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EMIL GACHEV, KRASSIMIR STOYANOV (BLAGOEVGRAD)

PRESENT DAY SMALL PERENNIAL FIRN-ICE PATCHES IN THE MOUNTAINS OF THE WESTERN BALKAN PENINSULA

Abstract. This article contains descriptions of the most significant contemporary firn-ice patches of the Albanian Alps (Prokletije) and the Durmitor. These two mountain ranges form the highest part of the Dinaric Alps and, besides the Pirin Mountains (in Bulgaria), are the only places on the Balkan Peninsula where perennial firn-ice patches have been discovered. The article gives a brief review of previous studies on the topic and presents the results of an expedition of the authors to both mountain ranges in the autumn of 2011.

In the Albanian Alps we recorded the existence of at least 6 persistent firn-ice patches situated at altitudes between 2280 and 2520 m a.s.l., four of which had distinct characteristics of glacierets. The other two had tongue-shaped lower ends but still more research is needed to prove if they can be categorized as small mountain glaciers. All firn-ice patches in the central part of these mountains have reduced their size since 2007–2008 (Milivojević et al. 2008, Hughes 2009), and the largest one mentioned in the previous studies — Maja e Koljaet glacier, was found to be extinct in 2011.

The only perennial ice body in the Durmitor Mountains of Montenegro, the Debeli Namet glacier, is still recognized as the only small glacier in the Balkans. In October 2011 it was measured to have an area of 2.7 ha, which is less than in 2005–2007 (Hughes 2008) and more than in 1998. For the last 14 years the glacier has shown substantial variation of its area and volume, partly due to the specific morphology of the glacier bed.

Key words: glacieret, small glacier, Albanian Alps, Durmitor

INTRODUCTION

Although small in size and mass, perennial firn-ice patches are undoubtedly a real phenomenon in the present day high-mountain environment of Southern Europe, and in that respect the Balkan region is not an exception. Numerous studies of the two perennial firn-ice patches in the Pirin Mountains (Bulgaria) (Popov 1964, Grunewald et al. 2006, 2008; Grunewald, Scheitchauer 2008, 2011; Gachev 2009, Gachev et al. 2009, Gache, Gikov 2010; Gachev, 2011), and the drillings done in 2006 (Grunewald et al. 2008, Grunewald, Scheitchauer 2008, 2011) provided evidence that these forms have persisted without a complete melt at least since the 15th century. Using georadar sounding of glacierets in the High Tatras, B. Gądek and A. Kotyrba (2003, 2007) discovered buried layers of sediment disposed in a pattern reverse to the slope inclination, which they explain with the presence of dynamic downward movement of the firn mass. Although still not proved, similar hypothesis exists for Snezhnika in Bulgaria (Grunewald, Scheitchauer 2008, 2011). On the basis of these findings all mentioned researchers have accepted the term "microglaciers" (German: "Mikrogletcher") or "glacierets" for such persistent small firn-ice patches.

At present, forms of this type are found also in some of the mountains in the western Balkans. There the climatic conditions are more favourable for glacier survival than in the eastern part of the peninsula. This mostly concerns the high mountains near the Adriatic coast with abundant precipitation. The existence of small firn-ice patches has so far been confirmed in just two of the high-mountain ranges in this region: the Albanian Alps (Prokletije, 2694 m a.s.l.), and the Durmitor (2522 m a.s.l.). At the same time, no such forms have been found in the highest massifs of Mt. Korab (2754 m a.s.l.) and Šara (2747 m a.s.l.) or in the mountains of Greece.

The need to know more about the present day small firn-ice patches in the mountains of Southeastern Europe, as well as the idea to make a direct visual comparison between these features in the Western Balkans and Bulgaria, inspired us to undertake a field trip in the Albanian Alps and the Durmitor in the beginning of October 2011 which resulted in an up-to-date description and review of perennial firn-ice patches in those mountains. Based on this new information we partially confirm previous findings, but evidenced some new facts that require a discussion.

From a scientific point of view it is good that our visit took place after one relatively dry and warm summer, when firn-ice patches were "in a retreat" in comparison with the last two years (especially for the Durmitor this has been confirmed by the images present in Google Earth's "Panoramio").

SMALL FIRN-ICE PATCHES IN THE ALBANIAN ALPS

The Albanian Alps (Albanian: *Bjeshkët e Nemuna* or *Alpet Shqiptare*, Serbian: *Prokletije*) rise impressively between the tectonic depression of Lake Shkodra (Skadar) (to the SW), Metohija Basin and the valley of Beli Drin (to the SE), the valleys of the rivers Moraća and Lim (to the NW), and the valley of the Ibar River (to the NE). The main ridge has a complicated pattern and and runs in a SW-NE direction (Fig. 1). The Albanian Alps consist of several ridges that converge in the centrally located massif of the highest peak named Maja e Jezerces (Jezerski vrh, 2694 m a.s.l.). The largest part of these mountains is situated in Albania, just a section of the northern slope (highest: Zla Kolata peak,

Fig. 1. A map of the Albanian Alps

2534 m a.s.l.) belongs to Montenegro, while the eastern periphery (Djeravica peak, 2656 m a.s.l.) falls within the borders of Kosovo.

The southwestern part of the Albanian Alps is built up of Mesozoic limestone and dolomite, while north-east of the Vermosh-Tropoja line silicate metamorphic rocks prevail. The strong glaciation of the Albanian Alps during the Pleistocene (the snow line dropped down to 1750 m a.s.l., Milivojević et al. 2008) in combination with the tectonically reworked bedrock has produced probably the roughest mountain topography in Southeastern Europe (Fig. 2). In the highest elevations, the ridges have been turned to arętes, and solitary peaks often resemble inaccessible rock needles. The mountain is dissected into several ranges by very deep glacial valleys: Ropojana, directed north towards the Montenegrian towns of Gusinje and Plav; the Valbona Valley, heading to the east; and the Theth Valley, opened to south-west. The combination of severe frost weathering and karstification has lead to a further defragmentation of relief and formation of vast areas of barren rock and debris that dominate the present-day high mountain landscape.

There is little data about climate in the Albanian Alps. On the basis of the annual air temperature at the Vermosh station (6.7°C at 1152 m a.s.l. at the northern foot), Palmentola et al. (1995) estimated the temperatures at an altitude of 2000 m a.s.l. to be about +1.6°C, about –1.3°C at 2500 m a.s.l., and about –2.5°C at 2650 m a. s. l. According to the data of the Albanian Academy of Sciences (Fjalor enciklopedik shqiptar 1985; Gjeografia fizike e Shqipërisë 1990) the Albanian Alps are among the wettest places in Europe. An average precipitation of 3033 mm was recorded at Boga village at the SW flank of the massif (we have no data about the measurement period). For the highest mountain parts precipitation totals of about 2000 to 2500 mm/y are assumed. Data shows that precipitation decreases considerably towards NE

Fig. 2. Albanian Alps — a panoramic view to the NW from Maja e Jezerces peak. In the centre — the cirque Buni i Jezerces and Karanfili ridge

where the valleys and hollows receive around 1000 mm per year (Andrijevica, 1024 mm).

