



# JOURNAL

OF THE BULGARIAN GEOGRAPHICAL SOCIETY

## Periglacial landforms and the geological controlling factors: examples from the highest mountains of the Balkan Peninsula

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### ABSTRACT

#### Key words:

frost action, mountains, rocks,  
rock glaciers, screes

Periglacial landforms are typical features of the high mountain environment on the Balkan Peninsula. Their formation and diversity is determined by climatic, topographic and geological factors. Presently active periglacial processes occur above 1700–2000 m a. s. l., while relict features are observed down to 1100–1400 m a. s. l. Among the most prominent periglacial landforms are the extensive talus screes and fans, the numerous rock glaciers (especially in Rila, Pirin, Shar and Prokletije Mountains) – considered mostly relict – and nivation features (nivation cirques, long-lasting snow patches), as well as cryo-clastic landforms (stone seas and strips). The present study aims to focus on the importance of geological conditions (bedrock composition and structure, tectonic settings) for the diversity and style of periglacial landforms – a factor, whose role has often been underestimated. The analysis and the derived conclusions are based mainly on regional and local comparisons between the high mountains throughout the peninsula.

#### Article processing

Submitted: 24 May 2021

Accepted: 06 August 2021

Published: 27 August 2021

Academic editor: Alexander Gikov

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### 1. Introduction

Periglacial landforms are characteristic features in areas where frost heave predominates or was predominating in certain past periods. In a narrow sense, “periglacial” characterizes the regions adjacent to existing (continental or mountain) glaciers. In the broader sense the term is used for all processes and landforms formed under the predominance of frost processes (Glovnia 1959; Rączkowska 2004). In the mountains of the Balkan Peninsula, classical periglacial conditions existed during the glacial phases of the Pleistocene, when mountain glaciers occupied vast areas in the high mountain belt. During those time episodes, periglaciation occurred at altitudes above 1400 m a. s. l. (to the east), to above 1100 m a. s. l. (to the west), as both the glaciers ELA and the lower limit of snow action dropped towards the west with the rising precipitation amounts. The upper limit of periglacial processes reached the highest peaks in the areas above the ELA which were not glaciated (ridges, arêtes, rock walls, sunny open slopes). During the Holocene, and also throughout previous interglacials, when glaciation was limited to a small number of sites of a peculiar topography in the high mountain glaciokarst areas of Prokletije, Durmitor and Pirin, while all other areas were deglaciated, active cryogenesis had been predominating above 1900–2000 m a. s. l. in the eastern areas of the Balkan Peninsula (Velchev, 2020), above 1700–1800 m in the central parts (Nešić et al., 2012) and above 1400–1500 m a. s. l. in the farther west (Perica et al., 2002). However, that altitude drop is most expressed in snow-related processes (nivation, avalanche activity, snow patches), while the lower limit of frost-related processes and forms exhibit much smaller altitude change with longitude, since those are more temperature dependent. Both relict and contemporary forms exist in the high mountain zone.



Cryogenic processes are climatically determined. Crucial controlling factors are the number of days with freeze-thaw cycles, especially the number of water freezing events (as the transition of water into ice is associated with volume increase and enormous mechanical impact on rocks, especially within cracks and fissures), as well as precipitation, especially around temperature transition days. A tiny amount of water in the ground and in rock walls limits the efficiency of frost action. Too much snow, however, is also not favourable for frost-related processes, as thick snow cover isolates the surface from diurnal air temperature variations. In this context, the topography is another important factor on a local scale: periglacialation on ridges and open slopes is much more intense than in cirques and depressions (Gachev, 2017; Mitkov, 2020).

The importance of climate and topography for the formation of periglacial landforms has been discussed in many previous studies (Corte, 1980; Haerberli, 1985; Hughes et al., 2003; Berthling, 2012 and others). At the same time, less attention has been paid to the influence of the geological setting (rock composition, structure and tectonics), which plays a crucial role in the regional diversity of cryogenic features. The geology of the Balkan Peninsula's mountain areas is extremely diverse, which allows us to observe and analyze its essential effects on periglacial landscapes.

The present paper aims to provide an overall review of the typical periglacial features in the mountains of the Balkan Peninsula, and to assess the controlling effect of geology through comparisons between various sites.

## 2. Materials and methods

### 2.1. Study areas

The Balkan Peninsula is located in Southeast Europe. To the west, it is bordered by the Adriatic Sea, to the southwest – by the Ionian Sea, to the south – by the Aegean Sea, to the southeast – by the Marmara Sea, and to the east – by the Black Sea. The northern border, which makes a broad connection to the rest of the European continent, follows the river currents of the Danube, the Sava, the Sora and the Socha (Ivanov, 2018). The relief of the peninsula is primarily mountainous. Geologically, the mountains belong to the Alpo-Himalayan belt. According to morphography, mountains can be divided into several groups (massifs, ranges): the Dinaric range, the Pindus range, the Thrace-Macedonian massif, the Balkan range (Fig. 1). In all these areas, there are mountains that rise above 2000 m a. s. l., and in most of them (except for the Balkan range) the elevation exceeds 2500 m a. s. l.

