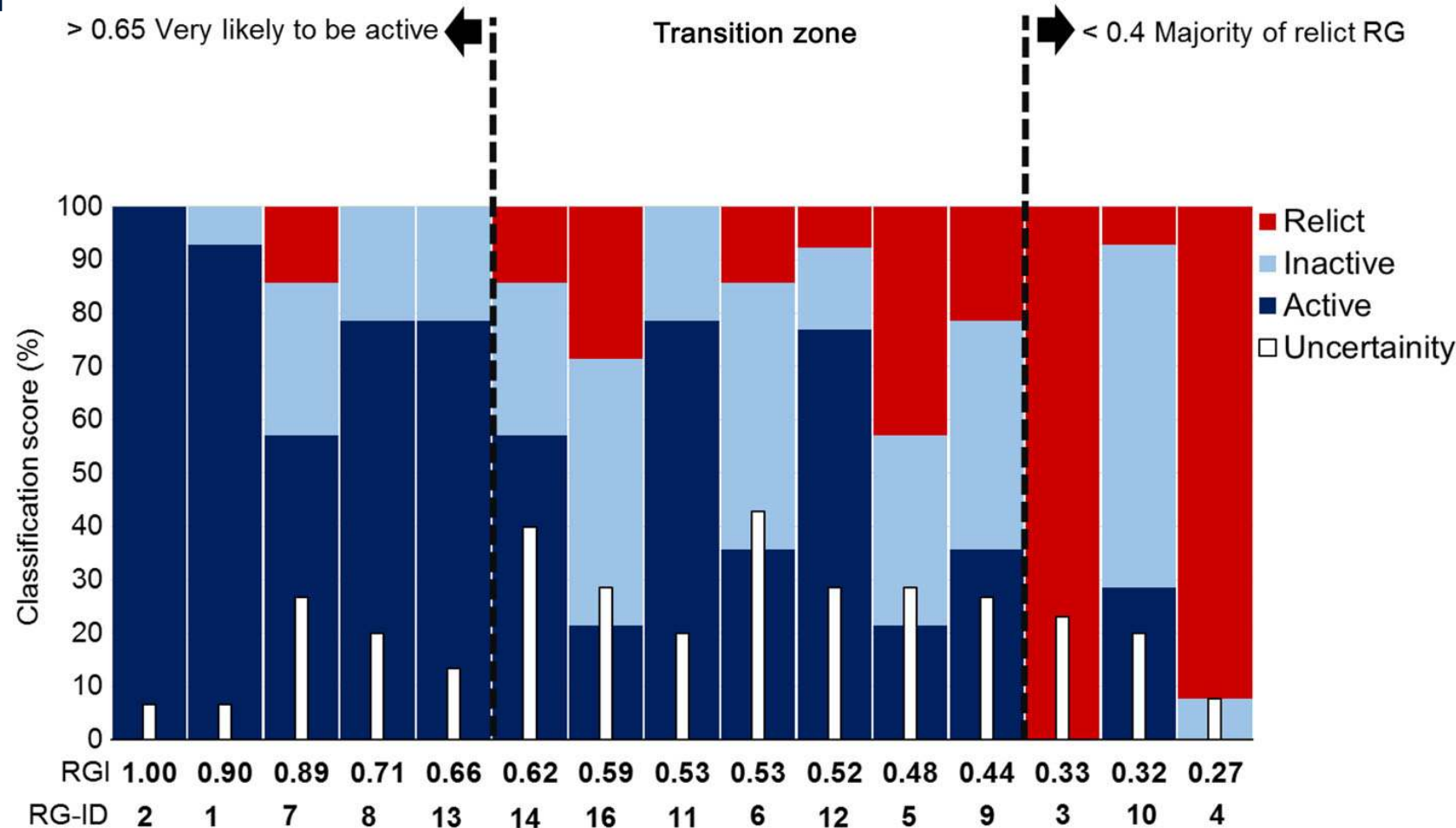


Lack of consensus: Effects on activity

An inventorying exercise conducted in 2018 and involving rock glacier **international experts** showed:

- heterogeneity in **RG detection**
 - heterogeneity in **RG delineation**
 - heterogeneity in **RG activity**
- from 3 to 11 **RELICT RGs**
from 11 to 18 **ACTIVE RGs**
from 3 to 11 **INACTIVE/TRAN RGs**

(Brardinoni et al., 2019)