The karstified part of the mountains has a deficit of surface waters but several lakes are present. The biggest group, of 6 lakes, is situated in the cirque of Buni i Jezerces at 1745–1792 m a.s.l. The largest and deepest one, Veliko Jezero, reaches a maximum area of 4.5ha (Milivojević, Kovaćević-Majkić 2005), but often dries completely in the summer. Of this group only the lowermost lake is permanent.

The Albanian Alps are relatively poor in vegetation. Deciduous forests on the northern slope reach 1700 m a.s.l., and scattered groups of black pines are spread to about 1800 m a.s.l,. Above this altitude vegetation (including grasses) is sparse.

The glacial morphology of these impressive mountains has not been well recognized. The presence of a relict glacial relief was mentioned by J. Cvijić (1913). The first description of permanent ice in the Albanian Alps was given by K. Roth von Telegd (1923) who mentioned numerous firn-ice fields in the vicinity of Maja e Jezerces peak, the largest one being about 1 km long. More recently the problem has been discussed in a rather limited number of works. G. K. Palmentola et al. (1995) published notes about the rock glaciers. Researchers from the University of Belgrade (Milivojević et al. 2008) mapped and provided a detailed description of the relict and contemporary glacial forms at several locations in the Albanian Alps. They reported the presence of one "active glacier" with an area of 4.5 ha and two "active rock glaciers" in the cirque of Buni i Jezerces. In the adjacent cirque of Llugu i Zajave, situated to the east of Maja e Jezerces peak, they registered two more "active small glaciers", occupying the area of 2.4 ha and 2.2 ha, respectively. P. Hughes (2009) confirmed these findings, at least with respect to the small glaciers. He mentioned one more small glacier in the Llugu i Zajave cirque (with an area of 4.9 ha), and at the same time expressed doubt about the presence of presently active rock glaciers.

During our expedition in the autumn of 2011 we ascended to the highest peak of the Albanian Alps — Maja e Jezerces (2694 m a.s.l.) from the town of Gusinje (the valley of the river Lim, Montenegro) passing through the great northern cirque Buni i Jezerces (Fig. 2), where, according to the previous studies, Maja e Koljaet — "the largest glacier on the Balkans" should have been situated at the bottom of the cirque, at 1980–2100 m a.s.l., right on the tourist path. In 2011, at this place we found only a small spot of snow (approx. 50 × 100 m) that filled the bottom of a doline (Fig. 3, 4). What we saw put a question mark on whether Maja e Koljaet can be referred to as an active glacier, or even a glacieret, as in this case the typical morphology of these forms is lacking. Here we do not doubt the scientific value of the studies made in 2008 and 2009, as it is clear that at that time the form existed and was of a much greater size (as evidenced by painted marks on the rock 4 m above the rocky ground). However, the specific location of the snow spot under the summit of Maja e Koljaet peak (not at the base of a rock wall but at cirque bottom, below the slope screes) does not have the potential for the development of a firn-ice patch of a considerable thickness, and the low inclination of the surface makes dynamic movement of ice unlikely even when the snow patch remains relatively large in summer. Therefore we suggest that under present conditions at this place a long-lasting snow patch is more likely to exist than a glacier.

On the other hand, in October 2011 the two glaciers in the cirque Llugu i Zajave (under the NE wall of Maja e Jezerces), mentioned by M. Milivojević et al. (2008) were in good condition. These forms are situated at the base of high north-eastern rock walls. In our opinion however, these are glacierets rather than glaciers, and their morphology is almost identical to that of the Snezhnika glacieret in Pirin: — with a slope of about 35–40°, straight profile of

Fig. 3. A snow patch under Maja e Koljaet peak — the remnant of "the largest glacier on the Balkans"

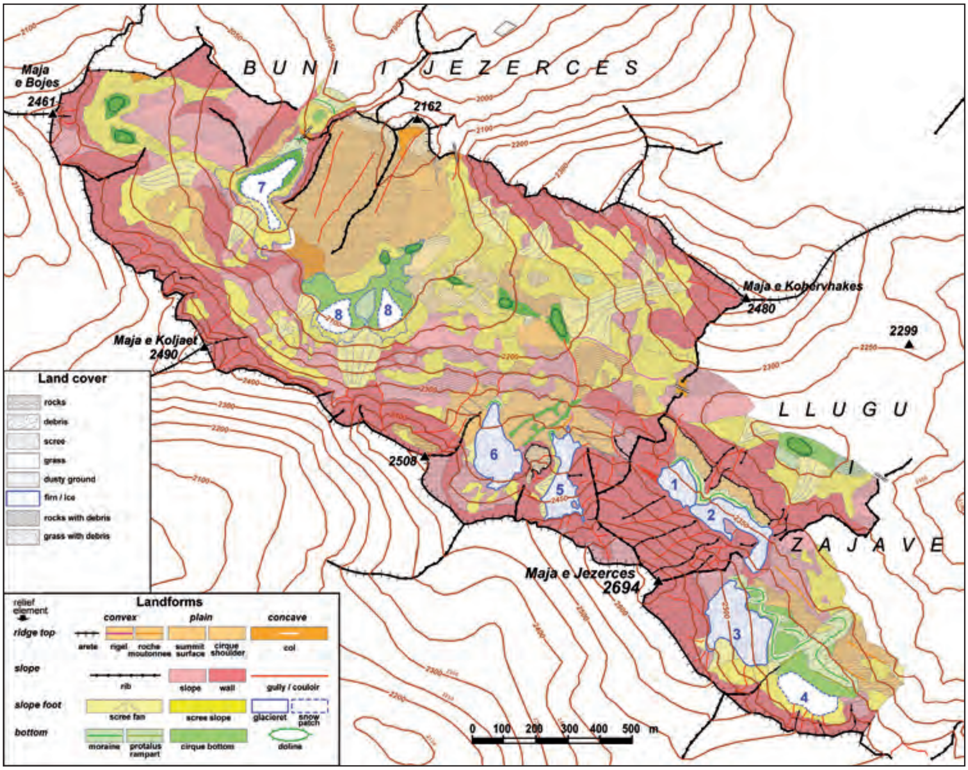

Fig. 4. A morphology map of the upper parts of the cirques Buni i Jezerces and Llugu i Zajave with the snow/firn-ice patches as seen in October 2011. Snow/firn-ice patches: 1 — Maja e Jezerces I; 2 — Maja e Jezerces II; 3 — Maja e Jezerces III; 4 — Maja e Jezerces III — southern patch; 5 — Maja e Jezerces IV; 6 — Maja e Jezerces V; 7 — Maja e Koljaet; 8 — patches under Maja e Koljaet

the firn surface, and a crack (bershgrund) on the back side (see the picture in E. Gachev (2011)). Each one of these glacierets is much bigger than the Snezhnika glacieret, but this mostly concerns the width, not the length (Fig. 4). We confirmed the observation of P. Hughes (2009) of the presence of a third firn body in the Llugu i Zajave cirque, situated at the base of the eastern wall of Maja e Jezerces (Maja e Jezerces III). The said author described it as "a glacier", but again, we consider that it has more the appearance of a large glacieret. P. Hughes (2009) mentioned Maja e Jezerces III to have had an area of almost 5 ha, but in 2011 it was split in two separate parts and the southern, smaller part resembled a snow spot. As we saw Maja e Jezerces III only from a distance, a closer inspection is needed to accurately determine the type of this form.