#### 2.1.1. Dinaric range

The Dinaric range (the Dinaric Alps) is situated parallel to the Adriatic Sea coast, stretching along 590 km from Slovenia to the northwest to the Drin River in Albania to the southeast. The Dinarides comprise three ranges parallel to each other (Kanev, 1990; Ivanov, 2018), the highest being the central one (Prokletije, 2694 m a. s. l.; Durmitor, 2523 m). Other high mountains within this range are Maglič (2389 m), Komovi (2487 m) and Ljubišnja (2287 m). The coastal and northeastern ranges are generally lower. The Dinarides are composed mainly of carbonate rocks (limestone, dolostone, flysch) (Mirković, 1983). Silicate intrusive and metamorphic rocks (granites, gneisses, schists, quartzites etc.) have limited distribution and are exposed on the southeast and the northeast peripheries (the east parts of Prokletije, Kopaonik and others) (Osnovna geološka karta SFRJ, 1981).

#### 2.1.2. Pindus range

The Pindus range appears as a southeastern continuation of the Dinarides, from the Drin fault to the peninsula's southern tip. It consists of three parallel ranges which extend submeridionally: the external Ionian (western), the Gavrovo-Tripoli, and the Pindus (eastern) range (Ivanov, 2018). The former two are relatively low in altitude (with some exceptions, such as the 2130 m high Griba Mountain in southern Albania) and consist of separate, detached massifs. The highest and most compact is the Pindus range, which starts in the north with the mountains of northern and central Albania (Jablanica, 2250 m a. s. l., Tomor, 2417 m), and continues to the south with the massifs of Gramos (2523 m, on the Albanian-Greek border), Tymfi (2483 m), Smolikas (2637 m – the highest within the range). Still to the south, the mountain range crosses the Peloponnese peninsula (Taigetos, 2407 m) and continues to the southeast on the island of Crete (Lefka Ori, 2452 m, Ida, 2458 m, Dikti, 2148 m). The Pindus range is built mainly of limestones, sandstones and schists, while intrusive and volcanic rocks are rare.

#### 2.1.3. Thrace-Macedonian massif

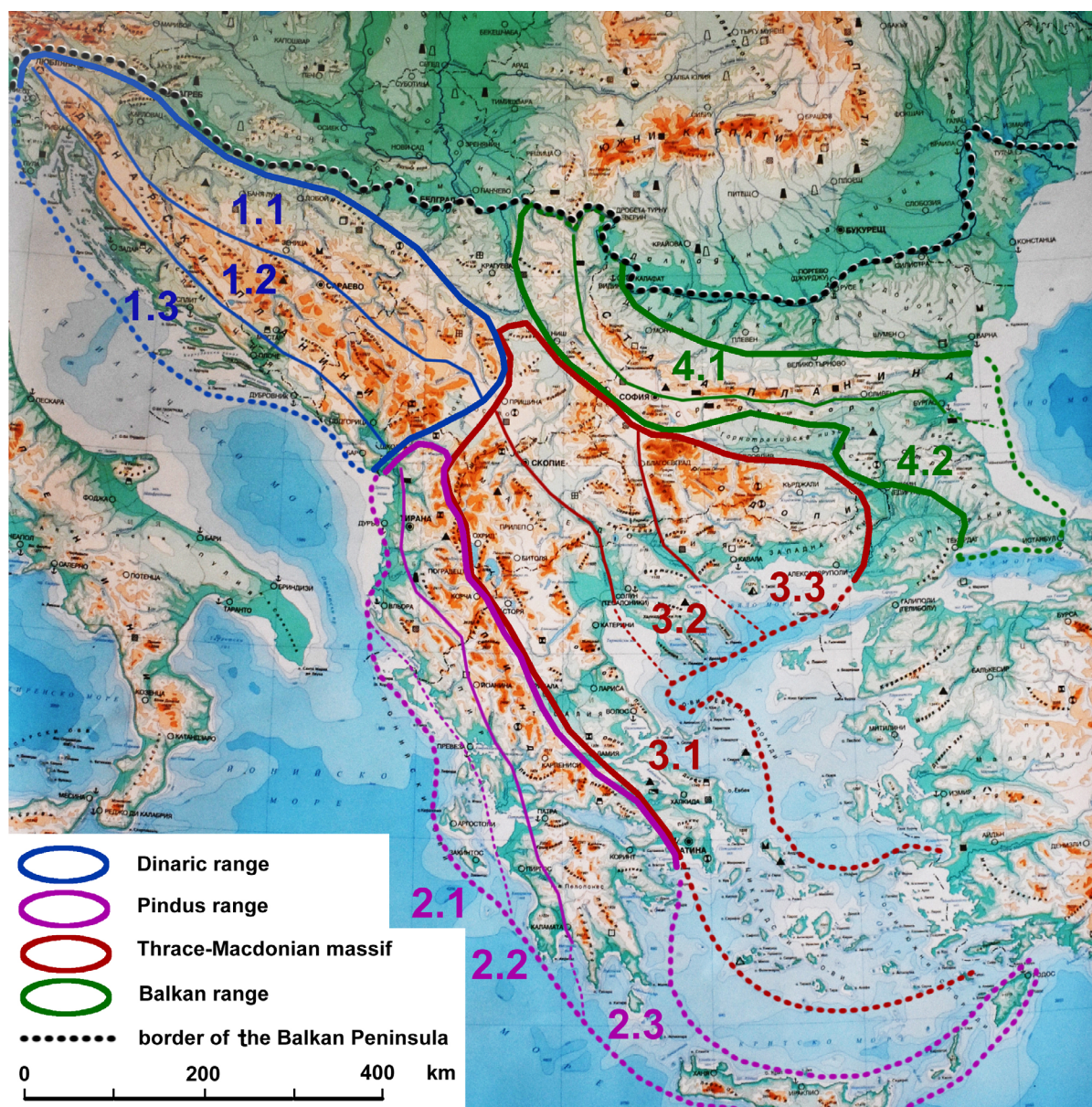
The Thrace-Macedonian massif occupies the whole mountainous space between the Crni Drin and the Aliakmon River to the west, and the Maritsa River to the east. It comprises three parts (massifs), separated by deep faults.