Cascading effects on applications

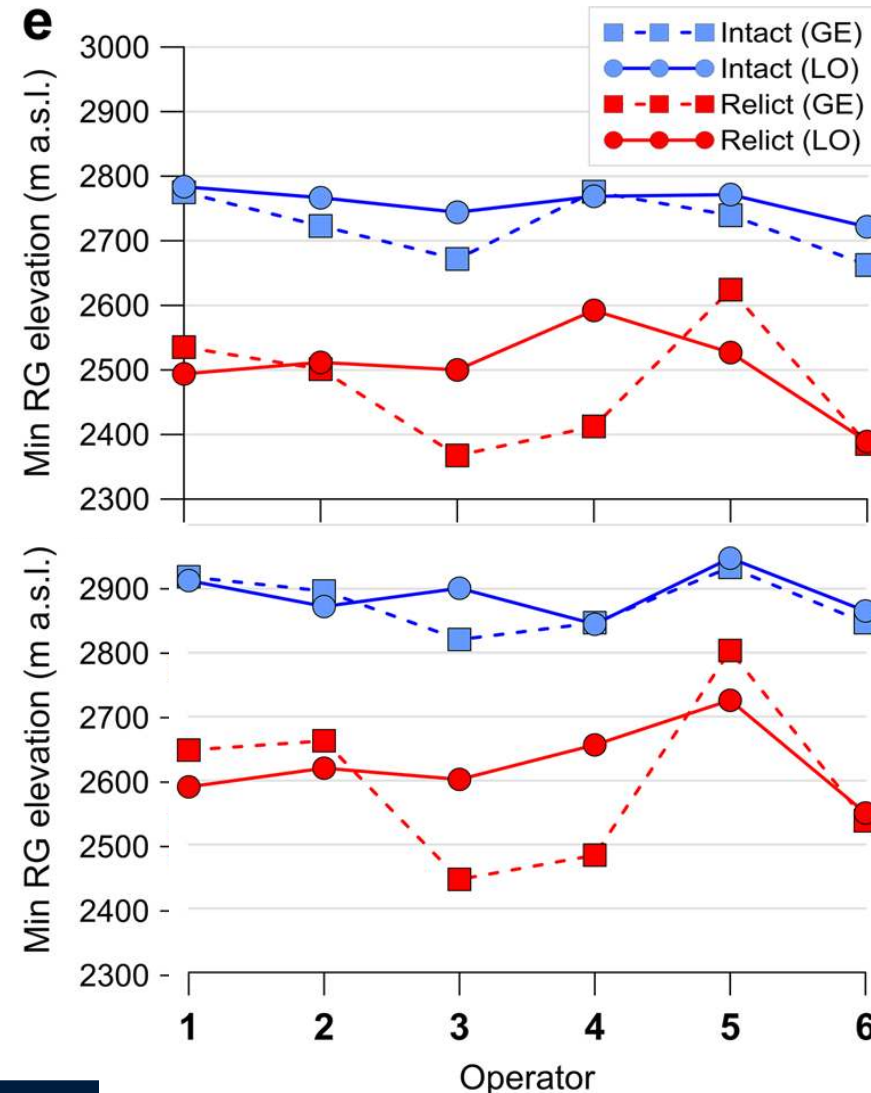
Heterogeneity in single RG **delineation** (mapping) can generate:

- discrepancy in **minimum** and **maximum elevation** among operators

Combined with discrepancies in RG **detection** and **activity** evaluation

→ Effects propagated at the valley scale can affect **inferred altitudinal thresholds**, especially for **relict features**

(Brardinoni et al., 2019)