We mapped another glacieret at the base of the NW wall of Maja e Jezerces peak — Maja e Jezerces IV (Figs. 4 and 5). It is located in a small hanging cirque, in a rocky depression of an irregular shape. Most likely it has not been mentioned before, as it lies on a terrace above the cirque bottom and cannot be seen either from the summit point or from the tourist trail.

Fig. 5. The glacieret Maja e Jezerces IV. a) a photograph from 6th of October, 2011; b) a fragment of the moraine with two parallel ridges

Further to the west, just below the col connecting Maja e Jezerces peak with its western neighbour – a nameless summit with a height of 2508 m, we observed another firn-ice patch of a relatively large size – Maja e Jezerces V (Fig. 6a, 6b). Its lowermost part cannot be seen from Maja e Jezerce's summit point. On the satellite image of Google Earth however, one can see that this part is formed as a small "tongue" that ends at a crescent-shaped moraine. Up to now Maja e Jezerces V can be considered the only firn-ice patch in the massif of Maja e Jezerces that has the appearance of a small glacier rather than that of a glacieret. In 2011 we did not have the possibility for an approach that would have enabled us to confirm this observation.

It appeared (Tab. 1) that in October 2011 the described small firn-ice patches were much smaller in size than it had been noted by M. Milivojević et al. (2008) and also by P. Hughes (2009). The greatest shrinking is registered for Maja e Koljaet glacier – the area in the autumn of 2011 was 70% smaller than in 2008. For the glacierets Maja e Jezerces I and II (which are in fact one), the overall size decrease is estimated at about 17%, and for the Maja e Jezerces III – about 10%.

The panoramic view from the summit point of Maja e Jezerces in one of the driest periods of the last several years revealed the presence of many snow spots on the northern slope of the massive Maja e Popluks (2569 m a.s.l.) within the Buni i Gropavet cirque (south of the summit of Maja e Jezerces). Almost all of them resembled typical couloir patches – no moraine ridges were observed. According to M. Milivojević et al. (2008) all these patches vanish in extremely dry and warm summers. A regular, long-term (several years) observation is needed to categorize these snow patches more precisely.

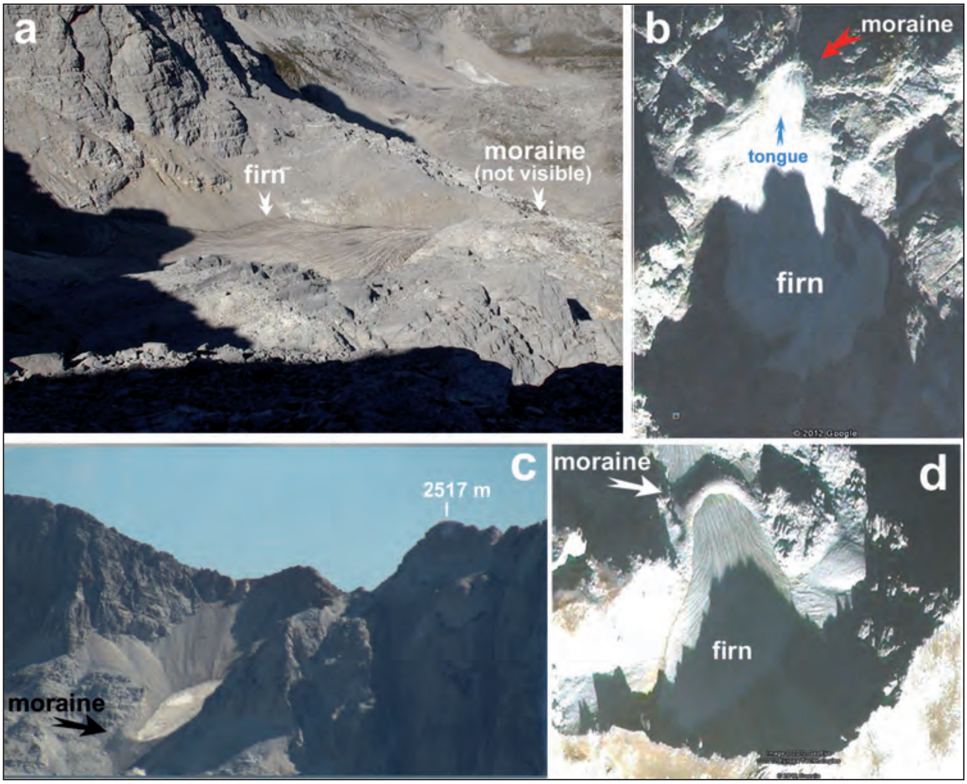

Fig. 6. The suggestible small glaciers Maja e Jezerces V and Mertur. a – a photograph of Maja e Jezerces V from Maja e Jezerces summit point; b – Google Earth's satellite image – 29.10.2006; c – a photograph of the firn-ice patch in the ridge of Mertur from Maja e Jezerces peak, d – Google Earth's satellite image – 29.10.2006.

Far to the southeast, across the deep Valbona Valley, in the highest part of the northern slope of the massif of Mertur (Maja e Made) we noticed a large firn-ice patch, surrounded by a distinct crescent moraine (Fig. 6c, 6d). The patch lies about 1 km east of the highest point of the ridge of Maja e Made (2576 m a.s.l.), and to the NE of a nameless peak with an altitude of 2517 m a.s.l. It is quite well visible on the satellite image of Google Earth from October 2006, and has the appearance of a small glacier with a short tongue. Its approximate area, calculated on the basis of this image, is about 1.7 ha.

Most firn-ice patches are located in positions with N to NE aspect (Tab. 1). This shows that strong shading is among the leading factors for the all year long persistence of snow and ice in the Albanian Alps. Only Maja e Jezerces III faces east but it is also shaded from the south by a high mountain ridge. A contribution of windblown snow is expected for the glacierets located north-east of Maja e Jezerces peak, as the peak has the shape of a truncated pyramid with a flat surface at the top.

Table 1

Parameters of some small firn-ice patches in the Albanian Alps for the autumn of 2011, derived from calculations on the basis of Google Earth imagery (2006) and ground photos (2011). Size is given in real (not projected) surface assuming average slope of 33° (numbers in the first column correspond to the legend of Figs. 4 and 7)

No	Feature	Location	Coordinates		Type	Altitude a. s. l. [m]	Aspect	Size		
			Latitude N	Longitude E				Length [m]	Width [m]	Area [ha]
1	Maja e Jezerces I	NE from M. e Jezerces	42°26’43”	19°48’55”	Glacieret	2320–2380	NE	123	147	1.34
2	Maja e Jezerces II	NE from M. e Jezerces	42°26’40”	19°49’03”	Glacieret	2320–2410	NE	157	222	2.33
3	Maja e Jezerces III	SE from M. e Jezerces	42°26’28”	19°49’03”	Glacieret	2400–2570	E	188	271	2.91
4	Jezerces III snowpatch	SE from M. e Jezerces	42°26’22”	19°49’13”	Snow patch	2365–2390	NE	93	201	1.50
5	Maja e Jezerces IV	NW from M. e Jezerces	42°26’43”	19°48’39”	Glacieret	2345–2520	NNW	346	105	1.86
6	Maja e Jezerces V	W from M. e Jezerces	42°26’46”	19°48’30”	Small glacier?	2320–2420	N	290	153	2.35
7	Maja e Koljaet	N from M. e Kojlaet	42°27’13”	19°47’57”	Snow patch	2070–2120	NNE	150	70	1.65
8	M. Koljaet snowspots	NE from M. e Kojlaet	42°27’00”	19°48’11”	Snow patches	2090–2120	N	116	135	1.54
9	Maja e Popluks	N from M. e Popluks	42°25’56”	19°48’00”	Snow patch	2280–2520	N	315	66	1.08
10	Maja e Made (Mertur)	E from M. e Made	42°23’56”	19°53’02”	Small glacier?	2320–2480	NNW	230	140	1.72

Unlike the melt of Maja e Koljaet glacier, we must emphasize the good condition of all other firn-ice bodies described above. In October 2011 the snow on their surface looked quite white, showing no traces of intensive melt, while a month earlier the Snezhnika glacieret in the Pirin Mountains looked dirty, and snow layers from several previous years had melted. It seems that during the previous year the climatic conditions in the Albanian Alps had been more favorable to sustain glaciers, at least above 2200 m a.s.l. For the same period, the surface of the other glacieret in the Pirin, Banski Suhodol, resembled Maja e Jezerces I and II, but it is situated 400 m higher.