The Pelagonian massif is the westernmost part of the Thrace-Macedonian massif. It lies between the Drin and the Aliakmon River, Ohrid and Prespa lakes to the west, and the Vardar River to the east. To the north is the compact and high system of Šara-Korab-Dešat (Titov vrh, 2747 m a. s. l., Golem Korab, 2754 m, Dešat, 2375 m, Bistra, 2163 m, Stogovo, 2318 m), which runs from NE to SW and delimits the northwestern borders of North Macedonia. South of that range the massif splits into three branches which spread to SSE, and are separated by wide flat depressions (Pelagonia, Campania). The westernmost of these ranges include the mountains of Galichitsa (2288 m), Baba (2600 m) and Vernon (2128 m); the middle range: Nidje (2521 m), Vermio (2027 m) and Olympus (2917 m) – the highest of the Pelagonian massif. The only high mountain that belongs to the eastern range is Kožuf (2171 m a. s. l.). The geology of the Pelagonian massif is incredibly diverse: block-fault structures, which predominate, include gneisses, mica-schists and marbles. Granitic intrusions have been incorporated in numerous folds, while various sedimentary rocks (limestones, shales, sandstones) are also widely present (Ivanov, 2018).

The Dardanian massif is situated between the Vardar and the Struma River. To the north, it includes the mountains of Kraishte (Doganitsa, 1992 m a. s. l.), their southern neighbours, Osogovska mountain (2252 m), Vlahina (1924 m), Belasitsa (2029 m) and the continuation in northern Greece, ending with the mountains of Halkidiki Peninsula (Mt. Athos, 2033 m). The massif mainly consists of metamorphic rocks, silicate in Vlahina and Belasitsa, marble in Mt. Athos. Granitoids compose the eastern dome-like part of Osogovska mountain, while volcanic rocks prevail to the west (Milevski, 2008).

The Rila-Rhodope massif occupies the area between the Struma River (to the west), the Maritsa River (to the east), and the area between the Upper-Thracian plain (to the north), and the Aegean Sea (to the south). This is a vast and relatively compact mosaic of ranges, separated by deeply incised valleys and small or larger depressions. The highest massifs: Rila (2925 m a. s. l. – the highest





**Figure 1.** Main mountain areas on the Balkan Peninsula: 1. Dinaric range: 1. 1. Coastal range; 1. 2. Central range, 1. 3. Northeastern range; 2. Pindus range: 2. 1. Ionian island range; 2. 2. Gavrovo-Tripoli range, 2. 3. Main Pindis range; 3. Thrace-Macedonian massif: 3. 1. Pelagonian massif, 3. 2. Dardanian massif, 3. 3. Rila-Rhodope massif; 4. Balkan range: 4. 1. Stara planina/Predbalkan, 4. 2. Srednogorie.

on the Balkans) and Pirin (2914 m) rise to the west and northwest, neighbored by the Rhodope massif to the east. The southern parts of the Rila-Rhodope massif consists of smaller mountains separated by a mosaic of depressions: Slavyanka (2212 m), Falakro (2232 m), Menikio (1963 m), Pangaion (1956 m), etc. A huge granitic batholith occupies the NW flanks of the massif (central and eastern Rila, NW Rhodopes). Also, three granitic intrusions build up the core of the Pirin horst structure, and two smaller bodies are found in the West Rodopes. Silicate metamorphic rocks are widespread in the Rhodopes, NW Rila and parts of Pirin. The primary carbonate and karstified rock in the Rila-Rhodope massif are marbles (in Pirin, Slavyanka and the West Rhodopes), while limestones are rare. Volcanic rocks (mainly rhyolites) build up large covers in the Central Rhodopes.

