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Glaciation Traces in the Area of the Risnjak Mountain Massif

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Key words: Glaciation, Cirque, Terminal depression, Glacial valley, Moraine, Erratic blocks.

Abstract

The area of the Risnjak mountain massif is a submorphological region - part of the mesomorphological region of the south-western Gorski Kotar. This area exceeds 1,500 metres in height. In the relief structure of the massif, the system of ranges and erosion surfaces - plateaux, has been formed on the folded-block, mostly carbonate base by subsequent microtectonic activity and exomorphological processes.

Such relationships of relief under conditions of exceptionally low temperatures and abundance of snow precipitation during the Pleistocene, were prerequisites for the development of glaciation. Glaciation of the mountain massif was marked by formation of the valley, plateau and cirque glaciers, which is proved by the discovery of glacial moraines and other morphological features and corresponding sediments.

1. INTRODUCTION

1.1. THE RESEARCH PROBLEMS

The problem of the Pleistocene glaciation of the Dinaric mountain system in Croatia is one of the most interesting geoscientific problems, and one which has intrigued other natural science disciplines, especially biology, and has drawn the attention of many natural scientists during the 20th century.

Glaciation was mentioned for the first time by HRANILOVIĆ (1901) as one of the possible means of formation of the Drežnica plain. GAVAZZI (1903) wrote about the Southern Velebit glaciation, and based his assumptions upon research on the Mala and Velika Paklenica plains. SCHUBERT (1909) produced the first concrete data in his speech about the Southern Velebit glaciation. A German geomorphologist BAUER (1935) detailed the problems of the Jezera area in Northern Velebit, and thought that the Pleistocene snow-line on the Velebit Mountain had been somewhere between 1,400 and 1,500 m above sea-level.

A Hungarian biologist DEGEN (1936) and geomorphologist MILOJEVIĆ (1922) also wrote about the Velebit glaciation. POLJAK (1947) had the opposite opinion. He negated the possibility of Velebit glaciation. POLJAK (1947) declared that there were snow-waters which filled some bigger sink-holes of the upper part of Velebit. The geographer ROGIĆ (1957) thought similarly.

The most recent research (NIKLER, 1973 and BELIJ, 1985) proved the existence of glaciation in Southern Velebit, and the research of SOKAČ et al. (1976) and BOGNAR et al. (1991) achieved the same in Northern Velebit. Furthermore, other authors also wrote about the possible glaciation of particular mountains in Croatia: MILOJEVIĆ (1922) wrote about the glaciers of Troglav on the Dinara Mountain; ŠIFRER (1959), a Slovenian geomorphologist, wrote about glaciation of Croatian Snježnik, Platak and Obruč; RIĐANOVIĆ wrote about glaciation of Orjen (1962, 1966); MIHLJEVIĆ (1995) about the possible existence of cirque glaciers on the upper reaches of the Učka Mountain, and ČEČURA (1995) published on the glaciation of the Kamešnica and Dinara Mountains.

1.2. THE STUDY AREA

The study area of the Risnjak mountain massif, and part of the Croatian Snježnik mountain range is a component of the Outer Dinarides mountain zone in the setting of the megageomorphological region of the Dinaric mountain system.

The research was conducted within the following boundaries: from Gornje Jelenje in the south to Gerovo in the north, from the Croatian Snježnik mountain range in the west to Crni Lug in the east. The study area covers approximately 100 km^2 (14°35' - 14°42' E; 45°23' - 45°30' N) (Fig. 1).

The largest part of this area is protected as part of the "Risnjak" National park (64 km^2).

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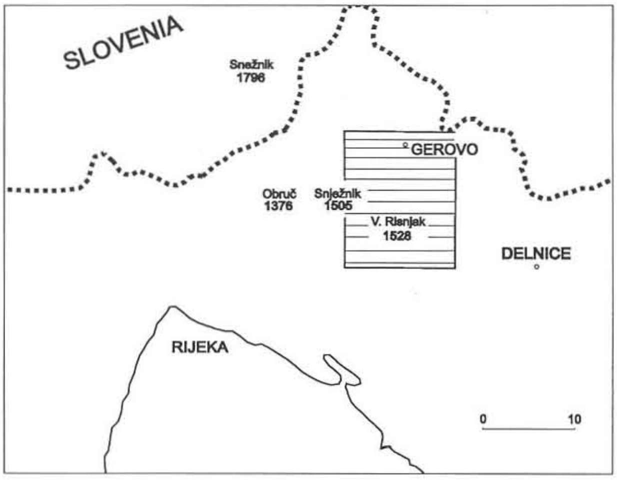

Fig. 1 Geographical position of the study area of the Risnjak mountain massif.

