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DOI:
10.1002/ppp.2034

Document Version
Accepted author manuscript

Permafrost and Periglacial Processes

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Journal:	*Permafrost and Periglacial Processes*
Manuscript ID	PPP-19-0068
Wiley - Manuscript type:	Editorial
Date Submitted by the Author:	04-Oct-2019
Complete List of Authors:	Ruiz-Fernández, Jesús; Department of Geography, University of Oviedo Oliva, Marc; University of Barcelona, Physical Geography Hughes, Phil; University of Manchester, Geography
Keywords:	Periglacial processes, mid- and low-latitude mountains, Permafrost

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***Permafrost and Periglacial Processes* (PPP)**

Permafrost and periglacial processes in mid- and low-latitude mountains regions

Jesús Ruiz-Fernández[1]| Marc Oliva[2]| Philip Hughes[3]

[1] Department of Geography, University of Oviedo, Spain

[2] Department of Geography, Universitat de Barcelona, Catalonia, Spain

[3] Department of Geography, School of Environment, Education and Development, University of Manchester, Manchester, UK

Short title: Periglacial processes in mid- and low-latitude mountains

Correspondence: Jesús Ruiz-Fernández, Department of Geography, University of Oviedo. C/ Amparo Pedregal s/n, 33011, Oviedo, Asturias, Spain.

Email: ruizjesus@uniovi.es

ABSTRACT

The Special Issue that justifies this Editorial has been designed to commemorate the 25th anniversary of the 1st Spanish scientific meeting of the International Permafrost Association (IPA) organized in 1994 in Madrid. This Special Issue entitled "Permafrost and periglacial processes in mid- and low-latitude mountains regions" includes nine papers from various mountain regions of the globe, such as the Pyrenees, Sierra Nevada, Galician and Cantabrian Mountains in Iberian Peninsula, Atacama and Central Andes in South America, Absaroka ranges in North America, and Seckauer Tauern Range in the European Alps. These articles provide new methodologies and approaches focusing on a

wide range of periglacial phenomena, such as past cryogenic environments, active periglacial processes, permafrost and ground thermal regime, as well as rock glaciers. As a result of this Special Issue, we have detected several knowledge gaps that should be addressed in the future by the scientific community studying permafrost and periglacial processes in mid- and low-latitude mountains regions, namely: i) improving the geochronology of past periglacial environments and associated paleoclimatic implications; ii) the study of periglacial features existing in low-altitude mountain environments and/or in the lowlands; iii) improve our current knowledge of active periglacial processes, permafrost distribution and ground thermal regime in mid-altitude mountains; iv) the monitoring of periglacial mass wasting processes and mechanisms of sediment transfer; v) the interaction between glaciers and periglacial processes, and vi) geoecological dynamics in response to climate scenarios anticipating significant changes of temperature and moisture in periglacial regions.

KEYWORDS

Permafrost, periglacial processes, mid- and low-latitude mountains

1 | INTRODUCTION

Climate and environmental changes condition Earth's ecosystems in a great variety of ways in cold-climate regions. The most commonly used records to reconstruct environmental and climatic conditions are marine and lake sediments and ice cores[1-4]. The evolution of glaciers, which also constitute an important source of climate and environmental information, has also been extensively studied at various scales and perspectives[5-9]. Conversely, the study of periglacial environments has received, in general, less attention from the scientific community, except in the case of some specific topics (such as permafrost[10-13] and rock glaciers[10,14-16]). However, their study is crucial to understand past and present-day dynamics of large areas of the Earth's surface as 25% of the land surface is currently affected by periglacial conditions[10]. The geomorphology, hydrology, soil formation and ecology of these areas is strongly conditioned by the presence of seasonal or permanent ground ice conditions[17,18].

Research on permafrost and periglacial geomorphology has mainly focused on polar regions (mainly in the Arctic[15,19], but also in Antarctica[11,13,20]), as well as in the world's major mountain ranges, many of them located in mid-latitude mountain regions (Alps[12,21-22], Andes[23,24], Himalaya[25], Pyrenees[26], etc.). The magnitude of periglacial processes and associated landforms that exist in these areas have led to a greater development of periglacial research in these sectors, compared to other environments. This has also been encouraged because of the pressing problems that occur in many of these regions in relation to the degradation of permafrost and related mass wasting processes[19,27], as well as the logistical facilities provided by polar and alpine research bases.

