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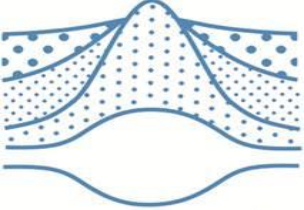
SUBCOMITÉ DE CIENCIAS
DE LA CRIÓSFERA



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Environmental status of the cryogenic permafrost conditions in the last decade in the Central Andes, one example: Morenas Coloradas rockglacier, Mendoza, Argentina.

Dr. Dario Trombotto Liaudat
Ianigla – Geocriología – CCT Conicet Mendoza



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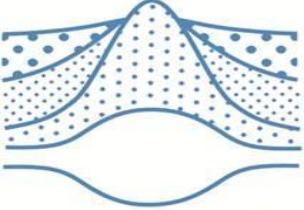


Walery Ritter von Lozinski, 1909:

Über die mechanische Verwitterung der Sandsteine im gemäßigten Klima.

BULLETIN INTERNATIONAL DE L'ACADEMIE DES SCIENCES DE CRACOVIE.

- The Geocryology is the study of earth materials including rock at temperatures below 0°C. It is the science that studies the environment and ecology of cold regions, the natural, geological, physical and chemical processes related to the freezing-thawing cycles, and the relationship with *Permafrost* and human activities (Trombotto Liaudat et al, 2014).
- The principal goal of the Study and Research of the Geocryology at the IANIGLA institute is to research frozen ground, to deduce where frozen ground in the Andes occurs, how and where are the principal cryoforms, that contain permafrost, and to investigate the cryogenic dynamic processes, that will be affected by climatic changes.



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Permafrost is ground (soil or rock and included *Ice* and organic material) that remains at or below 0°C for at least two consecutive years.

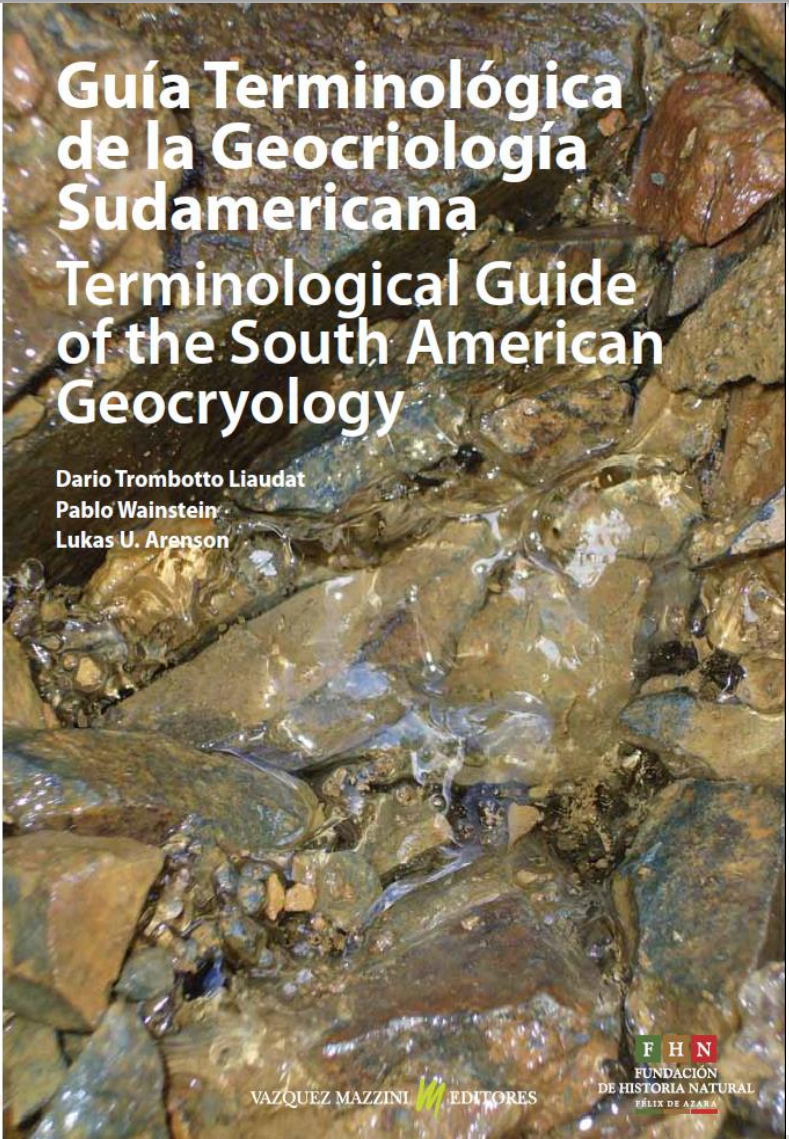
Permafrost is synonymous with perennially *Cryotic Ground*: it is defined on the basis of temperature. It is not necessarily frozen, because the *Freezing Point* of the included water may be depressed several degrees below 0°C; moisture in the form of water or *Ice* may or may not be present. In other words, whereas all perennially *Frozen Ground* is *Permafrost*, not all *Permafrost* is perennially frozen. *Permafrost* should not be regarded as permanent, because natural or man-made changes in the climate or terrain may cause the temperature of the ground to rise above 0°C (Trombotto Liaudat et al, 2014).

In South America distinctive cryogenic regions with permafrost were detected by Trombotto (2000). They were registered considering the MAAT between 0 and -5 °C. The regions cannot discriminate glacial ice. Some regions are extra Andean.



El objetivo de esta **Guía Terminológica de la Geocriología Sudamericana** ilustrada es asistir a los especialistas, profesionales y aficionados en la materia, para el mejor entendimiento de las crioformas y procesos criogénicos encontrados en el fascinante mundo periglacial de la Cordillera de los Andes. Esta guía bilingüe presenta definiciones claves, tanto en castellano como en inglés, que fueron formuladas, y son actualmente usadas, por las comunidades científicas internacionales en los ámbitos de la Geocriología y la Glaciología. La guía incluye también particularidades de la Cordillera de los Andes y ayuda a apreciar las características, a veces complejas, de los procesos y geoformas criogénicas andinas.

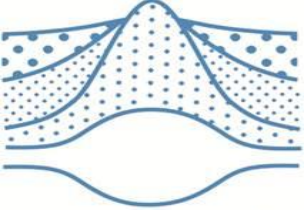
The goal of this illustrated **Terminological Guide of the South American Geocryology** is to assist in better understanding the fascination and often foreign cryoforms found in the South American Andes. This bilingual guide presents key definitions in Spanish and English that were coined and are used by the international glacial and periglacial research community, lists Andean individualities and assists in appreciating the sometimes complex characteristics of these landforms and geomorphic processes.