The detailed study of the Google Earth satellite image, which was taken on October 29, 2006, shows an abundance of snow spots not only in the central, highest part, but in several other places across the Albanian Alps (Fig. 7): on the slopes of Maja e Popluks, on the Karanfili ridge, in the Mertur massif (two spots above 2 ha), as well as in the area between the peaks Zla Kolata and Dobra Kolata (no. 11 in Fig. 7), where at the time the image was taken a snow patch occupied an area of 3.7 ha that is 4 times larger than Snezhnika glacieret in the same year! As 2006 was much snowier than 2011 (in the autumn of 2006

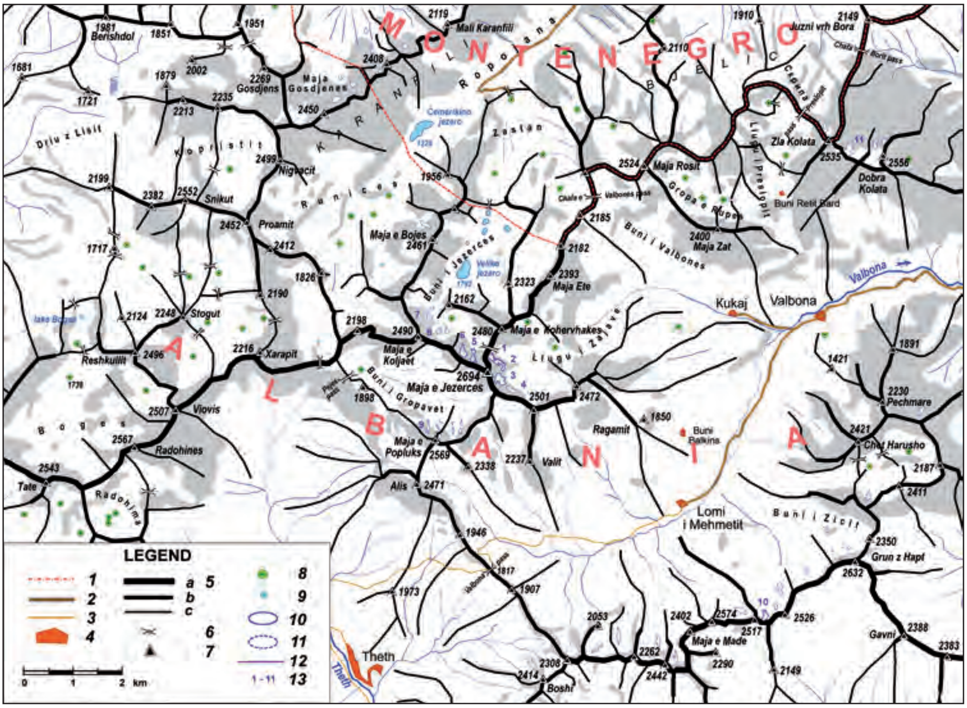

Fig. 7. An inventory of the long-term persistent patches of snow and firn/ice in the central Albanian Alps. 1 — state border; 2 — road (makadam); 3 — dirt road (trail); 4 — village; 5 — mountain ridge (a — major; b — secondary; c — a side ridge); 6 — col/pass; 7 — peak; 8 — doline; 9 — lake; 10 — glacieret/small glacier; 11 — snow patch; 12 — glacieret/small glacier's frontal moraine; 13 — numbers of snow/firn-ice patches: no. 1–10 correspond to the numbers in table 1, no. 11 — Dobra Kolata snow/firn-ice patch

for example, the Snezhnika glacieret in the Pirin reached its maximum size in the last 17 years, E. G a c h e v 2011), we expect that after a sequence of dry and warm summers the actual number of snow spots, as well as the surface they occupy, is considerably smaller than what is shown in the figure. However, some of them might represent other glacierets or small glaciers. More research is needed to verify this claim.

DURMITOR MOUNTAINS — THE DEBELI NAMET GLACIER

The massif of Durmitor is situated in the central part of the Dinaric chain, and is relatively small in size. It rises like a toothed crown above a flat karst plateau (Jezersko-Pivska površ, B. C e r o v i ć 1991). The plateau is levelled at 1450–1600 m a.s.l. and is surrounded by the valleys of the tributaries of the Drina River — the rivers Tara (to the NE), and Piva (to the S and W) with the deepest canyons in Europe, reaching respectively 1341 m and 1034 m depth in their deepest parts (D j u r o v i ć, P e t r o v i ć 2007). To the southeast, a vast karstic depression (saddle) separates the Durmitor Mountains from the adjacent Sinjaevina (2251 m a.s.l.) (Fig. 8b).

Durmitor has one main ridge which rises to 2250–2500 m a.s.l. and forms an arc open to NE. The highest summit, Bobotov kuk (2523 m a.s.l.), is situated almost in the middle. Four major ridges crawl out to the NE from the main ridge: these are Medjed, Ćvorov bogaz, Rbatina and Polica. They delimit four deep cirques of impressive size: Velika Kalica, Ledeni Do, Valoviti Do and Ališnica (Fig. 8c). Just one deep cirque is formed to the south of the main ridge — its bottom is filled by the waters of Lake Veliko Škrćko.

The larger, eastern part of the Durmitor is built up entirely of Triassic and Jurassic limestone with some dolomite (M i r k o v i ć 1983), while to the west of the highest peaks a flysch formation of Cretaceous age occurs. The proximity of the Adriatic Sea, reflected in high precipitation, caused intensive corrosion of the limestone and the development of a classical complex of karst landforms still before the Pleistocene. Subsequently the massif was repeatedly subjected to a considerable glacial reworking (the snow line dropped down to 1400–1600 m a.s.l., P. D j u r o v i ć 2009). The rough pre-glacial relief with a great number of closed depressions inhibited the advance of glaciers, making them overdeep the existing uvalas. As a result, the present relief is dominated by deep cirques with bottoms that are labyrinths of sinkholes, dolines, small hills, caves and abysses (the deepest reaches –770 m, P. D j u r o v i ć 2011). The cirque-dividing ridges were transformed into inaccessible sharp edges — arętes, and the height of the vertical walls in the main cirques is now typically between 200 and 400 m. In few places on the southern and western slopes of the massif some well-preserved remains of the old summit surface can be seen — a feature distinguishing the relief of the Durmitor from that of the Albanian Alps. The