However, to fully understand the dynamics of periglacial environments, it is necessary to extend research to other mountainous areas that are much less studied. This is often due to their lower altitude/latitude and more marginal character compared to the classic periglacial areas of the world. Likewise, it is not only necessary to examine the present-day periglacial processes and associated landforms, but it is also important to improve our understanding of the periglacial paleoenvironments.

This Special Issue has been designed to commemorate 25 years since the first Spanish scientific meeting of the International Permafrost Association (IPA). Dr D. Palacios and

Dr A. Gómez-Ortiz organized this meeting in 1994 in Madrid. In the same year, the IPA-Spain group was created and integrated as an associate member of the IPA[28,29]. Since then, six IPA-Spain meetings have been organized and, from 2007 (with the creation of the IPA-Portugal group in 2005[29]), the IPA sections of both countries have jointly organized seven Iberian congresses[28,29]. The last congress was held in Jaca (Spanish Pyrenees) in June 2019. Throughout these 25 years a thriving network of scientific collaboration has been developed amongst the researchers integrated in the Iberian section of the IPA[29]. In addition to the aforementioned meetings, this scientific collaboration has led to the publication of several monographic books and special issues in scientific journals[28]. For example, between 2000 and 2017, 230 scientific publications have been counted within the Iberian network of the IPA[29]. These publications involved 198 researchers belonging to 64 different institutions (29 Spanish, 5 Portuguese and 34 from other countries), allowing a considerable advance in the knowledge of the Cryosphere of the Iberian Peninsula[29-31], but also of the polar regions (where Iberian researchers are making significant contributions[13,18,20,27]), and in many other mountainous of the Earth[24,32-34].

Thus, with the purpose of better understanding permafrost and periglacial processes in mid- and low-latitude mountains regions, this Special Issue includes nine studies focusing on a wide and diverse range of specific topics that we have synthesized in three main sections: i) periglacial paleoenvironments, ii) active periglacial processes, permafrost and ground thermal regime, and iii) rock glaciers.

2 | PERIGLACIAL PALEOENVIRONMENTS

The study of paleoenvironments from different perspectives represents one of the classic topics of periglacial research. Two articles focused on this topic have been included in this Special Issue. Rodríguez-Ochoa et al.[35] study relict periglacial soils on Quaternary terraces in the NE sector of the Iberian peninsula, through geochronological, micromorphological and physico-chemical methods. The main results show the existence of various features related to cryogenic processes in the soil profiles.

Viana-Soto and Alberti[36] reconstruct paleotemperatures in northwest Iberia based on periglacial geomorphological evidence, such as block fields, block slopes, rock glaciers and stratified slope deposits. During the coldest part of the Late Pleistocene between 21 and 25 ka cal BP, permafrost and genesis of block fields, block slopes and rock glaciers occurred at elevations above 700 m. Prior to this, before 30 ka cal BP, the prevailing snow conditions favored the formation of stratified slope deposits and genesis of glaciers in all of the mountain systems, although without the presence of permafrost.

3 | ACTIVE PERIGLACIAL PROCESSES, PERMAFROST AND GROUND THERMAL REGIME

The relationship between periglacial processes and soil thermal regime is one of the topics that has been more intensely studied over the last decades. In this Special issue, a number of works have also focused on the monitoring of periglacial dynamics and the activity of periglacial landforms. This is the case of the research article by Gómez-Ortiz et al.[37], focusing on Sierra Nevada, one of the best studied massifs with regards to its past environmental history and current periglacial dynamics. The authors show evidence widespread periglacial conditions in this massif above 2500 m, although permafrost is only present in glaciated environments during the Little Ice Age.

Gjorup et al.[38] studied the local variability of soil temperature and moisture at different depths in three sites along a altitudinal gradient in the Licancabur Volcano (Atacama, northern Chile). Temperature profiles of all study sites are characterized by absence of permafrost, abundant freeze-thaw cycles, greater thermal variations close to soil surface year round, and most soil temperatures readings close to 0ºC.

In the eastern margin of the European Alps Kellerer-Pirklbauer[39] investigated the characteristics and distribution of sporadic permafrost. The main results of this work indicate sporadic permafrost occurrence in the summit sector of the study area, with mean annual temperatures close to 0ºC at the soil surface, and -1.4ºC at 2.5 m depth, as well as the existence of permafrost patches in the transition area between rock glaciers and talus cones. From the projection of statistically significant trends, this work highlights the presumably disappearance of permafrost in the next decades in part of the sites studied.