Guía Terminológica de la Geocriología Sudamericana

Terminological Guide of the South American Geocryology

Dario Trombotto Liaudat
Pablo Wainstein
Lukas U. Aranson



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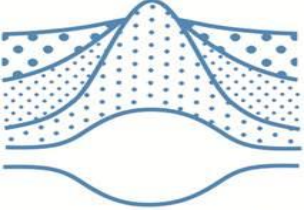


Important cryogenic regions with permafrost in South America

Fig. 1: MAAT map of South America (adapted by Trombotto)
black: MAAT 0-(-5) °C (including ice covers); dash line: MAAT > 5 °C



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Santiago de Chile, Chile, 27-29 de Octubre de 2014, Dario Trombotto



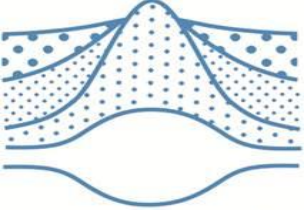
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Monitoring sites

Monitoring Site	Region	Location	A (m)	Method	
Lagunita del Plata, southern slope (Mendoza), interrupted (LL5)	Cordón del Plata, Cordillera Frontal, Central Andes	S 33° 02' 51" W 69° 24' 40"	4491	Bth, Tex	TP AL
Lagunita del Plata, northern slope (Mendoza), interrupted (LL2)	Cordón del Plata, Cordillera Frontal, Central Andes	S 33° 03' 46" W 69° 24' 06"	4008	Bth, G	TP AL
Balcón I (Mendoza)	Cordón del Plata, Cordillera Frontal, Central Andes	S 32° 57' 43" W 69° 22' 19"	3560	Tex, G Bth, G	TP AL
Balcón I Superior (Mendoza)	Cordón del Plata, Cordillera Frontal, Central Andes	S 32° 57' 18" W 69° 22' 14"	3586	D Bth, G	TP AL
Balcón II (Mendoza)	Cordón del Plata, Cordillera Frontal, Central Andes	S 32° 56' 95" W 69° 22' 49"	3770	Bth, D G, Tex	TP AL
Glaciar de escombros Dragón (Mendoza), discontinued	Cordillera Frontal, Central Andes	S 34° 14' 48" W 69° 31' 08"	3553	Bth Tex	TP AL
Termistor Cº Laguna (2)	Cordillera Principal, Central Andes	S 34° 11' 00" W 69° 35' 53"	3688	Bth	TP AL
Volcán Peteroa (Mendoza) (1)	Cordillera Principal, Central Andes	S 35° 14' 27" W 70° 33' 50"	3489	Bth	TP AL
Glaciar de escombros Pachón (San Juan)	Cordillera Principal, Central Andes	S 31° 44' 40" W 70° 25' 12"	3872	BD Tex	TP AL
Gelifluxión N Pachón (San Juan) ice at 6 m depth	Cordillera Principal, Central Andes	S 31° 45' 33" W 70° 27' 03"	3846	BD Tex	TP AL
Gelifluxión S Pachón (San Juan) ice at 5 m depth	Cordillera Principal, Central Andes	S 31° 45' 23" W 70° 26' 59"	3816	BD Tex	TP AL
Glaciar de escombros Pit (San Juan) Pozo 352, depth = 15 m	Cordillera Principal, Central Andes	S 31° 45' 06" W 70° 25' 47"	3738	D	TP AL
Valle del Silencio (Caradoc, Chubut). air temperature	Cordón Rivadavia, Wet Andes	S 42° 50' W 71° 30'	1600	BTS D	TP AL
Sitio Histórico de Aguilar P 17 - San Juan, inst = 15 m depth = 56.1 m, water at 16.5 depth	Cordillera Principal, Central Andes	S 31° 44' 54" W 70° 25' 14"	3787	D Tex	TP AL
Pozo 376 (San Juan) depth = 5 m, inst = 4 m	Cordillera Principal, Central Andes	S 31° 44' 45.4" W 70° 25' 57.3"	3878	D	
Volcán Copahue (Neuquén)	Cordillera Principal, Andes Australes	S 37° 50' 38.58" W 71° 06' 53.64"	2095		BTS

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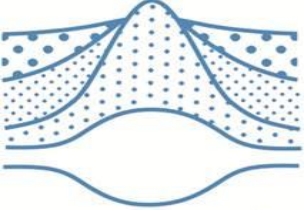


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Monitoring site: Morenas Coloradas rock glacier

Monitoring Site	Region	Location	A (m)	Method
Balcón I (Mendoza)	Cordón del Plata, Cordillera Frontal. Central Andes	S 32° 57' 43" W 69° 22' 19"	3560	Tex, G Bth, G
Balcón I Superior (Mendoza)	Cordón del Plata, Cordillera Frontal. Central Andes	S 32° 57' 18" W 69° 22' 14"	3586	D Bth, G
Balcón II (Mendoza)	Cordón del Plata, Cordillera Frontal. Central Andes	S 32° 56' 95" W 69° 22' 49"	3770	Bth, D G, Tex

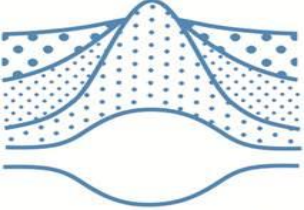


creeping permafrost

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Ice Content	Hygric Potential	Permafrost Type	Variety	Features	Restrictors And Processes	Tropical Andes	Dry Andes		Southern Andes (35° - 55° 30' S)
							Desert Andes (17° 30' - 31° S)	Central Andes (31° - 35° S)	
+	+	1) Creeping	1- Talus rock glaciers 2- Debris rock glaciers	Active and inactive rock glaciers, Cold, Discontinuous (Rock glacier pattern)	Creeping, Energy balance, Precipitation		Bolivia: rock glaciers, Cerro Caquella, ~5400 m ASL (21° 30' S) Chile: Rock glaciers > 175 mm / y (24° - 27° S)	Argentina: lower limit of active rock glaciers 3500 m ASL, Chile: 3300 m ASL (33° S)	Argentina: active rock glaciers