Cascading effects on applications

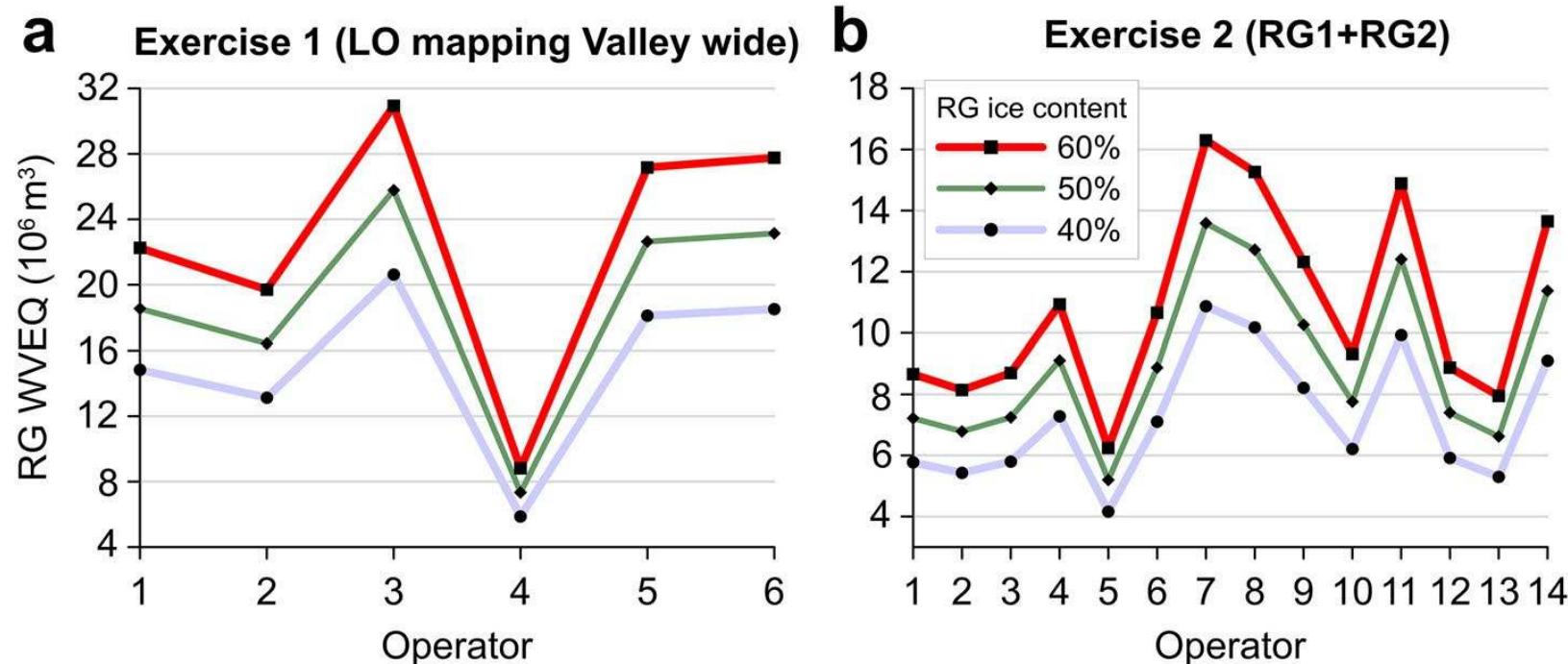
Heterogeneity among operators in **detection, delineation, and activity assessment** can generate at the inventory scale:

- high variability in estimated **water equivalent** (panel A)

from 9 to 31 10^6 m^3 WVEQ (at 60% ic)

Heterogeneity in **delineation** alone can also impart:

- some variability in estimated **water equivalent** of two active rock glaciers (panel B)



(Brardinoni et al., 2019)

Need for a consistent approach to RGs

RGIK WORKING DEFINITION OF ROCK GLACIER:

rock glaciers are debris landforms generated by the former or current creep of frozen ground (permafrost), detectable in the landscape with the following morphologies:

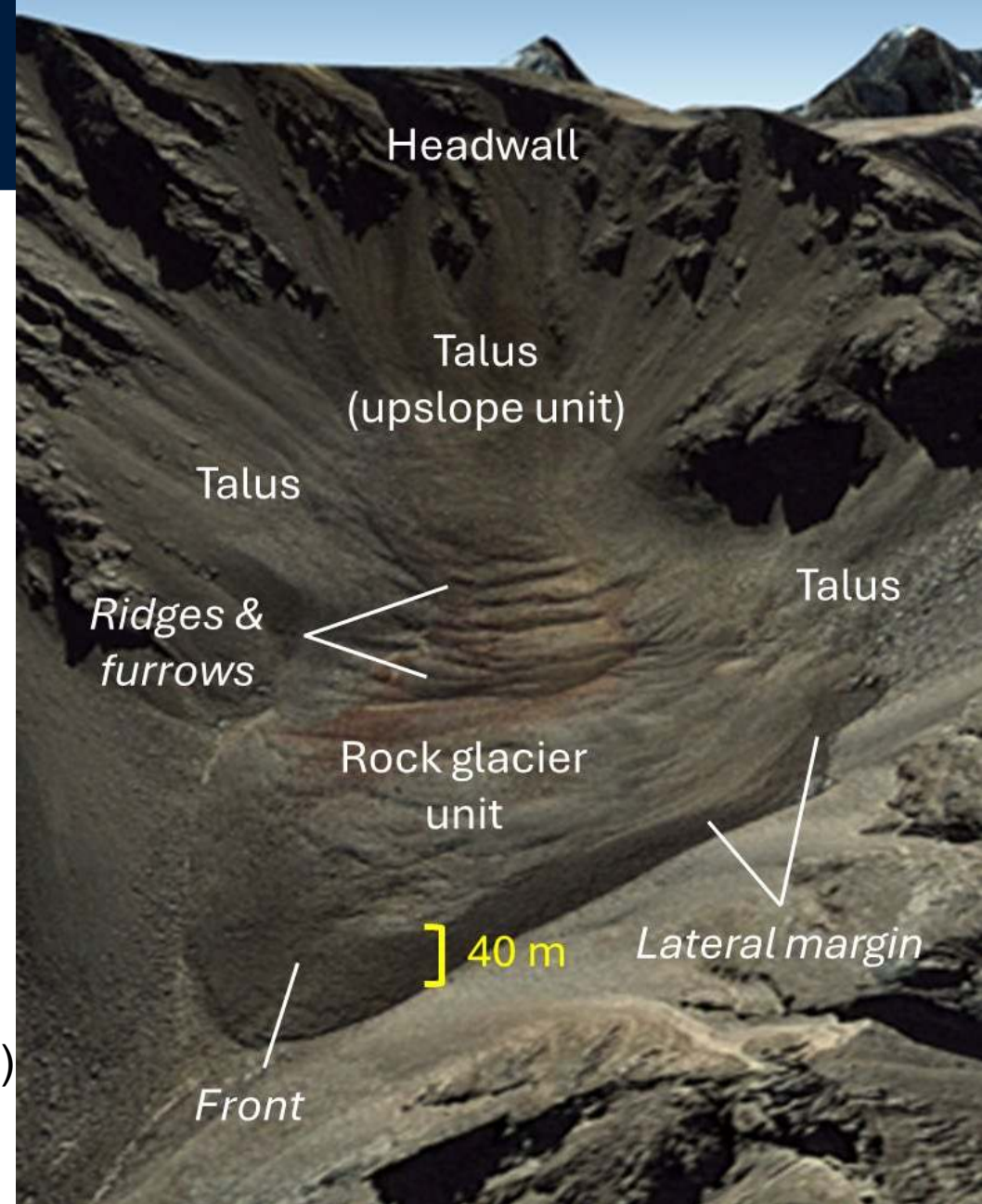
- **front**
- **lateral margins**
- optionally **ridge-and-furrow topography**

With CREEP intended as a combination of **internal deformation** of the frozen ground (i.e., strictly creep) and **shearing at depth** (along one or multiple horizons/layers).

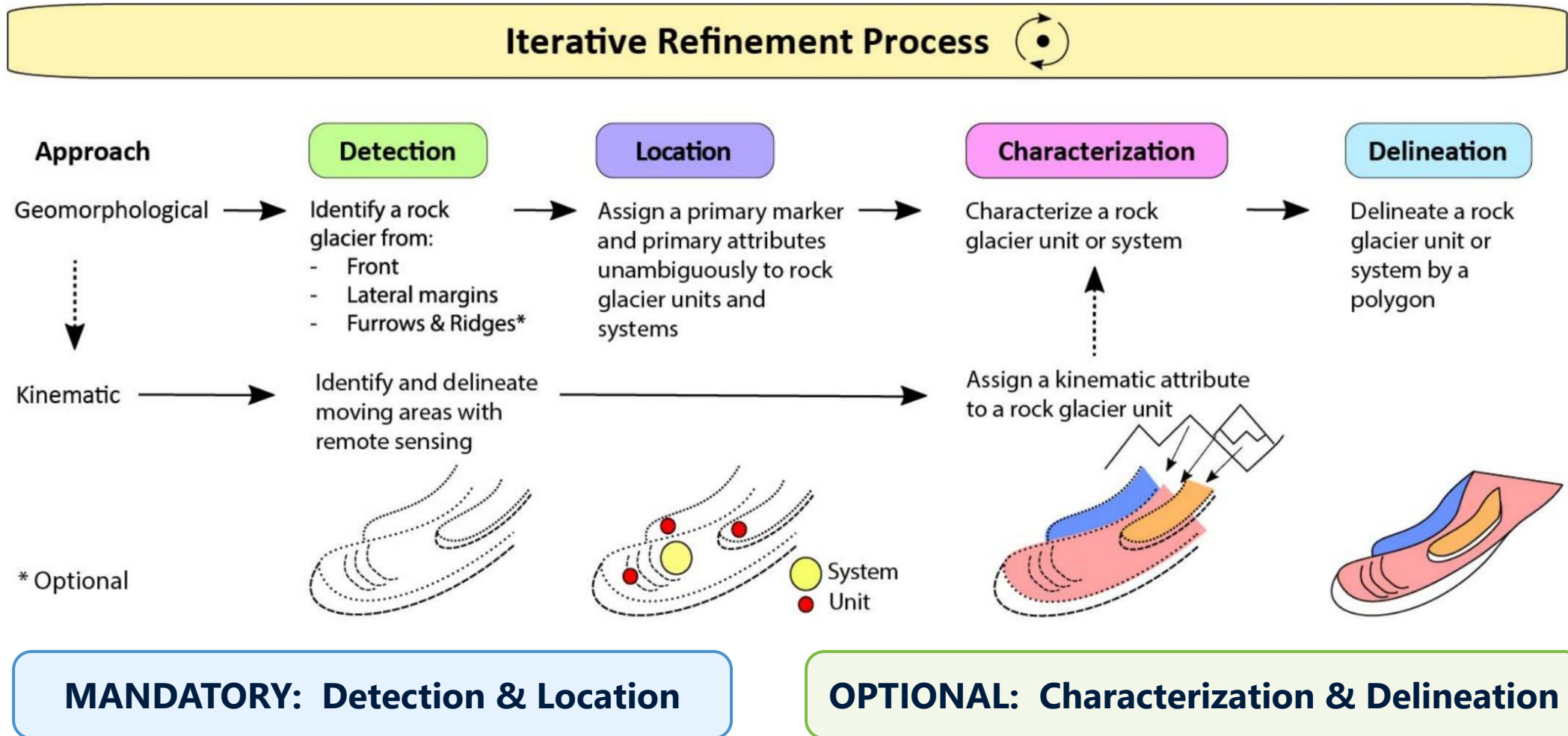
(Brardinoni et al., 2026)