Tapia Baldis and Liaudat[40] examine the evidence of rockslides and rock avalanches in the Central Andes of Argentina and investigate their possible association with permafrost degradation. Over the long-term permafrost degradation favors a deeper failure process, whereas in the shorter term shallow active layer detachment is favored by shear-displacement along pre-existing joints, as a result of short-term periods of climate warming. It is expected that the magnitude and frequency of rockslide hazards will increase during the 21st century.

Serrano et al.[41] provide a comprehensive review of the periglacial environments and frozen ground in four massifs of the Central Pyrenean high mountain area (Infierno-

Argualas, Posets, Maladeta and Monte Perdido). In these areas, the lower limit of frozen ground is at ~2,650 m a.s.l. and permafrost is dominant above 2,900 m a.s.l. Future projected changes in temperature and precipitation are likely to have a significant influence on high mountain the snow cover and mountain permafrost in this areas.

4 | ROCK GLACIERS

Rock glaciers are probably the best indicators of permafrost conditions in mid- and low-latitude mountains regions[30]. In relict features, the analysis of their morphometric dimensions can reveal patterns of past activity[31]. In this Special Issue, González-Gutiérrez et al.[42] examined the surface macro-fabrics in relict rock glaciers in the Cantabrian Mountains (NW Spain) and shown evidence of the topographical and morphostructure controls on their formation and activity.

The scale of periglacial landscapes in the mountains of North America is highlighted in the paper by Seligman et al.[43], who identify 661 rock glaciers in the Beartooth and northern Absaroka ranges, Montana, USA. Landscapes in these areas are shifting from predominantly glacial to periglacial regimes. As glaciers retreat in response to climate warming, the authors show that rock glaciers could soon become the most important source of ice in the region.

5 | PERSPECTIVES

The nine papers included in this Special Issue cover different areas of mid- and low-latitude mountains regions, both of the Northern and Southern Hemispheres, namely Pyrenees, Sierra Nevada, Ebro Basin, Galician and Cantabrian Mountains in Iberian Peninsula, Atacama and Central Andes in South America, Absaroka ranges in Montana

(North America), and Seckauer Tauern Range in the European Alps. This Special Issue brings together important new information to help judge the effect of past and present-day periglacial morphodynamics in various mountains regions around the globe. Individual studies published here address wide-ranging topics in periglacial paleoenvironments, active periglacial processes, permafrost and ground thermal regime, and also rock glaciers.

These studies have also highlighted knowledge gaps, and many issues still require more attention, such as the need to:

- Substantially improve the knowledge of past periglacial environments, especially regarding geochronology and paleoclimatic implications.
- Examine the periglacial features developed in the lowlands and/or low altitude mountain environments of mid-latitude ranges, which are currently still poorly known.
- Improve our current knowledge of active periglacial processes, permafrost distribution and ground thermal regime in intermediate elevation belts of mid-latitude mountain areas, as well as in the high intertropical mountain ranges, including large stratovolcanoes.
- Increase the monitoring of periglacial mass wasting processes and mechanisms of sediment transfer in mid- and low-latitude mountain areas.
- Further understand the dynamic relationship between glaciers and the periglacial environment, which directly affect paraglacial processes and mechanisms of sediment transfer, especially under a changing future climate.

- Improve understanding of wider geoecological dynamics in response to the climate scenarios anticipating higher temperatures and lower moisture conditions in most of these regions[44].

ACKNOWLEDGEMENTS

The guest editors appreciate the opportunity given by the journal Permafrost and Periglacial Processes, particularly by the editor-in-chief Prof Dr Mauro Guglielmin, to organize this Special Issue on Permafrost and Periglacial Processes in Mid- and Low-latitude Mountains Regions. We would like to congratulate all authors for the research papers submitted and acknowledge all reviewers for their work in reviewing the manuscripts. This work fits within the research topics of the CRONOANTAR (CTM2016-77878-P) and PALEOGREEN (CTM2017-87976-P) projects of the Spanish Ministry of Economy, Industry and Competitiveness, and the NUNANTAR project (02/SAICT/2017 - 32002) of the Fundação para a Ciência e a Tecnologia of Portugal. Marc Oliva is supported by the Ramón y Cajal Program (RYC-2015-17597) and the Research Group ANTALP (Antarctic, Arctic, Alpine Environments; 2017-SGR-1102) funded by the Government of Catalonia through the AGAUR agency.

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