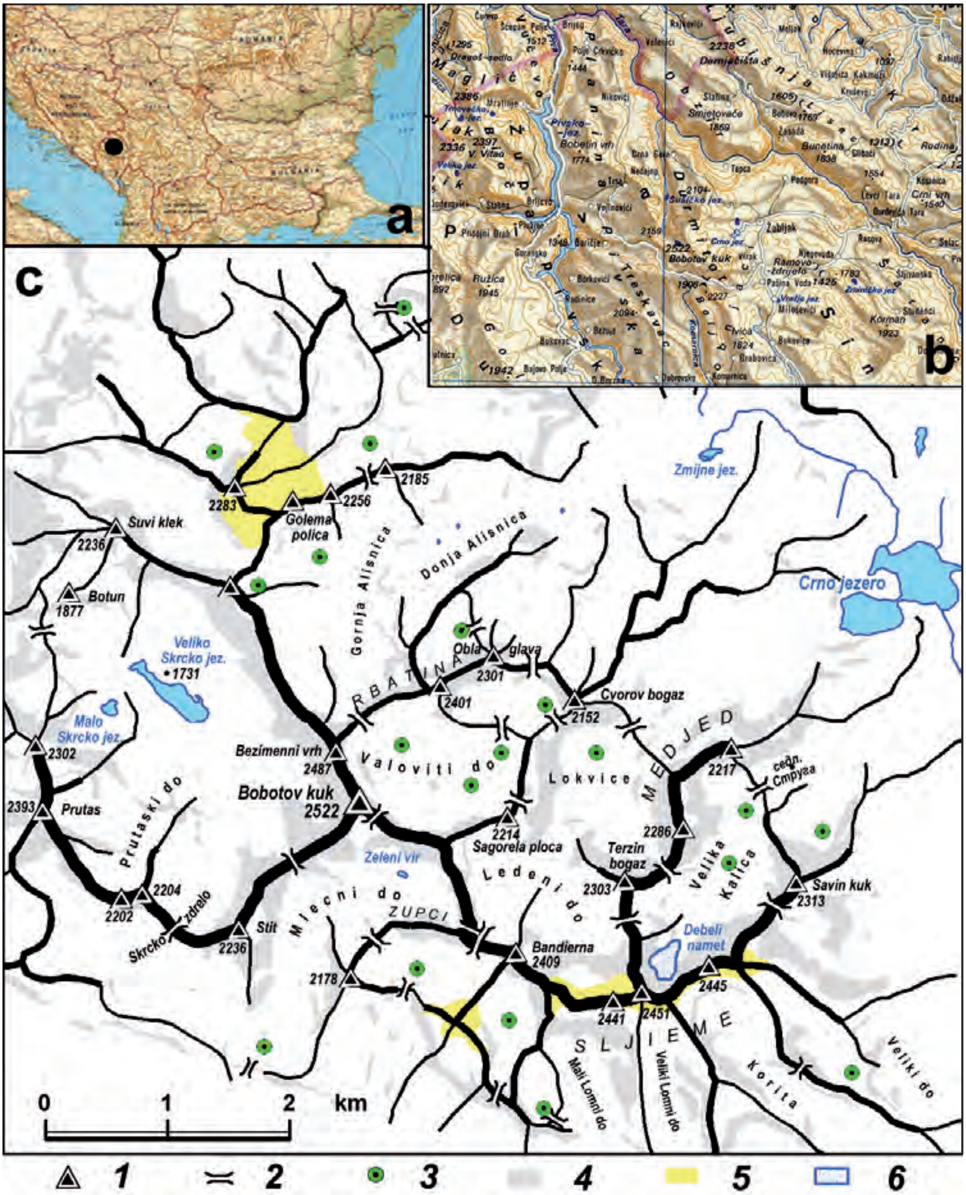

Fig. 8. Maps and orographic sketch of the Durmitor mountains. a) location within the Balkan Peninsula; b) general map; c) orography: 1 — peak, 2 — col/pass; 3 — doline bottom; 4 — rock walls; 5 — summit plateau; 6 — glacier

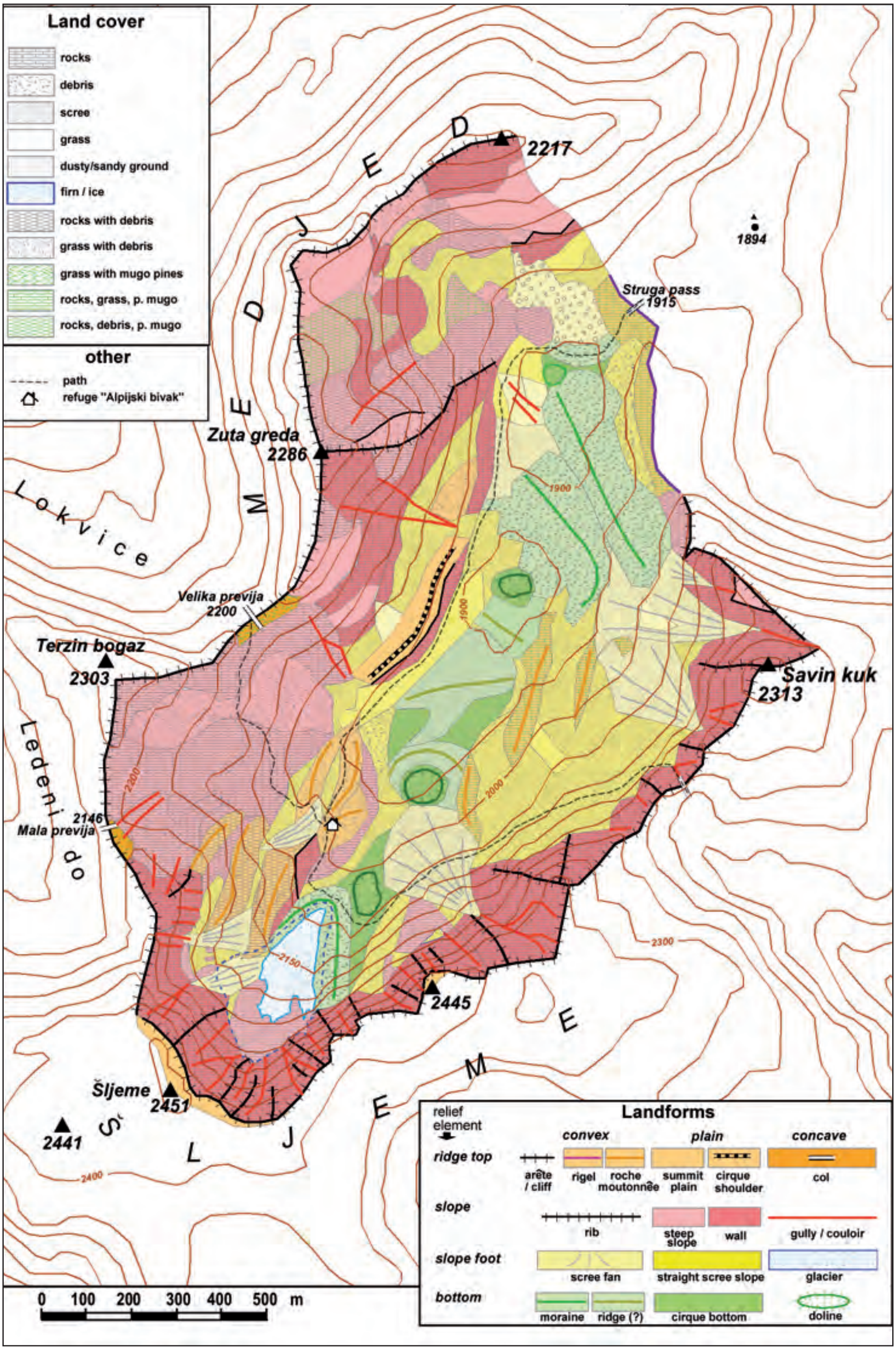

Fig. 9. A morphology map of Velika Kalica cirque

most prominent is the Šlijeme — a flat or gently tilted summit surface at about 2400 m a.s.l., located south of Velika Kalica cirque.