Caucasus Mountains

(42.8310°N, 43.9004°E, 3250–3400 m a.s.l.)



RGIK Methodological Workflow



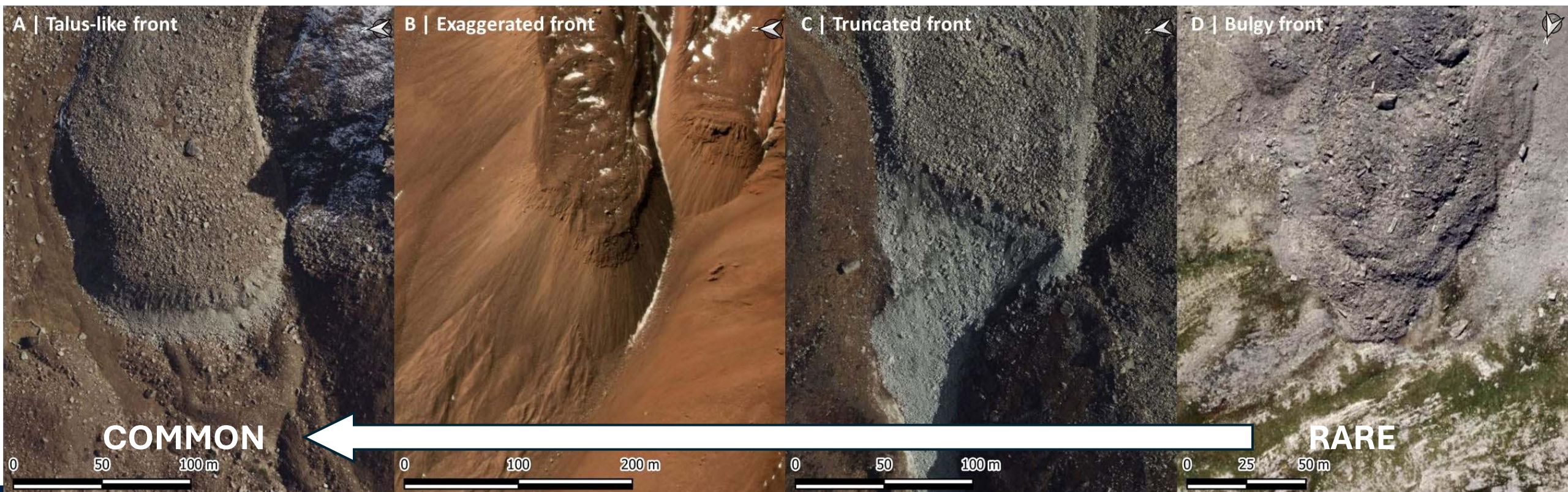
(Brardinoni et al., 2026)

1. DETECTION: FRONT TYPES

We look for debris, flow-like landforms that bear:

- (i) A **front**
- (ii) Lateral margins
- (iii) Ridges and furrows (when present)

(Brardinoni et al., 2026)



FRONT TYPES

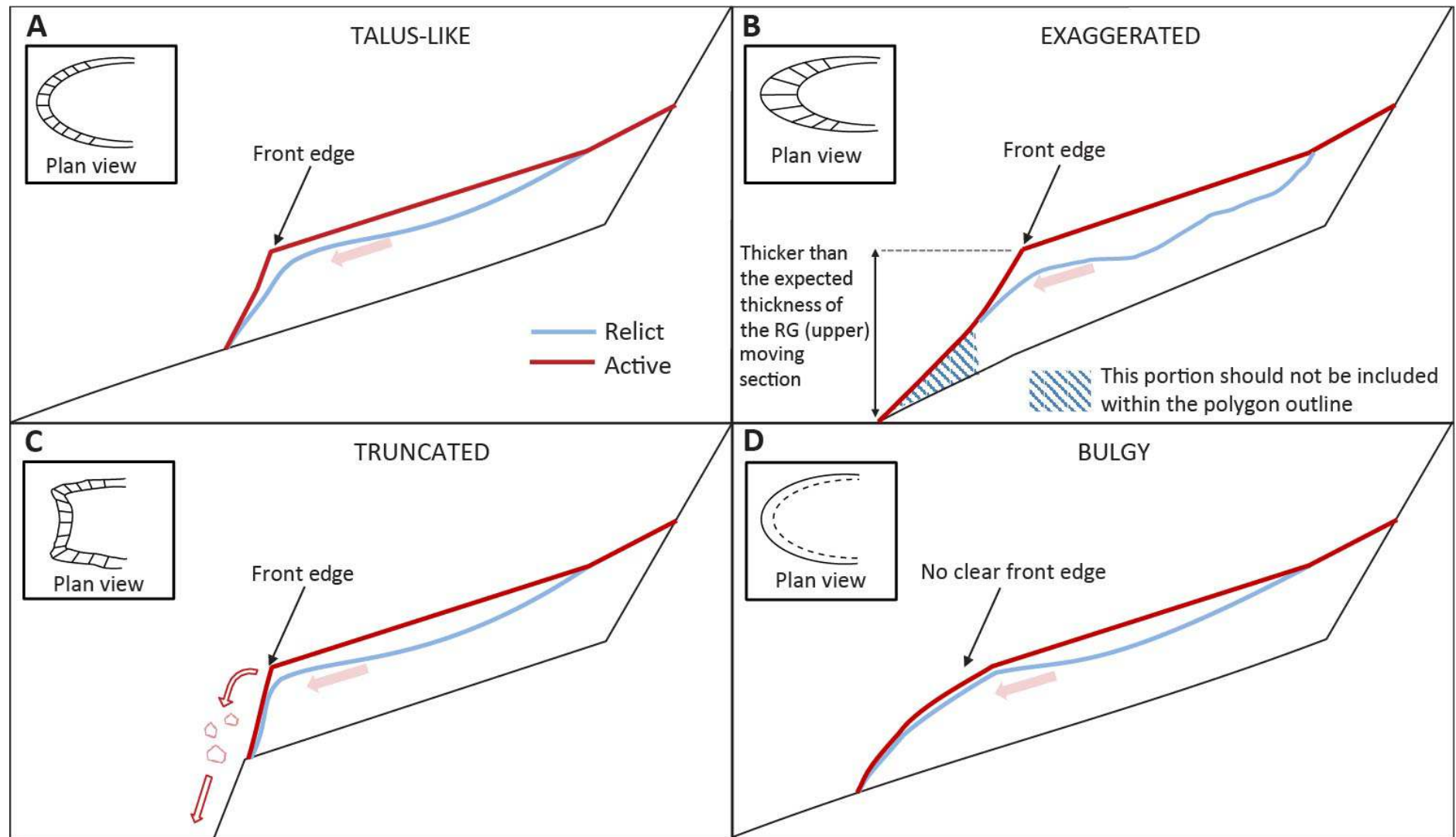


Talus-like “funny” front



Bulgy and Exaggerated (foreground)
side by side

FRONT TYPES: Side view



(Brardinoni et al., 2026)

LATERAL MARGINS

TALUS-LIKE: a morphology that resembles a talus-like front, which may sometimes form an exaggerated talus and, in rare instances, may be truncated.

LEVEE: a former talus-like margin that has ceased growing, due to subsidence of the rock glacier surface. Sometimes it may be confused with **lateral moraines**, especially in the case of **relict rock glaciers**.