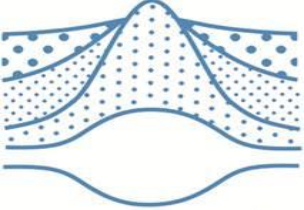


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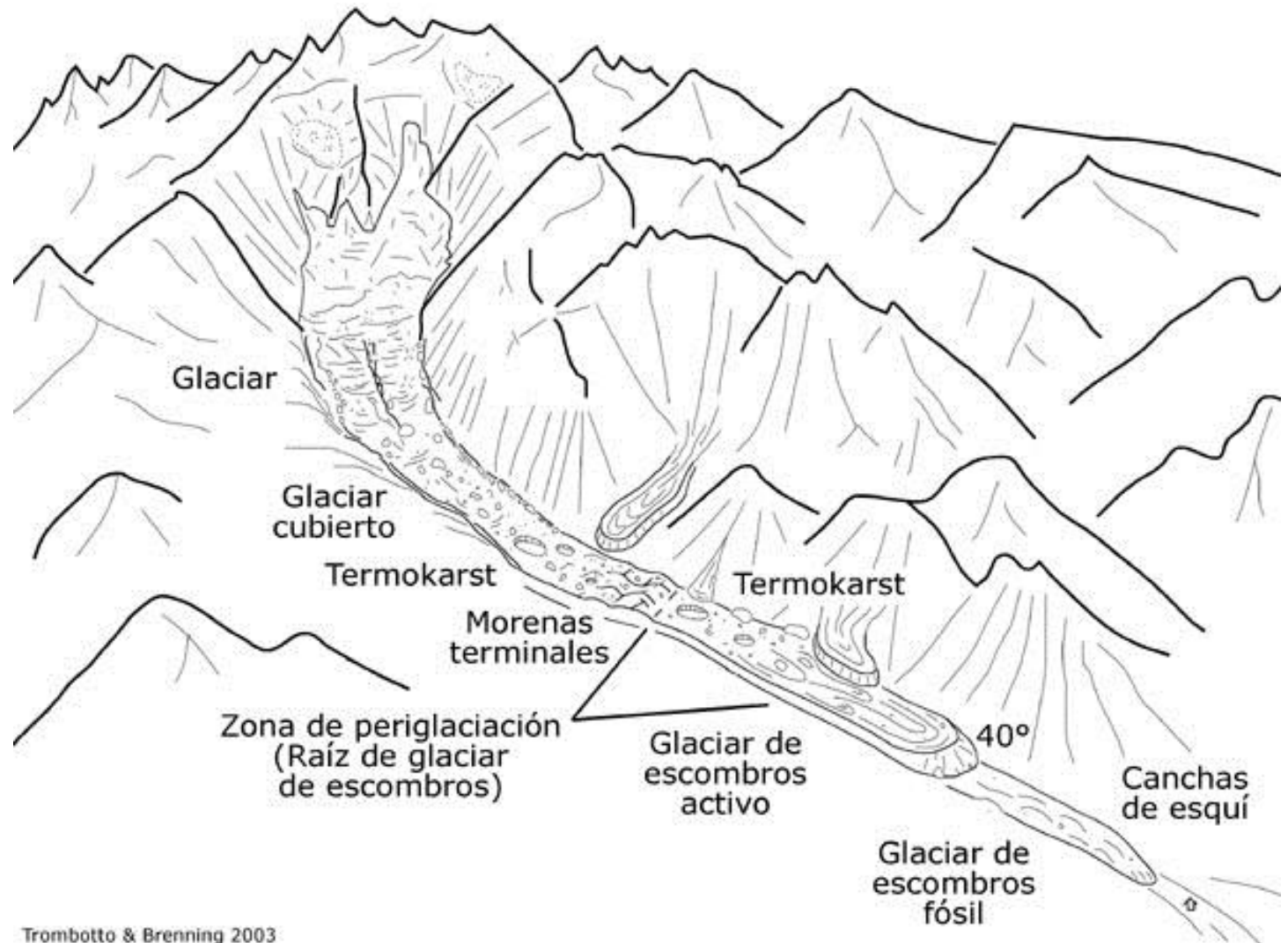
Rock glacier definition

A rock glacier is a mass of rock fragments and finer material, on a slope, that contains either interstitial, pore or/ and injection ice and shows evidence of past or present movement. It is a cryogenic landform, supersaturated with ice that if active, moves down slope by the influence of gravity which produces creep and deformation of the Mountain Permafrost. Rock glaciers do not form where there is insufficient moisture to form the interstitial Ice that permits movement of the mass. Active rock glaciers possess steep fronts with slope angles greater than the angle of repose. Most rock glaciers have transverse ridges and furrows on their surface. In general, rock glaciers present a lobate shape with surficial morphology similar to a lava flow. However, especially in the central Andes, the morphologies can be considerably complex with multiple basins contributing material and the superposition of two or more lobes.

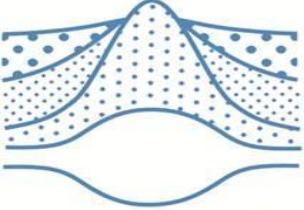


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Model of the rock glacier environment in the Central Andes