According to the data presented by P. Djurović (1996, 2011), for the period 1958–1993 the average annual air temperature in the town of Žabljak on the karst plateau at the NE foot of Durmitor (1450 m a.s.l.) was +4.7°C, about +1.9°C at 2050 m a.s.l, and slightly above 0°C at 2450 m a.s.l. However, since 1980 a tendency has been observed for a steady increase in the temperature at Žabljak, which at the beginning of the 1990s reached +5.4°C (Djurović 2011), and for the period 2003–2007 it was even +6.4°C (Hughes 2008). The total precipitation in the highest mountain parts is expected to be about 2600 mm/y, about 2000 mm/y on the SW periphery (windward side), while to the north, on the karst plateau (leeward side) the precipitation totals rapidly decrease to about 1200 mm/y (Djurović 2009). Precipitation regime has two maxima: the main in October-December (36% of the annual total, according to P. Djurović (2011)) and a secondary one, much less expressed, in May-June. The larger part of the precipitation falls in the cold half of the year, mostly as snow. A thick snow cover is deposited on the plateau surfaces of Šlijeme — snow is blown by the prevailing SW winds down in the "abysses" of the great northern cirques. In the summer however, due to the high temperatures, snow patches melt even under the highest cirque walls. Melt is not complete only in the easternmost of the four great cirques — Velika Kalica.

Velika Kalica cirque (Fig. 9) is a vast "bath" opened to the north and surrounded from the other sides by 200–400 m high walls of limestone, tilted above 60°. Its elliptical bottom lies at 1900–2000 m a.s.l., while south of the cirque the main ridge rises up to 2451 m a.s.l. (Šljeme peak).

At the very southern end of the cirque bottom, just below an amphitheatre of rocks and couloirs, lies the Debeli Namet glacier. It has a NNE aspect and a rounded, pear-shaped contour. During the field measurement with a rope in October 2011, we recorded a length of 321 m and a width, in the middle section, of 136 m. (Fig. 10f). An elongated glacier tongue was visible at the lower end. The longitudinal cross-section of the firn-ice patch (Fig. 10d) revealed a concave upper section tilted 35–40°, a slightly bulged middle section tilted 25–30°, and a bulge in the lower end that represented the tongue. On the basis of these characteristics and of the presence of curved strips of sediment on the tongue which, as described by P. Hughes (2007), should indicate dynamic movement of ice, the Debeli Namet is classified as a small glacier rather than a glacieret.

On October 7, 2011 we recorded the following structure of the glacier surface: less polluted snow in the upper concave section, dirty snow in the middle, slightly convex section, and melting ice in the area of the tongue (numbered respectively 1, 2 and 3 in Fig. 10c). Near its eastern edge the glacier surface was covered by scattered debris fallen from the adjacent rocky slopes, with several boulders exceeding 0.5 m in diameter.

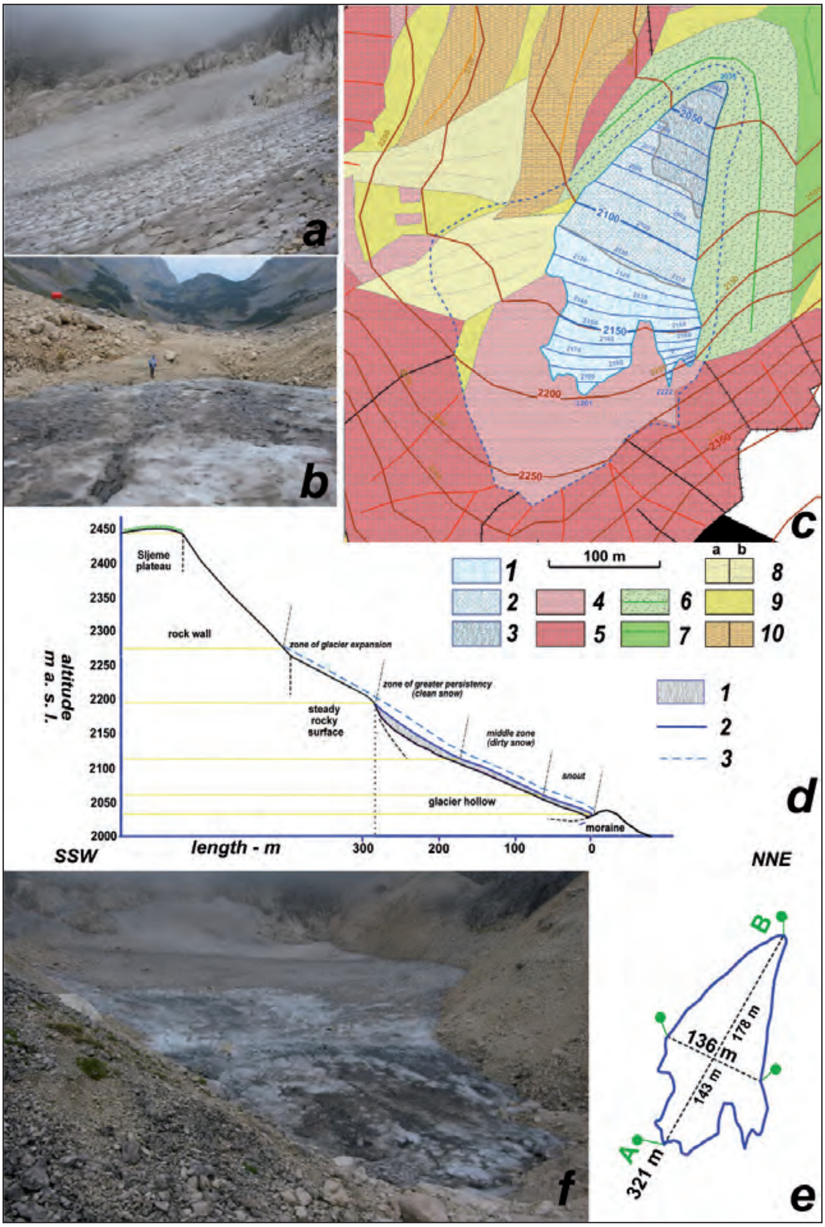

Fig. 10. The Debeli Namet glacier — October 7, 2011. a — the upper part of the glacier; b — the snout; c — a morphology map of the glacier and its surroundings: zones of the glacier surface: 1 — "clean snow" (upper section), 2 — "dirty snow" (middle section), 3 — melting ice (tongue); 4 — rocky surfaces tilted 35–40°; 5 — rock walls tilted 55–70°; 6 — moraine; 7 — cirque bottom (doline), 8 — scree fan (a — pebbles, b — boulders), 9 — scree mantle, 10 — roche moutonnee (a — grassy, b — rocky); d — longitudinal cross-section of the back part of the cirque: 1 — firn body in October 2011, 2 — firn surface in October 2011, 3 — a potential position of the firn surface in snow abundant years; e — a general view of the glacier, f — lengths and widths, measured on October 7, 2011

The moraine that surrounds the glacier front is of an impressive size, rising up to 20 m a above the ice surface on the eastern side. Three separate ridges were distinguished by P. H u g h e s (2007) in the front part of the moraine.