#### 2.1.4. Balkan range

The Balkan range stretches from west (northwest) to east in the eastern part of the peninsula, starting from the Danube River (the Iron Gate gorge) and reaching the Black Sea. To the north it is bordered by the Danube (Lower Danube) lowland and to the south – by the Upper-Thracian plain and the Dardanian massif. In general, the Balkan range consists of two parallel ranges: northern (Stara Planina) and southern (Srednogorie), separated by a line of tectonic depressions (hollows). Stara Planina is the higher range, consisting of many interconnected mountains. It culminates at several points: in the central section (Kaloferska Planina, 2376 m a. s. l., Zlatishko-Tetevenska Planina, 2198 m), and to the west (Berkovska Planina, 2016 m, Chiprovska Planina, 2168 m a. s. l.). The Srednogorie range is generally much lower in altitude, with the only exception: the 2290 m high Vitosha massif south of Sofia. The second highest is Suva Planina (1808 m).



## 2.2. Geology as a controlling factor

### 2.2.1. Rock composition

The chemical composition of rocks determines their main weathering mechanisms (Skinner and Porter, 1995). In this aspect, the lithology can be divided into two main categories: carbonate and non-carbonate (silicate). Carbonate rocks are among the very susceptible to chemical dissolution by water and to the occurrence of karst processes (Cholakova, 2018). However, unlike lower altitude zones, due to the decreased solution capacity of cold water, in high mountain carbonate rock environments, physical (frost) weathering competes for the karst processes and even starts to prevail at altitudes above 2500 m a. s. l. on ridges and open slopes, which do not retain snow cover for long (Gachev, 2017; Mitkov, 2020). It should be noted that most carbonate rocks are more resistant to mechanical weathering than many silicate rocks. In some situations this may lead to an “armoring effect” (Kanev, 1988) when carbonate “hats” build up the highest mountain peaks, while the adjacent uncovered areas have been lowered by erosion (such examples are Pirin Mountain in Bulgaria, where the highest areas are built of marble, Komovi Mountain in Montenegro and also Korab Mountains in Albania and N. Macedonia, where domes of limestone rise high above the adjacent areas, made of shale and phyllite rocks predominantly) (Fig. 2). Due to their low mechanical fragmentation, carbonate rocks form vertical cliffs and rough relief more often than silicates. Non-permeability of silicate rocks makes them much more erodible by surface runoff (rain and snowmelt), and more susceptible to frost heave, due to the highest water retention. Magmatic (especially igneous) and high-grade metamorphic rocks are rich in cracks, formed in the process of cooling (Skinner and Porter, 1995). All that leads to greater and faster mechanical fragmentation of these rocks and the formation

of smoother slopes and thick scree covers. The mineral composition of rocks determines the rate and the most effective mechanical weathering ways for each type of rock. Insolation weathering is strongest on intrusive rocks, because they are made of large and often colourful crystals, and quickly start to pile up when exposed barren on the surface (Kurchatov, 2004). Their weathering often produces thick layers of regolith (Kanev, 1990). Volcanic and carbonate rocks are much more resistant to solar action. They usually produce much less and finer elluvial sediments.

### 2.2.2. Rock texture and structure

The presence of stratification in rocks and the crack patterns can have an important impact on the morphometry of relict glacial landforms (Haynes, 1968; Barr and Spagnolo, 2015), and therefore – on the periglacial features which they host. Layered rocks, such as sedimentary and metamorphic ones, often determine landform asymmetry, since in mountains layers are almost always tilted or folded (Fig. 2). Usually, Pleistocene glacial exaration was stronger when layers are discordant to the slope, and strongest in cases where they dip in the opposite direction. This is because layer boundaries created additional friction to glacier ice in the accumulation zone, and ice had to accumulate in much larger amounts before starting a downward movement. In such conditions, glaciers moved slower and tended to overdeepen the ground, producing deeper cirques and steeper slopes, respectively (Stoyanov and Gachev, 2011). On the opposite, when rock strata were parallel to the slope, and when the contact between layers was weak, the accumulating snow easily slid down and was unable to exert much exaration effect on the surface. Granite and other intrusive rocks, which lack stratification, provide conditions for a more symmetrical relief. Landform diversity in that case is more dependent on the tectonic setting and climate.