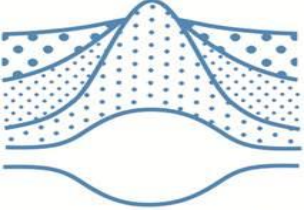
Trombotto & Brenning 2003



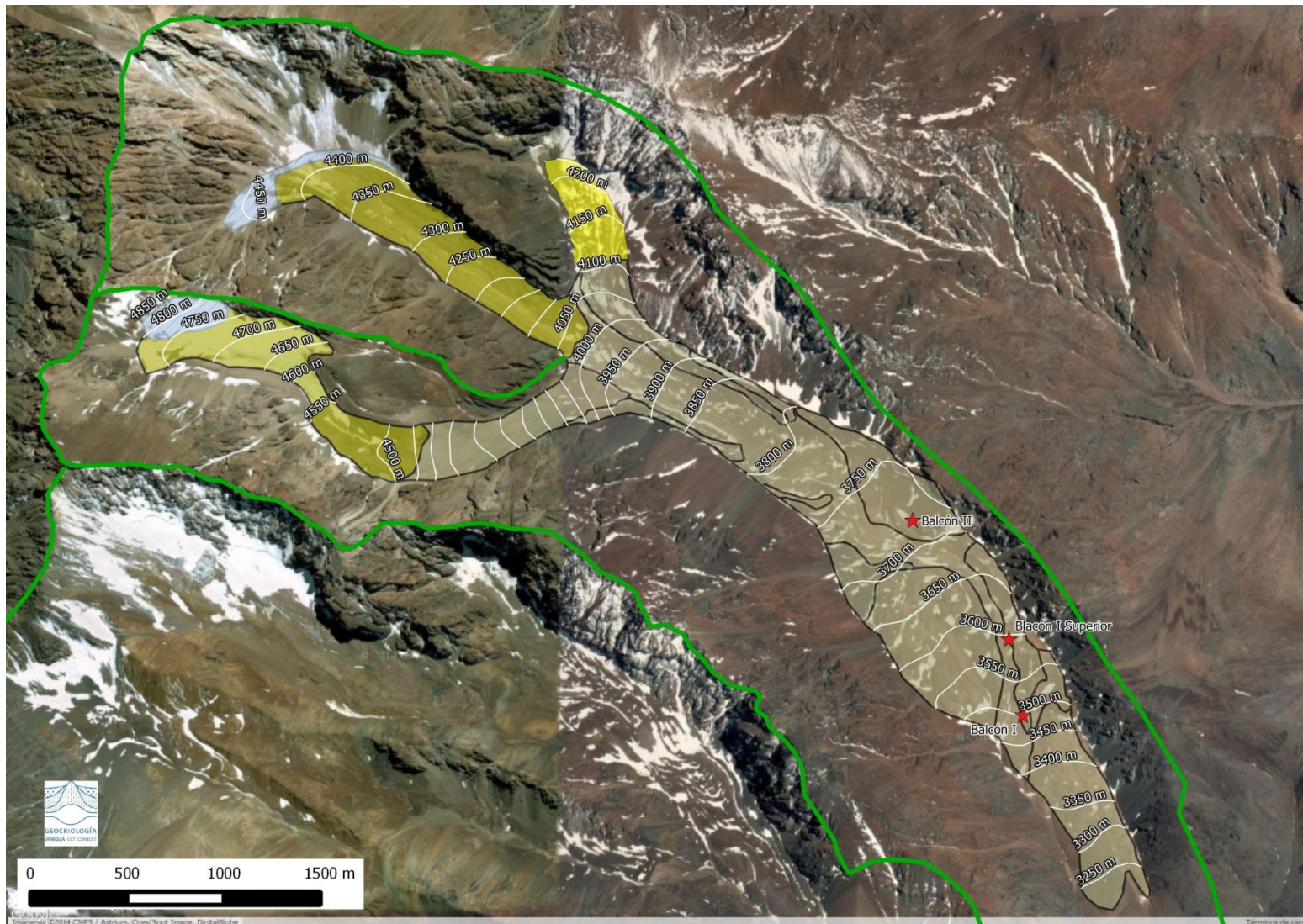
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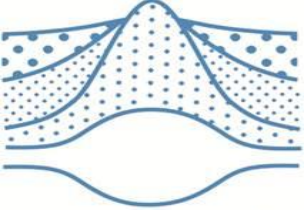
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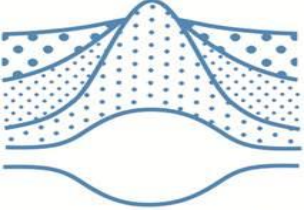
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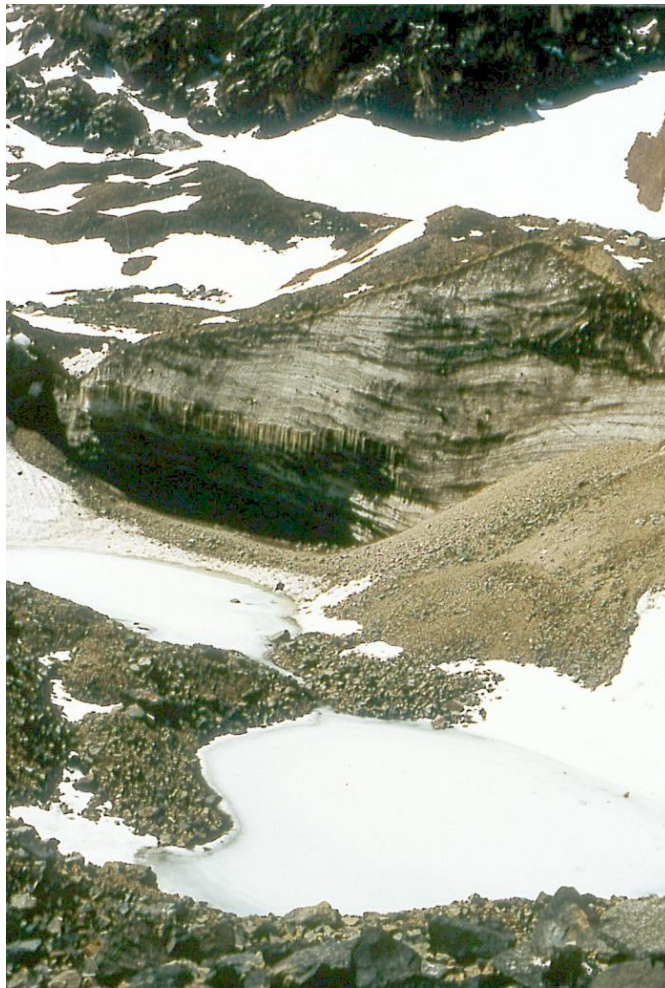


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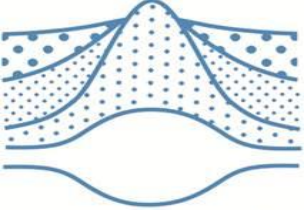
Degradación de hielo glaciario



Termokarst, 1999



Termokarst, 2005



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Degradación de hielo glaciario



Termokarst, 1999



Termokarst, 2005

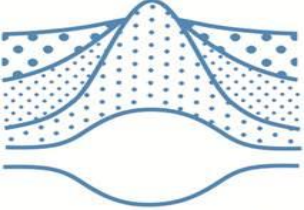


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Geomorphology of the rock glacier



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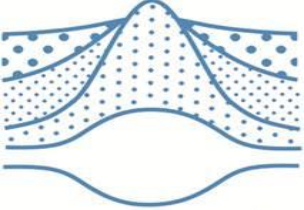


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Utilización del radar para detectar profundidad de capa activa



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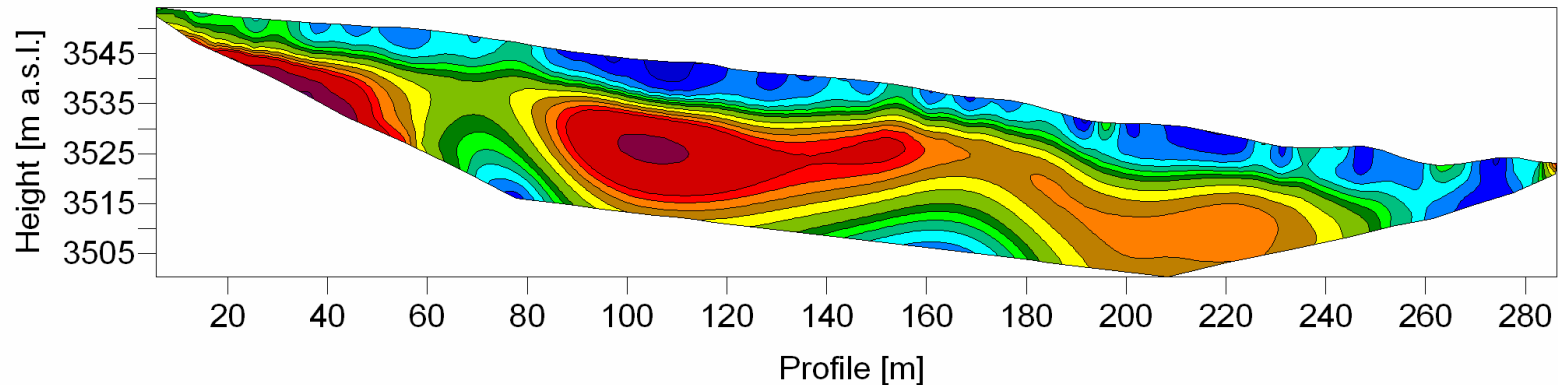


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Interpretación indirecta geofísica de la estructura interna del glaciar de escombros de Morenas Coloradas