The zone above the upper part of the glacier is especially interesting from a geomorphological point of view (see Fig. 10a). Just above the upper firn margin a rough barren rock surface of considerable size (length up to 140 m) is exposed. The tilt of this rocky surface (40-45°) is similar to that of the glacier surface, and is much smaller than the tilt of the cirque rock wall that lies behind it (60–70°). Because of this in colder and snowier years the glacier expands towards the frontal moraine, but much more backwards to the rock wall, until it covers the less inclined rocky surface (see the blue dashed lines on Figs. 9, 10c and 10d). This specific morphology allows the glacier to double its size in colder periods, and is a prerequisite for a great short-term variability of the glacier area.

The Debeli Namet was mentioned in a geographical description of the Durmitor Mountains in 1986, and later in the works of P. D j u r o v i ć (1996, 1999, 2009, 2011). The glacier was studied also by V e s e l i n o v i ć et al. (1997) and Z. K e r n et al. (2007), who sampled and analyzed the concentration of technogenic isotopes in the glacier ice. Dr. Philip Hughes from the University of Manchester, the UK, has been carrying out systematic geomorphic observations and paleoenvorinmental studies in the Durmitor, and especially at the Debeli Namet site, since 2003. He published results of repeated measurements of the glacier size for the period 2003–2007 (H u g h e s 2007, 2008). He dated the moraines that surround the glacier front with lichenometric analysis, using old tombstones from a graveyard in Žabljak for the calibration of the age/size curve of the lichen *Aspicilia calcarea* agg. Results show that the main ridge was formed in its present shape in the Little Ice Age and the following decades. The two outer ridges were deposited about 1878 and 1924 AD, respectively (H u g h e s 2007).

Two large, older moraines have been deposited 1 km down from the glacier, in the front part of the elongated cirque. These moraines were dated through the concentration of isotopes in the secondary calcite (“U-series” technique), and a Younger Dryas age was obtained for their formation (H u g h e s 2010).

Today the Debeli Namet glacier exists at a quite low altitude: 2035 to 2200–2250 m, and respectively at a quite high air temperature (annual average about +1°C and more). It is obvious that in this case the amount of snow necessary to compensate for ablation is much greater than the actual quantity (5094 mm of water equivalent according to P. H u g h e s (2008)). In fact half of this sum is gained by a substantial accumulation of snow fallen as avalanches and blown out from the flattened plateau of Šlijeme by the prevailing SW winds. Snow cannot hold on the steep surfaces that occupy about half of glacier catchment area, and due to the action of gravity falls on the other half, so the quantity there is actually doubled.

Research carried out until now (K e r n et al. 2007, H u g h e s 2007, 2008; D j u r o v i ć 1999, 2009) as well as our observations indicate that the Debeli

Namet in the Durmitor Mountains is a present-day small glacier. It is also the only one on the Balkan Peninsula that has been definitely categorized as such. The two firn bodies which were mentioned as possible small glaciers in the Albanian Alps still need further research. It is clear that the Debeli Namet glacier exists under specific environmental conditions that are unique and quite marginal. The glacier proved to have a great sensitivity to short-term climatic fluctuations (one to several years), and this is expressed by the inter-annual variations of its area (Tab. 2).

Table 2

Changes in the size of the Debeli Namet glacier (1998–2011)

Year (autumn)	Area – ha	Volume – m^3	Source
1998	about 1.2–1.4?	?	Gachev, Stoyanov – photo, 1998
2003	1.8	122,250	Hughes (2008)
2005	4.1	373,500	Hughes (2008)
2006	5.0	489,000	Hughes (2008)
2007	3.7	325,000	Hughes (2008)
2011	2.7	?	Gachev, Stoyanov – measurement, 2011

Measurements made in the period 2003–2011 show glacier persistence along with a considerable fluctuation of glacier mass – variations up to almost 3 times were recorded. A photograph from September 2002 (Kern et al. 2007), as well as images in Google Earth's Panoramio from 2009 and 2010, also show both large area and volume of the glacier at the end of the melting season. An interesting information is provided by a photograph taken by the authors of the present article during a tourist trip in the Durmitor Mountains in September 1998 (Fig. 11). At that time the glacier was almost melted in its middle part and the tongue was absent, so the rest of the firn body resembled rather a small glacieret than a glacier. This strong reduction of the glacier must have resulted from the sequence of several dry and very hot years during the 1990s. In the Pirin, the absolute minimum of Snezhnika glacieret for the last 18 years was recorded in 1994 (Grunewald et al. 2008; Grunewald, Scheitchauer 2008). Sadly, we have no data about the state of the Durmitor glacier in the same year. However, the observation in 1998 showed a relatively "good" condition of Snezhnika glacieret, contrary to the severe shrinking of the Debeli Namet. Whether this is due to the differences in the regional climate between the two mountain massifs, for now we can only suggest.

Fig. 11. The Debeli Namet glacier in the autumns of 1998 and 2011

CONCLUSION

Beside the Northern Pirin Mountains in Bulgaria, at present small glacier features exist also in two high mountain ranges in the western part of the Balkan Peninsula – the Albanian Alps (Prokletije) in Albania, and the Durmitor in Montenegro. The preservation of permanent snow and ice is favoured by the high altitudes (above 2000 m a.s.l.), the lightly coloured and deeply karstified limestone bedrock that drains meltwaters and hampers snow melt, the presence of deep, strongly shaded cirques (a result of the great rate of Pleistocene glacier exaration). Being just about 70 km away from the Adriatic, both massifs receive substantial amounts of precipitation (about 2000–2600 mm per year), with most of it falling as snow. The specific closed topography supports a large extra accumulation of snow as avalanche and windblown snow, especially on the N to NE side of the high mountain ridges (the prevailing moisture bringing winds blow from SW). The existing firn patches receive annual precipitation amounts equivalent to 4137 to 5531 mm of precipitation (Hughes 2009), and this lets them survive all year round at relatively high air temperatures (annual averages in the range of +0.5°C to +1,9°C).

After the relatively warm and dry summer of 2011, the presence of several large snow fields was confirmed in the Albanian Alps. Two firn bodies show signs of typical small glacier morphology, with formed tongues and crescent-shape moraine ridges. The Debeli Namet glacier, which is the only present day firn-ice patch in the Durmitor, is a unique element of the Balkans' natural heritage because of its low altitude, its persistence through time, and its good accessibility.

All the research done in the Albanian Alps (including our expedition) confirm that these mountains have provided best conditions for the existence of small glaciers up to the present not only in the Balkans, but in all Europe south and east of the Alps. These conditions are most favourable in the highest massif of Maja e Jezerces, but also exist in some of the other mountain parts.