**Figure 2.** Formation of slope cliffs and talus in a monocline structure and alternating rocks (limestone and shale): Korab Mountains, North Macedonia. “Armoring effect” of limestone, which build up the highest peaks.



### 2.2.3. Tectonic structure

Devoid of rock composition or chemistry, the spatial configuration and expression of faults, as well as dykes or rock contact surfaces, determine to a great extent the diversity of landforms at local scale. Faults represent weakened zones of various width, where all types of weathering and denudation have been enhanced. These zones are presented by linear negative forms (gullies, passes) which concentrate falling debris, avalanches, and debris flows. Downstream those usually end with accumulation fans of various sizes.

### 2.3. Methodology

Data for the purposes of the study was collected during numerous field expeditions in Rila, Pirin, Prokletije, Durmitor, Korab, Shar, Stara Planina, Osogovska Planina, Belasitsa, Kopaonik, Olympus and other mountains on the Balkan Peninsula. During those expeditions, geomorphology mapping, photographing and measurement of landforms was performed. For this purpose, topographic maps and satellite images were used. Bathymetry maps were elaborated to study the underwater topography of Ledeno and Hridsko lakes, using a boat, sonar, GPS, and compasses (Gachev et al., 2008; 2019) (Fig. 3). Determination of rock glaciers and other periglacial landforms was also done by analyzing satellite images, while sets of geology maps were used to study and reveal the geological conditions. Relative dating of rock glaciers was done with the use of type N Schmidt hammer (Gachev, 2018). The obtained data was imported, analyzed and visualized in ArcGIS. Along with fieldwork data, information from numerous previous studies (case studies, as well as inventories) of other scientists was used.