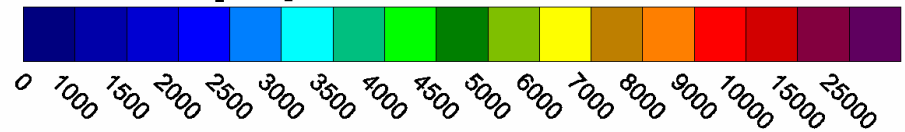
Morenas Coloradas Balcon 1

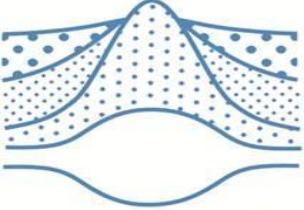
array length: 296 m
array: 2 * 196 m, 96 m central overlapping (roll-along)
type of array: wenner
spacing: 4 m
smoothed inversion
inversion software: res2din
date: 16.-17.2.2008



iterations: 3
RMS-error: 4.6 %
first electrode: 0 m
last electrode: 296 m

Resistivität [Ω m]



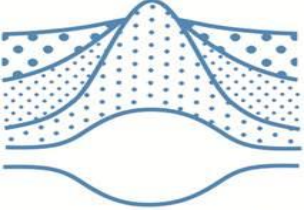


Pore ice

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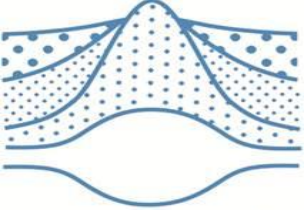
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Ice matrix

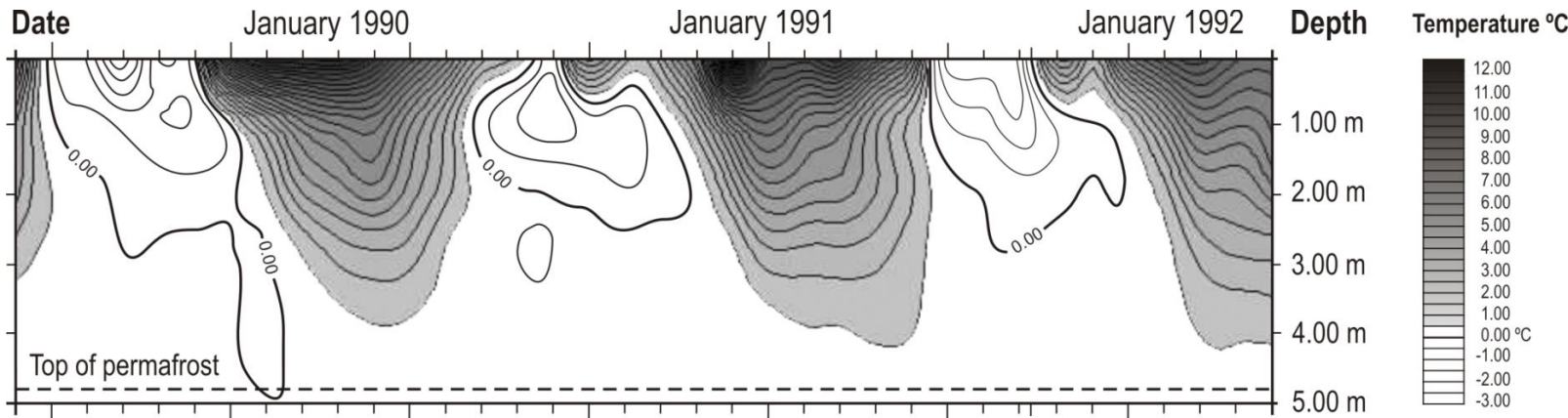


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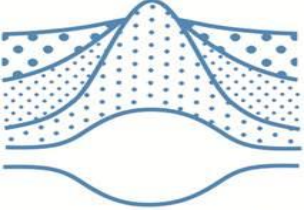


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Active layer, Morenas Coloradas rock glacier Balcón I, 3560 m a.s.l.