SHEAR MARGIN: a shallow, elongated furrow that forms along the mobile portion of a rock glacier due to shearing. Typically develops on the inner lower side of the levees and in the uppermost portion of a rock glacier.



Landform type: Uncertain rock glacier

Based on the identification of the two (or three) RGIK morphological elements, the so-called LANDFORM TYPE attribute is assigned. The attribute includes three categories:

1. ROCK GLACIER
2. UNCERTAIN ROCK GLACIER
3. NOT-A-ROCK GLACIER

From Mantha T.T. (to be defended)



Landform type: Not-a-rock glacier

Based on the visual recognition of the two (or three) **RGIK morphological elements**, the so-called LANDFORM TYPE attribute is assigned. The attribute includes three categories:

1. ROCK GLACIER
2. UNCERTAIN ROCK GLACIER
3. NOT-A-ROCK GLACIER
(i.e. OTHER FLOW-LIKE LANDFORMS)

LAVA FLOW



SOLIFLUCTION LOBES



Landform type: Not-a-rock glacier

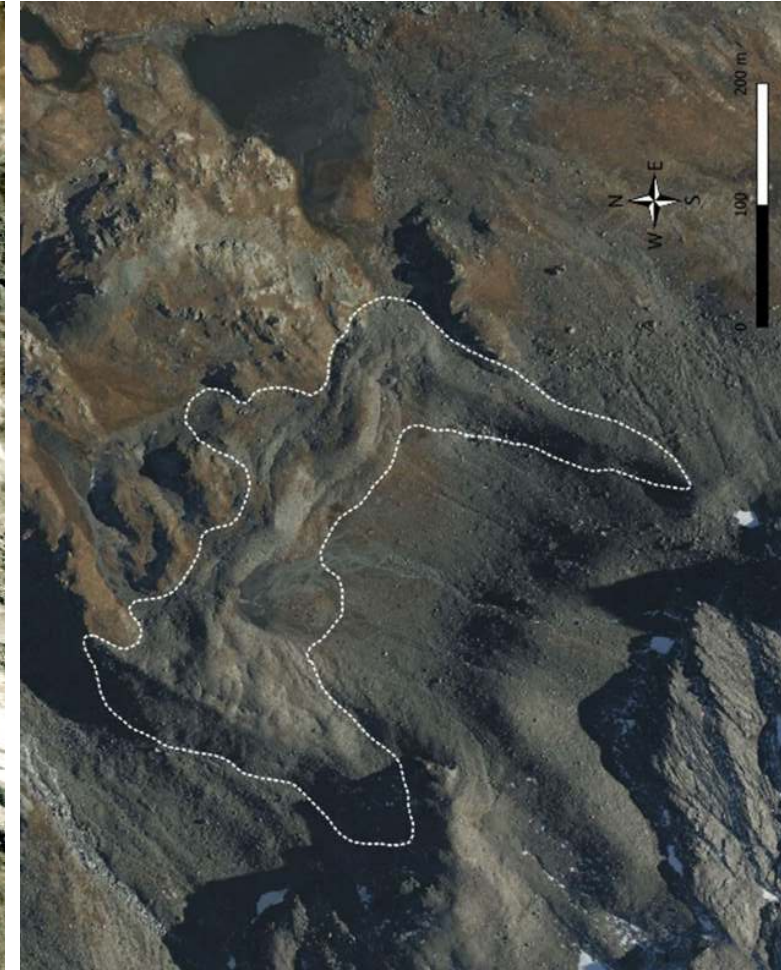
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DEBRIS-COVERED GLACIER