**Figure 3.** Bathymetry mapping of Hridsko Lake (Bogićevića Mountains, Montenegro), July 2017.

## 3. Results of periglacial landforms and their diversity

### 3.1. Cryo-gravity landforms

#### Rock glaciers.

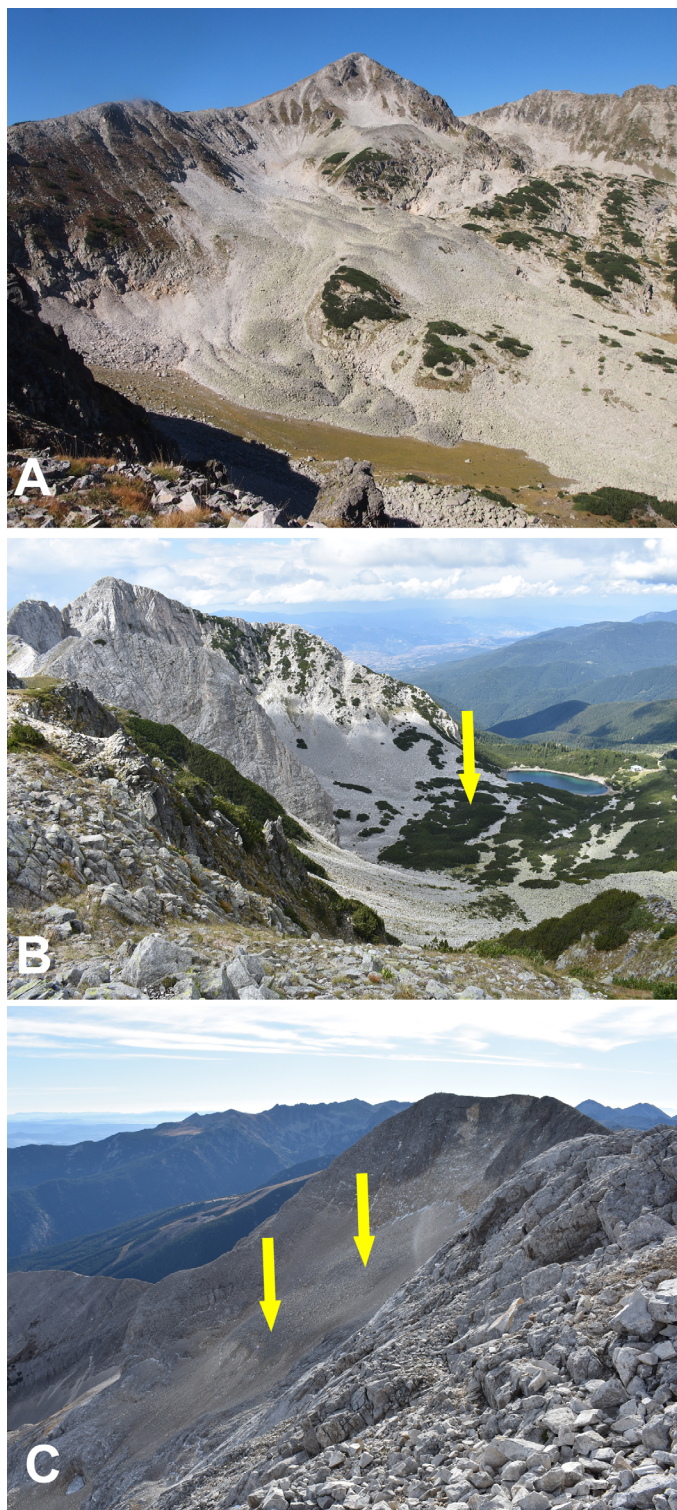
These are masses of coarse angular debris that can have the external appearance of small glaciers and, owing to their large non-ice component, retain much of their morphology long after they were active (Fig. 4, 5). They commonly display steep fronts and transverse surface ridges, possibly the product of the differential movement of discrete layers of debris (Hughes et al., 2004; Loewenherz et al., 1989). On the Balkan Peninsula, the presence of rock glaciers was documented for the highest mountains of the Rila-Rhodope massif: Rila (Glovnia, 1968; Gikov and Dimitrov, 2010; Dimitrov and Velchev, 2011; Gachev et al., 2017), Pirin (Dimitrov and Gikov, 2011; Gachev, 2020), for parts of the Pindus range (Tymphi massif – Hughes et al., 2004), in Shar and Korab Mountains (Kuhlemann et al., 2009), and the central and eastern parts of Prokletije (Palmentola et al., 1995; Milivojević et al., 2008; Gachev, 2018), mainly at the foot of northern, northwestern and northeastern rocky cirque slopes. The highest number of these impressive and relatively large landforms has been documented for Pirin and Rila Mountains (Fig. 4): about 122, according to the studies of Magori et al. (2017) and Onaca et al. (2020), situated between 2700 and 2060 m a. s. l., while Pirin has the highest number: 83. Most of them are found in the central, granitic section of the largest, northern part of the massif, and a smaller number have been formed in metamorphic silicate rocks (mainly gneiss). In the highest section of Pirin, which is built of marble, rock glaciers are almost lacking, despite the favourable altitudes and slope exposures. The reason should be sought in the karstification of the soluble carbonate rocks, which drained most of the groundwater and thus prevented internal ice formation in the pores of debris accumulations. Marble is a carbonate rock, but at the same time it has crystalline properties, which makes it susceptible to frost weathering. In fact, marble fragments into blocks suitable for rock glacier formation, and this is illustrated by two rock glaciers on the margins of the marble part of the mountain (in Razlozhki Suhodol and Sinanitsa cirques), where marble block deposits lie on water-impermeable rock (granite, gneiss) (Mitkov, 2020; Gachev, 2020). Apart from those, just two small lobate ridges on the northern slope of Kutelo Peak (2908 m), at altitude of about 2850 m, could be categorized as talus rock glacier.

Rila Mountain comes second by number of rock glaciers, with 55 recorded so far (Gikov and Dimitrov, 2010; Gachev et al., 2017; Onaca et al., 2020) at altitudes between 2710 and 2096 m a. s. l. Most rock glaciers are formed in granite, while a much smaller number – in gneiss. The Brichebor ridge of Central Rila, which is predominantly of schists, is completely lacking rock glaciers, despite the well-developed cirques. The reason is the way schists fragment due to frost weathering: into small and flat tiles which pack densely while accumulating on the slope foot, leaving too small pore space.

Many rock glaciers exist in the eastern part of Prokletije, mostly in magmatic and silicate metamorphic rocks which produce relatively large angular debris: gabbro, serpentinite, quartzite (Fig. 5). At the same time, rock glaciers are lacking in the adjacent areas built of schists, marbles and limestone.

Rock glaciers in limestone are documented in the Dinaric and the Pindus mountain ranges, also in Korab Mountains, but they are generally very few compared to the vast area of limestone mountain lands. Similar to marble, limestone is a carbonated water-soluble rock, which is deeply karstified, especially in conditions of high winter precipitation. Limestone is less prone to frost weathering than marble, most often fragments into small (even pebble size)





**Figure 4.** Rock glaciers in Pirin: A – Polezhan rock glacier, the highest; B – Sinanitsa rock glacier; C – talus lobes below Kutelo Peak.



**Figure 5.** A rock glacier in quartzites at the foot of Ujkov Krš, eastern Prokletije Mountains, Montenegro. Note the smoothness of the adjacent grassy slopes made of schists.

debris, and accordingly, does not produce rock glaciers in normal conditions. Most of all, rock glaciers do exist in limestone massifs. Still, for their formation, they require special geological conditions: the presence of a layer of impermeable (non-carbonate) rocks below the limestone debris accumulations. Such relatively rare conditions exist where limestone rocks contact with flysch from below. Although Dinaric flysch contains a large proportion of limestone, it is often sandwiched between tiny layers of siltstone or sandstone. Such layers, when placed sub-horizontally, often form floors of glacio-karstic depressions and proper surfaces upon which the limestone slope colluvial debris mass can slide with the trapped and frozen water inside.