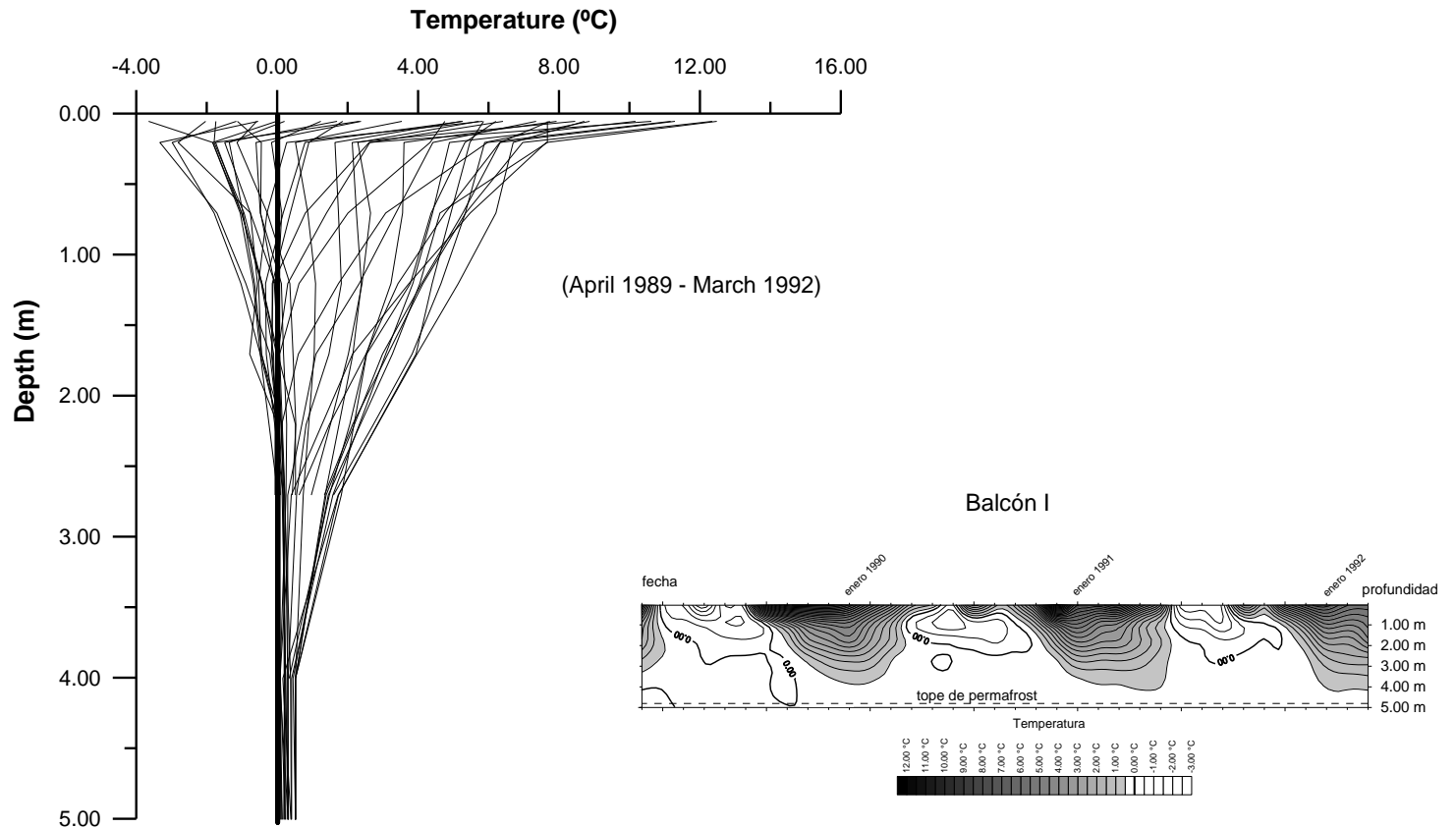
Trombotto, Buk &
Hernández, 1999

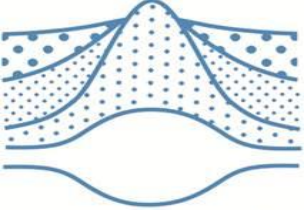


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April 1989 – March 1992

El Balcón I

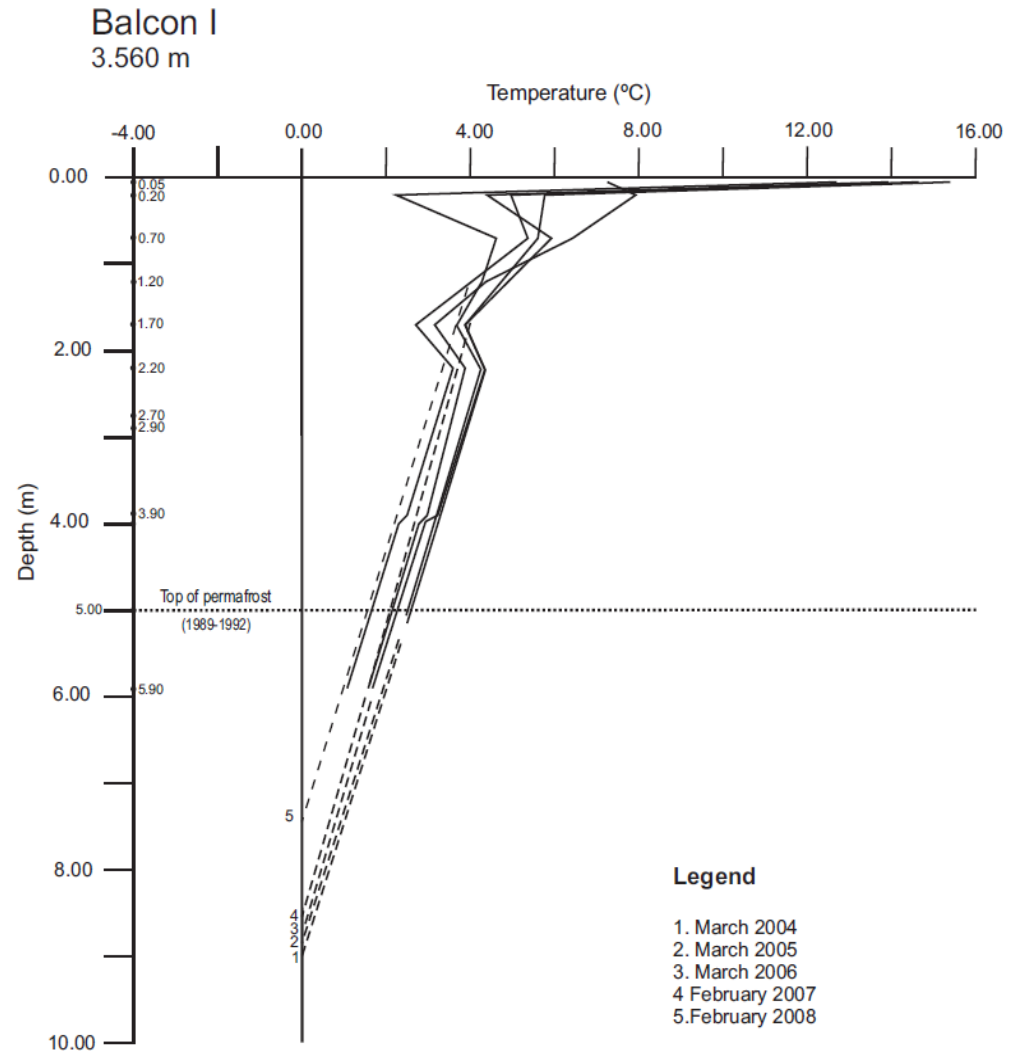


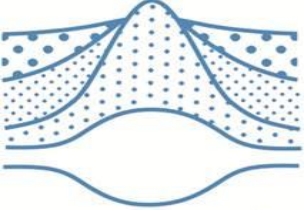


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Trombotto and Borzotta, 2009





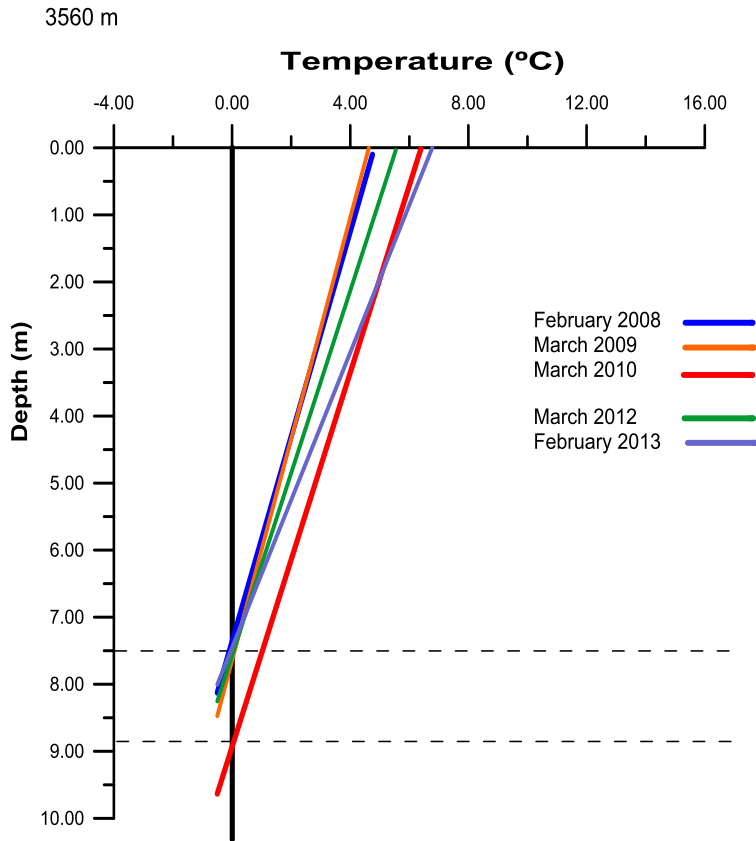
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Top of the permafrost at Balcón I between 1989 and 2013