The review of the distribution of small firn-ice patches in the mountains of the Western Balkans, as well as their development in the last years, has revealed the great interannual variability of these forms. In particular cases (such as the Debeli Namet glacier) these fluctuations are additionally amplified by the specific morphology of the glacier bed – presence of a less inclined rocky surface in front of the cirque wall that is invaded by firn after colder and snowier periods.

Delineation between snow patches, glacierets and small glaciers is abstract to a large extent, as it seems that the studied firn-ice patches are quite often passing from one category to another. Still more research is needed to make a complete and proper categorization of the small firn-ice patches in the Balkans.

South-west University "Neofit Rilski",
Faculty of Mathematics and Natural Sciences
66 Ivan Mihailov str., 2700 Blagoevgrad, Bulgaria

REFERENCES

Cerović B., 1991. *Durmitor i kanjon Tare*. Vodić , Beograd, 160 pp.

Cvijic J., 1913. *Ledeno doba u Prokletijama i okolnim planinama*. Glas — Srpska kraljevska Akademija, II, 93pp.

Djurović P., 1996. *Visokoplaninski kras Durmitora — geomorfološka studija*. Ph.D. thesis. Geografski fakultet, Beograd.

Djurović P., 1999. *Natural and anthropogenic influences as threats to pits in the Debeli namet glacier, Durmitor National park, Montenegro*. [in:] *Contribucion del estudio cientifico de las cavidades karsticas al conocimiento geologico*. B. A. Navarro, F. Carasco Cantos, J. J. Durán Valser (eds.), Malaga.

Djurović P., 2009. *Reconstruction of the Pleistocene glaciers on Mount Durmitor in Montenegro*. Acta geographica Slovenica 49–2, 263–289.

Djurović P., 2011. *Visokoplaninski kras Durmitora*. University of Beograd, Geographical Faculty, 206 pp.

Djurović P., Petrović A., 2007. *Large Canyons in Dinaric and Prokletije Mountains Region of Montenegro*. Geographica Panonica 11. 14–18.

Fjalor..., 1985. *Fjalor enciklopedik shqiptar*. Akademia e Shkencave e RPSSH, Tirana.

Gachev E., 2009. *Indicators for modern and recent climate change in the highest mountain areas of Bulgaria*. Landform Analysis 10, 33–38.

Gachev E., 2011. *Inter-annual size variations of Snezhnika glacieret (the Pirin mountains, Bulgaria) in the last ten years*. Studia Geomorphologica Carpatho-Balcanica 45, 47–68.

Gachev E., Gikov A., Zlatinova C., Blagoev B., 2009. *Present state of Bulgarian glacierets*. Landform Analysis 11, 16–24.

Gachev E., A. Gikov, 2010. *Opisanie i parvo izmervane na snezhnika v tsirkusa Banski suhodol. (A description and a first measurement of the glacieret in Banski suhodol cirque)*. Problems of Geography BAS 3–4, 90–98. (in Bulgarian)

Gądek B., Kotyrba A., 2003. *Struktura wewnetrzna Lodowczyka Męguszowieckiego (Tatry) w swietle wynikow badan georadarowych*. Przeglad Geologiczny 51, 1044–1047.

Gądek B., Kotyrba A., 2007. *Contemporary and fossil metamorphic ice in Medena Kotlina (Slovak Tatras), as mapped by ground-penetrating radar*. Geomorphologia Slovaca et Bohemica 1,75–81.

Geografi…, 1990. *Geografi fizike e Shqipërisë*. Akademia e Shkencave e RPSSH, Tirana,

Grunewald K., Scheitchauer J., 2008. *Klima- und Landschaftgeschichte Sudosteuropas. Rekonstruktion anhand von Geoarchiven im Piringebirge (Bulgarien)*. Rhombos Verlag, Berlin. 178 pp.

Grunewald K., Scheitchauer J., 2011. *Landscape Development and Climate Change in Southwest Bulgaria (Pirin mountains)*. Springer, 161 pp.

Grunewald K., Scheitchauer J., Gikov Al., 2008. *Microglaciers in the Pirin mountains. (Mikrolednitsi v Pirin planina)*. Problems of Geography BAS 1-2. (in Bulgarian)

Grunewald K., Weber C., Scheitchauer J., Haubold F., 2006. *Mikrogletscher als Klimaindikatoren und Umweltarchive in sudosteuropaischen Hochgebirgen? — Untersuchung des Vichrengletschers im Piringebirge (Bulgarien)*. Zeitschr. Gletscherkunde und Glazialgeologie 39 (2003–2004), 99–114.

Hughes P., 2007. *Recent behaviour of the Debeli Namet glacier, Durmitor, Montenegro*. Earth Surface Processes and Landforms 32, 1593–1602.

Hughes P., 2008. *Response of a Montenegro glacier to extreme heatwaves in 2003 and 2007*. Geografiska Annaler 90A (4), 259–267.

Hughes P., 2009. *Twenty-first century glaciers in the Prokletije mountains, Albania*. Arctic, Antarctic and Alpine Research 41, 455–459.

Hughes P., 2010. *Little Ice Age glaciers in the Balkans: low altitude glaciation enabled by cooler temperatures and local topoclimatic controls*. Earth Surface Processes and Landforms 35, 229–241.

Kern Z., Suranyi G., Molnar M., Nagy B., Balogh D., 2007. *Investigation of natural perennial ice deposits of Durmitor Mts., Montenegro*. [in:] *Procedings of the Second International Workshop on ice caves, Demanovska Dolina, Slovak Republic, 8th–12th May 2006*.

Milivojević M., Kovaćević-Majkić J., 2005. *Glacijalna jezera Buni i Jezerce — Albanija*. Glasnik srpskog geografskog drustva 85, 1, 11–17.

Milivojević M., Menković L., Ćalić J., 2008. *Pleistocene glacial relief in the central part of Mt. Prokletije (Albanian Alps)*. Quaternary International 190, 112–122.

Mirković M., 1983. *Geološki sastav i tektonski sklop Durmitora, Pivske planine i Volujka*. Geološki glasnik 5, Titograd.

Palmentola G., Baboci K., Gruda G., Zito G., 1995. *A note on rock glaciers in the Albanian Alps*. Permafrost and Periglacial Processes 6, 251–257.

Popov Vl., 1964. *Observations on the glacieret in the cirque Golemia Kazan, the Pirin mountains. (Nabljudenia varhu snezhnika v tsirkisa Golemia Kazan — Pirin planina)*. Izvestia na Geografskia institut BAN (Announcements of the Institute of Geography, Bulgarian Academy of Sciences) 8.

Roth von Telegd K., 1923. *Das albanisch-montenegrinische Grenzgebiet bei Plav (Mit besonderer Berücksichtigung der Glazialspuren).(Albanian-Montenegrian region of Plav)*. [in:] *Beiträge zur Geologie von Albanien, Neues Jahrbuch für Mineralogie 1*, Nowack E (ed.). Schweizerbart, Stuttgart; 422–494.

Veselinović D., Kovaćević D., Marković D., Vukmirović Z., Rajšić S., Stanković S., Stanković A., Djordjević D., 1997. *Sadržaj metala i radioaktivnost leda sa ostatka lednika Debeli namet na Durmitoru*. Zbornik radova: Rizik tehnoloških sistema i životna sredina. Nis, 145–148.