#### *Talus scree and fans.*

Talus deposits are widespread in periglacial areas, as cryogenic activity is greater on ridge tops and surfaces, and open slopes. Controlling factors for their formation are barren rocky surfaces, the slope tilt (the steeper the slope, stronger the denudation) and the abundance of cracks due to tectonic reasons. Best conditions are provided on the steep slopes of relict glacial cirques. Scree deposits are accumulated mainly at the foot of rock walls and fans are formed at the lower ends of slope gullies, where falling debris concentrates the most.

Geologically determined differences in the appearance, structure, and abundance of scree deposits, are due to rocks' different structural and chemical properties (Fig. 6). Limestone is very resistant to both insulation and frost weathering. It generates small (down to pebble) size debris, which has low mass and inertia. On the other hand, the strong chemical dissolution of those rocks, in combination with glacial action, has caused a widespread formation of very steep to vertical cliffs and escarpments (more than on any other type of rock), which stimulated debris downfall concentration as thick scree depositions at the slope feet. As a result, vast rectilinear small particle scree covers have been deposited at the bases of cirque walls. They are usually very dense, with small pore spaces inside, and, consequently, are poor of groundwater. Larger block deposits in limestone form as the result of simultaneous rockfalls (after earthquakes or tectonic slope weakening).

Although it has the same chemical composition, marble has different structural properties due to the partial metamorphic recrystallization. During that process, the former limestone obtained a compact massive structure, which caused blocky cracking when the rock was exposed to atmospheric pressure. That is why marble is susceptible to frost weathering when near the surface and produces





**Figure 6.** Slope screes: A – in limestone, Velika Kalica cirque, Durmitor; B – in marble, Golemiya Kazan cirque, Pirin; C – in granite, Musala, Rila.

coarse angular debris. The latter may be consequently subject to karstification by rain and snow waters.

Granites and other coarse-grained magmatic rocks are abundant of cracks at relatively right angles. They tend to produce blocky debris (from 30–50 cm to several meters in diameter) with a generally cubic shape. In coarse-grained metamorphic rocks or compact non-carbonate sedimentary rocks (sandstone, conglomerate), which have natural layers, blocks tend to have a rectangular prismatic form rather than cubic, but still have large sizes.

Schists, phyllite and shale are other cases: as they disintegrate into tiny flakes, their deposits are compact and smaller in thickness for the same volume of denuded rock. Usually, glaciers could not produce steep slopes in such mechanically weak rocks, which decreases the size and spread of slope foot screes, as most of the weathered material stays on the slope.

#### *Stone seas and rivers.*

These features have formed on ridge tops and open slopes, where slope tilt is low enough to prevent debris from rolling or sliding down. Such landforms are most typical for granite and other coarse-grained intrusive rocks (Fig. 7). Such rocks are simultaneously subjected to both insolation and frost weathering, so in order to produce in situ stone accumulations, fine grain weathering products must be constantly removed. In this context, their formation is stimulated by retaining thin drifted snow, which prolongs the seasonal period of frost action. Wind also plays a morphogenetic role on summit surfaces. It redistributes the fine products of mechanical weathering and maintains some surfaces barren (it in such places where stone rivers and seas form). On other sites, where fine grains are accumulated, thick regolith covers are formed.

Stone seas and rivers are not common in hardly fragmentable, fine-grained and karstified rocks. As a result of weathering, fine-grained rocks such as schists form soil cover directly, and exposed limestone, dolostone or marble surfaces dissolve rather than disintegrate, while the clay, which remains after dissolution, serves as a substrate for soil formation.