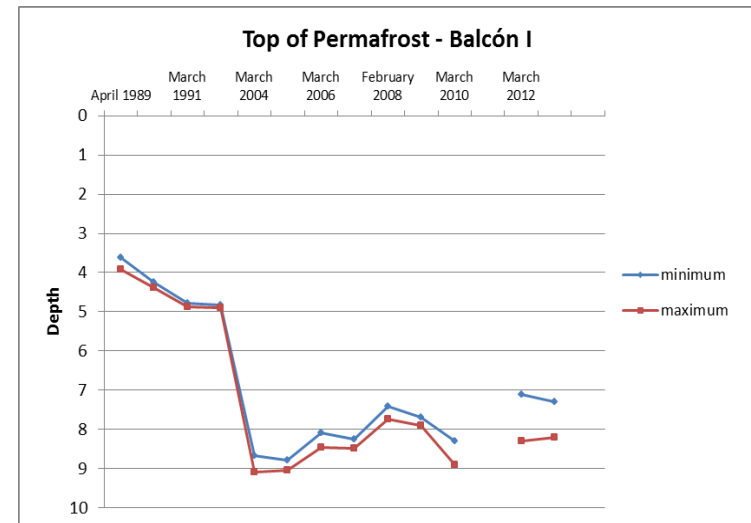
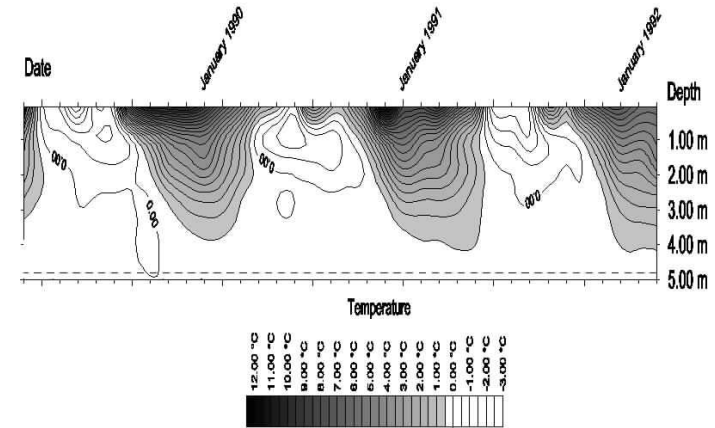
Simple linear regression $y = a.x + b$ ($y = \text{slope} \cdot x + \text{intercept}$)

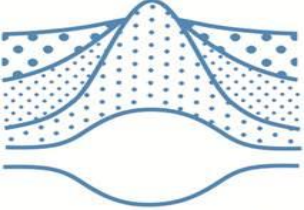


Balcón I



El Balcón I



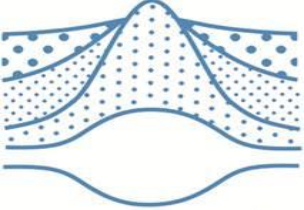


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Monitoring site: Morenas Coloradas rock glacier

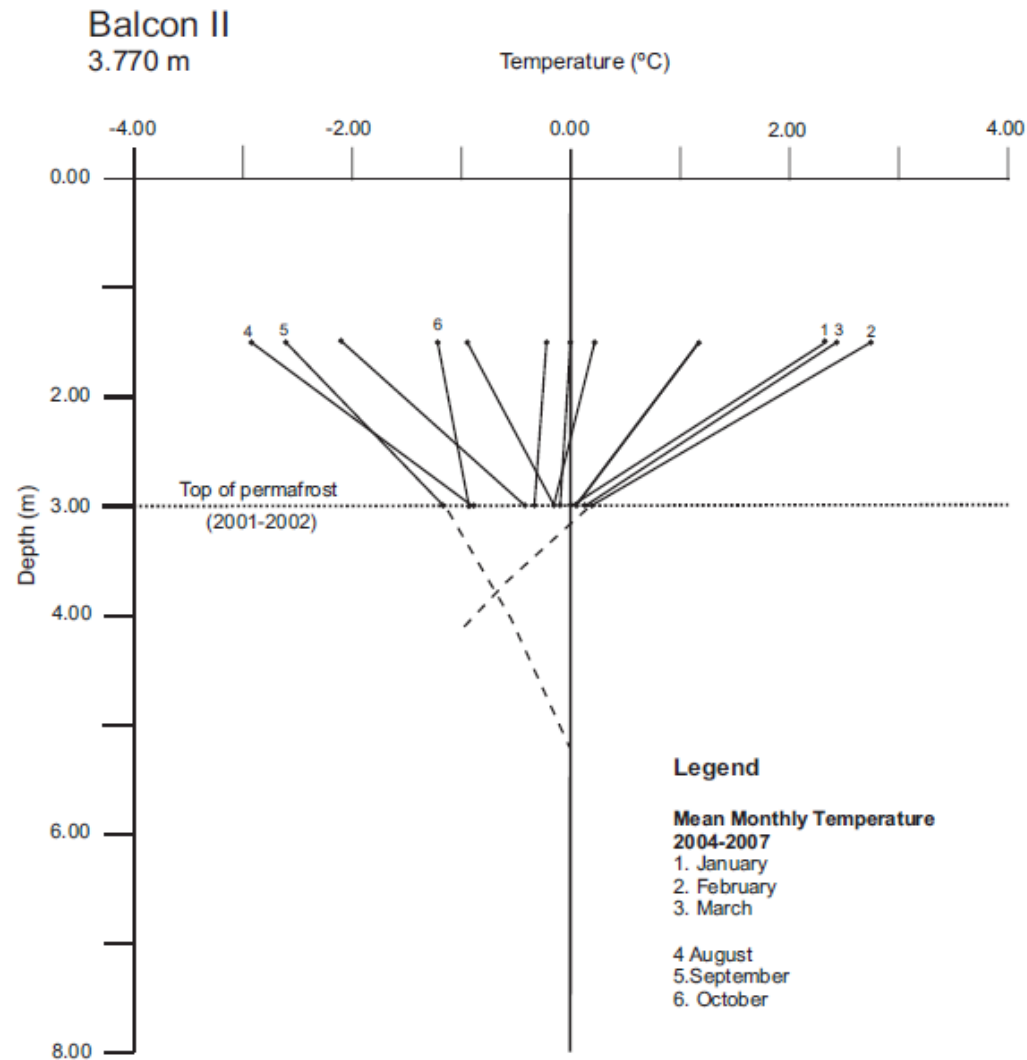


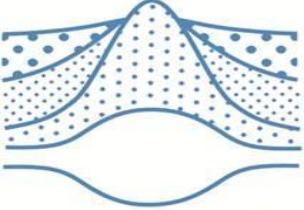
Monitoring Site	Region	Location	A (m)	Method		2004	2005	2006	2007	2008	2009	2010	2011 (abril)	2012	2013	2014 (abril)
Balcón I (Mendoza)	Cordón del Plata, Cordillera Frontal, Central Andes	S 32° 57' 43" W 69° 22' 19"	3560	Tex, G	TP	8,9	8,9	8,3	8,3	7,6	7,8	8,6		7,7	7,75	
				Bth, G	AL	*	*	*	*	*	*	*	*	*	*	*



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Trend of the mean monthly temperatures in the active layer at Balcón II