LATEGLACIAL MORaine

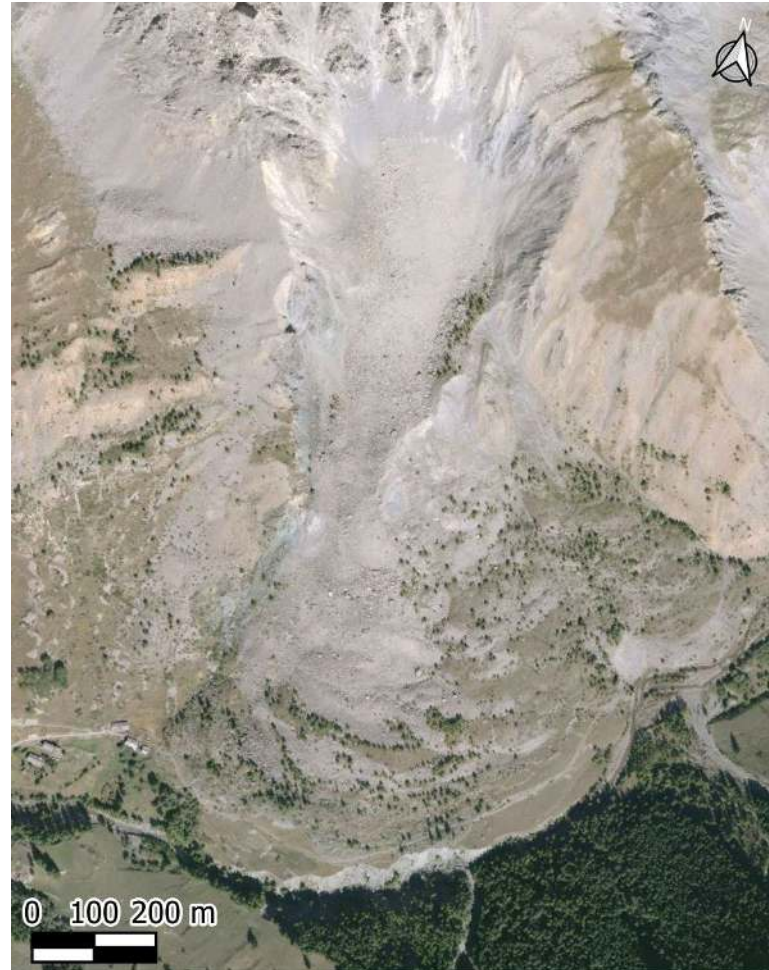


Landform type: Not-a-rock glacier

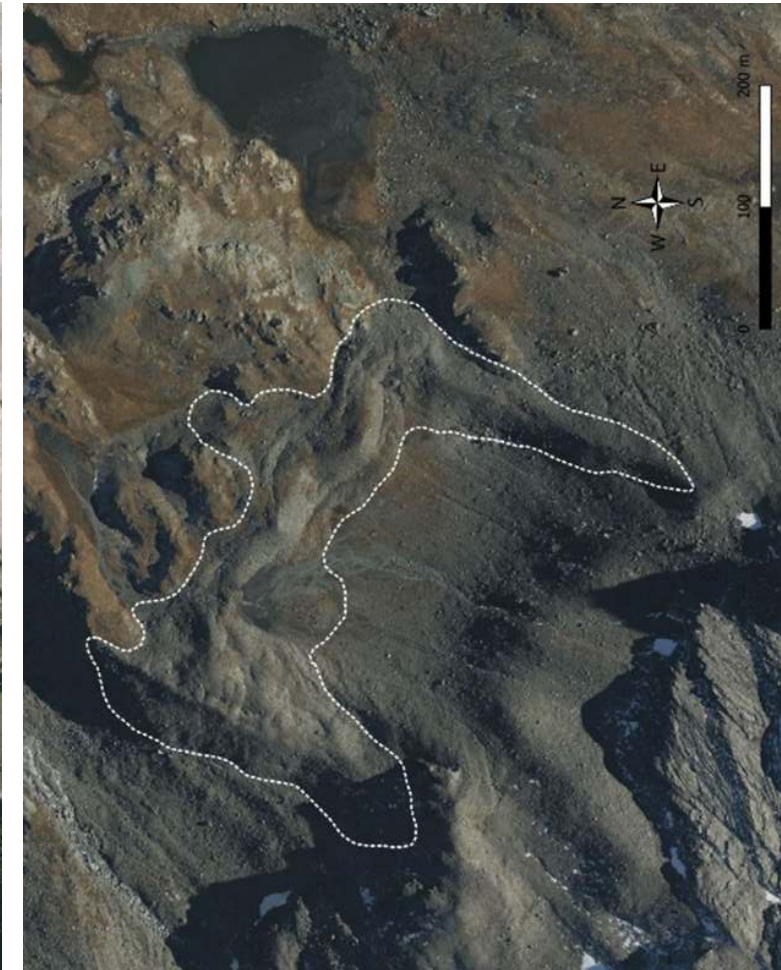
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LANDSLIDE



LATEGLACIAL MORaine



Assign a Primary Marker to each rock glacier



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- A PM must be assigned to every rock glacier
- Ideally, to be located on the lower half, not far from the front.
- PMs are used to:
 - (1) assign a unique identifier (primary ID) to each rock glacier,
 - (2) Define the relevant hierarchy (unit and system)
 - (3) Assign additional attributes

Tellers Davains,
Switzerland
46.5383°N, 9.6775°E
2200-2800 m.a.s.l.

(Brardinoni et al., 2026)