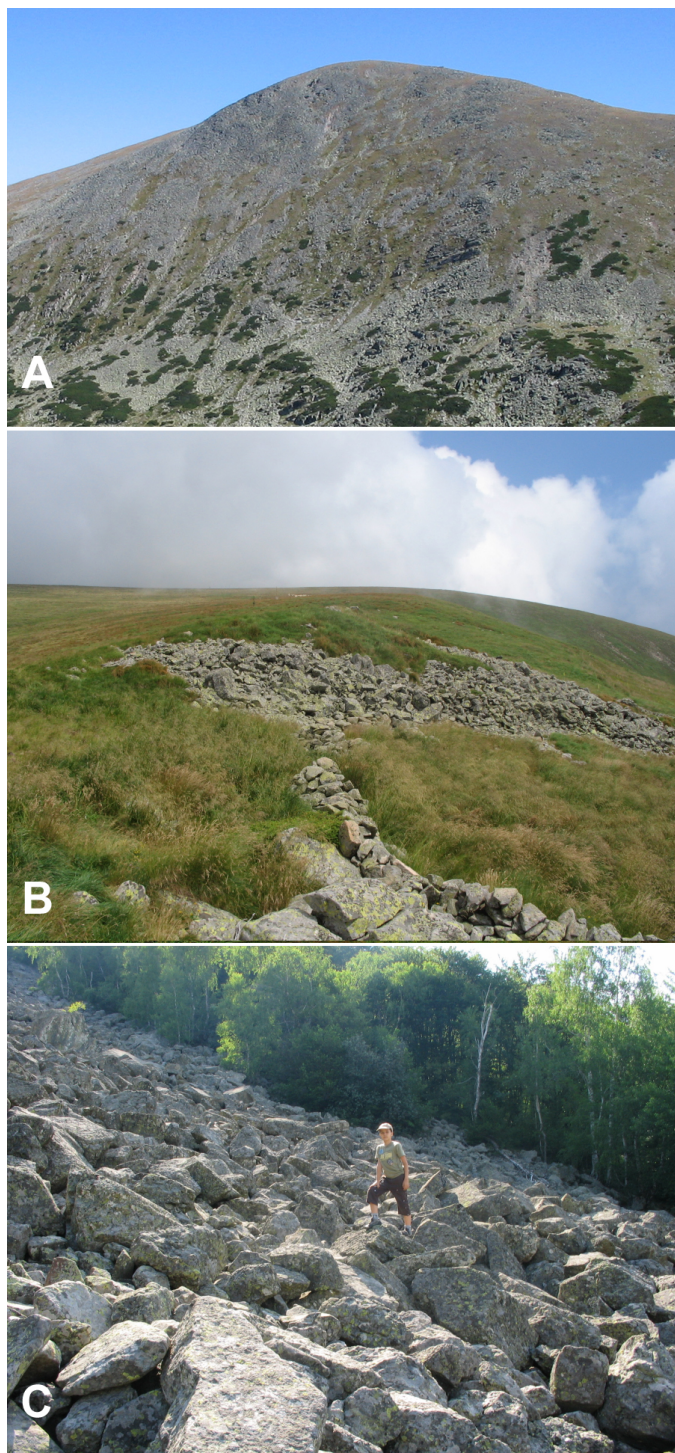
#### *3.2. Cryo-solifluction landforms*

These landforms require a developed soil cover and seasonally frozen ground below. They are observed primarily on areas made of silicate rocks, especially those prone to accumulation of water. They are not typical for karstic areas unless some special conditions are present (e.g. presence of flysch layers).

#### *3.3. Long-lasting snow patches*

The presence of long lasting (throughout summer) snow patches is considered a characteristic of periglacial conditions. Contrary to the solifluction landforms, such sustainable (even permanent) snow patches are much more abundant in mountains made of carbonate rocks. Several reasons can be pointed out for this: the lighter colour of exposed carbonate rocks, which reflects more solar radiation and absorbs less heat as a result; the generally steeper slopes in glacio-karstic terrains due to the vertical dissolution of rocks, which provide better shading and better concentrate avalanche snow on cirque floors; the drainage of snow meltwaters in karst caverns, which hinders basal melt of snow. Other prerequisites are the high altitude, which provides low enough temperatures throughout the year, and precipitation, especially in winter. Long-lasting snow patches are more common in Prokletije, and not so much in Pirin, Durmitor and Olympus. Despite the very high altitude, snow in Rila melts almost entirely in summer, except for a snow patch above Bliznaka Lake in the Seven Rila Lakes cirque. After cooler summers, numerous snow patches in the granitic parts of Rila and Pirin remain until the new snow in autumn.





**Figure 7.** Stone seas: A – in granites – in Rila (Deno Peak); B – Stara Planina (Vezhen Peak); C – in andesites in Vitosha.

#### 4. Conclusion

Periglacial landforms are prevalent in the present day subalpine and alpine zones of the Balkan Peninsula mountains. However, the variety of forms and their style differ significantly based on bedrock composition and tectonic setting inequalities. According to the differences observed in the mountains of the Balkan Peninsula, two main types of periglacial environment can be outlined: carbonate and silicate (non-carbonate). Silicate environments have a greater diversity of periglacial landforms. In contrast, carbonate environments provide a greater range of conditions: some landscapes have cryo-nival to almost glacial properties, while others are pretty warm and dry. Another important contrast is between coarse-grain and fine-grain rocks. The former provide better conditions for the formation of cryo-gravity landforms, while the latter – for cryo-solifluction forms.

The widespread relatively high mountains on the Balkan Peninsula, as well as the great diversity of environmental conditions, makes it possible to assess the influence of geology on landforms, based on regional and local comparisons.

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