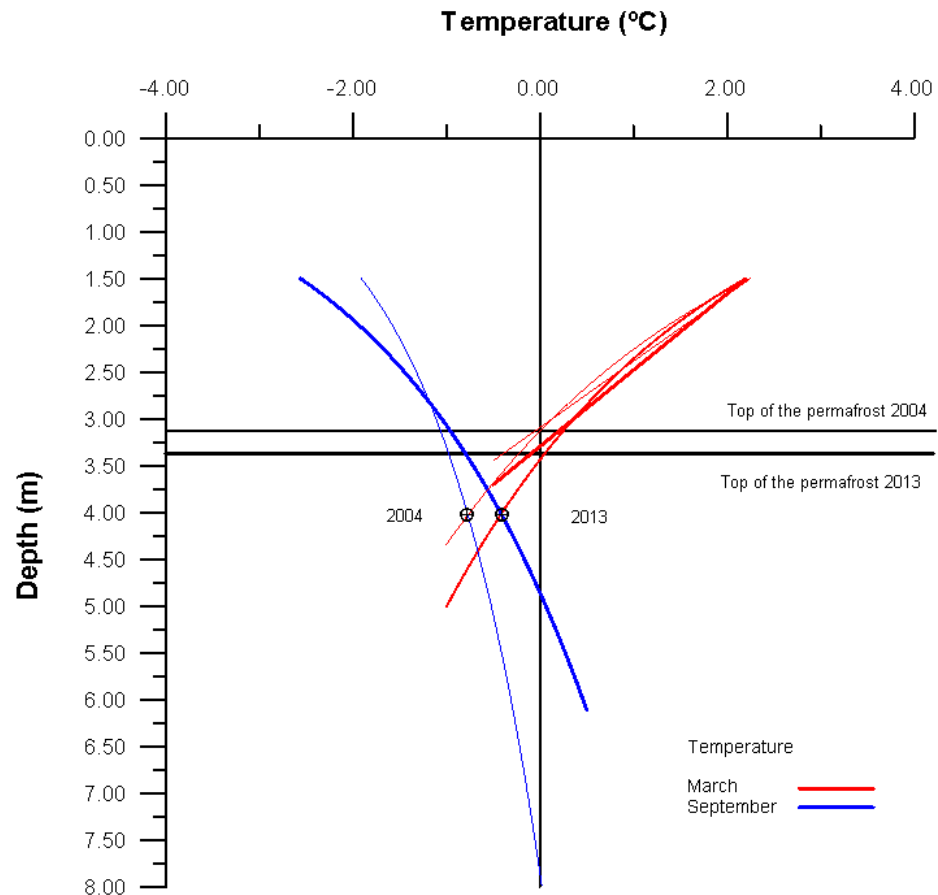


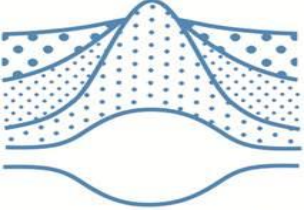
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Ground temperatures at different times ($t_0, t_1 \dots t_\infty$)
 T_0 to $T_0 + T\Delta$

Balcón II

3770 m



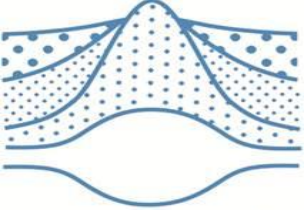


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Monitoring site: Morenas Coloradas rock glacier



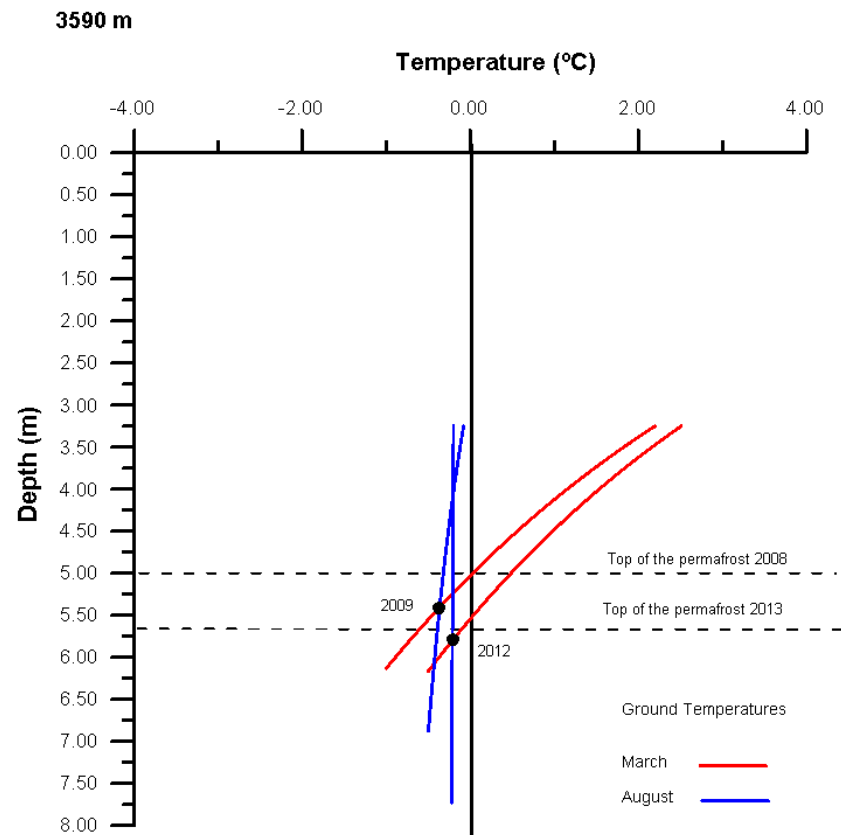
Monitoring Site	Region	Location	A (m)	Method		2004	2005	2006	2007	2008	2009	2010	2011 (abril)	2012	2013
Balcón II (Mendoza)	Cordón del Plata, Cordillera Frontal, Central Andes	S 32° 56' 95" W 69° 22' 49"	3770	Bth, D	TP										
				G, Tex	AL	3.20	3.1	3.05	3.05	3	3.2	3.2	3.2	3.25	3.35

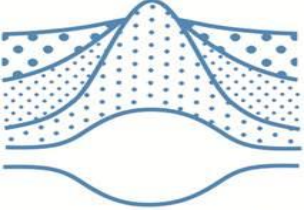


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Balcón I Superior Comparison between 2008 and 2012





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Monitoring site: Morenas Coloradas rock glacier



Monitoring Site	Region	Location	A (m)	Method		2004	2005	2006	2007	2008	2009	2010	2011 (abril)	2012	2013	2014 (abril)
Balcón I Superior (Mendoza)	Cordón del Plata, Cordillera Frontal, Central Andes	S 32° 57' 18" W 69° 22' 14"	3586	D	TP	*	*	*	*							
				Bth, G	AL	*	*	*	*	4,9	5	5,3	5,5	5,4	5,6	6,16

Thank you !



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