1.3. SOME BASIC GEOMORPHOLOGICAL AND GEOLOGICAL CHARACTERISTICS OF THE RISNJAK MOUNTAIN MASSIF

The Risnjak mountain massif represents a submorphological regional unit of the mesogeomorphological region of the north-western part of Gorski Kotar. The study area has been somewhat widened, so it includes a part of the subgeomorphological unit of the Croatian Snježnik mountain range.

The Risnjak mountain massif is divided into a series of geomorphological microregions: the mountain range of Veliki Risnjak (1,528 m) and Mali Risnjak (1,448 m); the mountain range of Janjičarski vrh (1,314 m), Veliki Bukovac (1,266 m) and Mali Bukovac (1,263 m); the mountain range of Velika Šija (1,172 m) and Mala Šija (1,149 m); the Oštra mountain range (1,221 m), the Šeginšček mountain range (1,145 m), the uvala Lazac (1,060 m), a series of uvalas at Gašparac (940 m) - Šegine (950 m), the uvala Lividraga (918 m) and the plain of the Suha Rečina river.

Similarly, the mountain range of Croatian Snježnik can be divided into a series of microrelief units, and this work deals with the Radeševo high mountain erosion surface.

The Risnjak mountain system is characterized by a folded-blocked-overthrusted geological structure. Accordingly, it falls under the type of conforming morphostructures (BOGNAR, 1987a, b).

In the regional geological structure of the wider area the oldest deposits are Permian, represented by an alternation of shales and sandstones. Lower Triassic sandy dolomites, containing intercalations of sandstones, overlie the Permian clastics. Middle Triassic deposits are missing and Upper Triassic terrigeneous clastics and/or dolomites unconformably follow the Lower Triassic dolomites. Karstified Jurassic carbonate rocks predominate within the "Risnjak" National park. They are represented by shallow marine limestones of the Dinaric carbonate platform, some of which (particularly those of Early Jurassic age), show late diagenetic dolomitisation. Middle and Late Jurassic carbonates are predominantly limestones. The Quarternary is represented by the Pleistocene and Holocene sediments (SAVIĆ & DOZET, 1984).

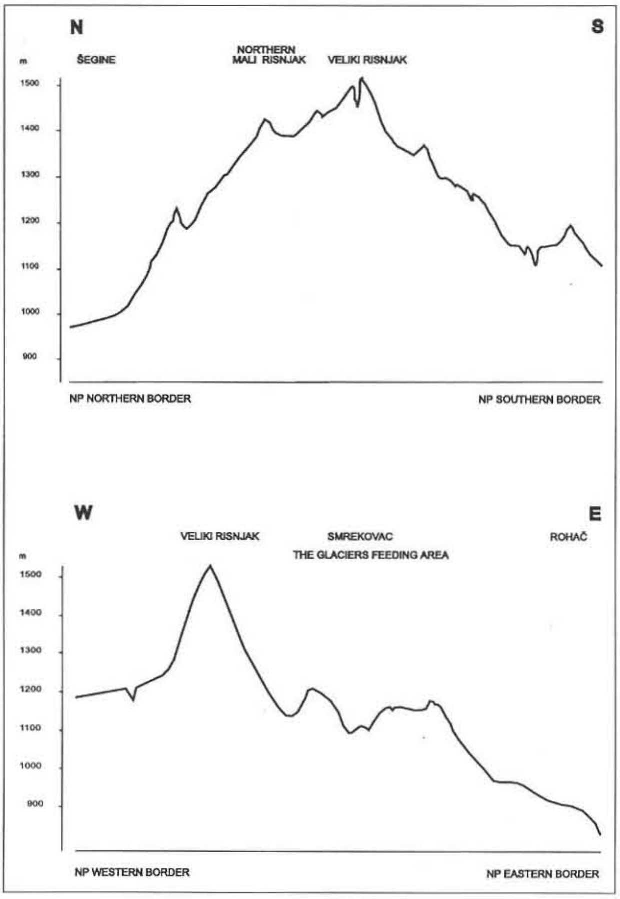

Fig. 2 Transverse profile of Risnjak (N-S, W-E).

The investigated area is characterized by folded-faulted tectonics. In places (Gerovo, Suha Rečina) there are some structures where the Permian and Triassic deposits overthrust various stratigraphic members of the Jurassic. In its neotectonic development stage the Dinaric platform experienced intensive fault disarrangements (vertical-subvertical faults), which, globally, resulted in uplift of the whole series of blocks. In relief they appear as chains of mountain ranges and massifs. One of these blocks is the block-massif of Risnjak where faulted tectonics predominates. On a dominantly carbonate base of limestone and dolomites, a compound orographic structure has been formed. A series of range elevations can be singled out (the range of Veliki and Mali Risnjak etc. - see the microgeomorphological division) as well as a series of little uvalas (Fig. 2).

Among the range elevations of the Risnjak massif we can see an older erosion surface (Smrekovac), which was additionally microtectonically broken and today has the characteristics of a plateau which has been, by exogenic morphological processes (corrosion and glacial processes), formed into a hilly region characterized

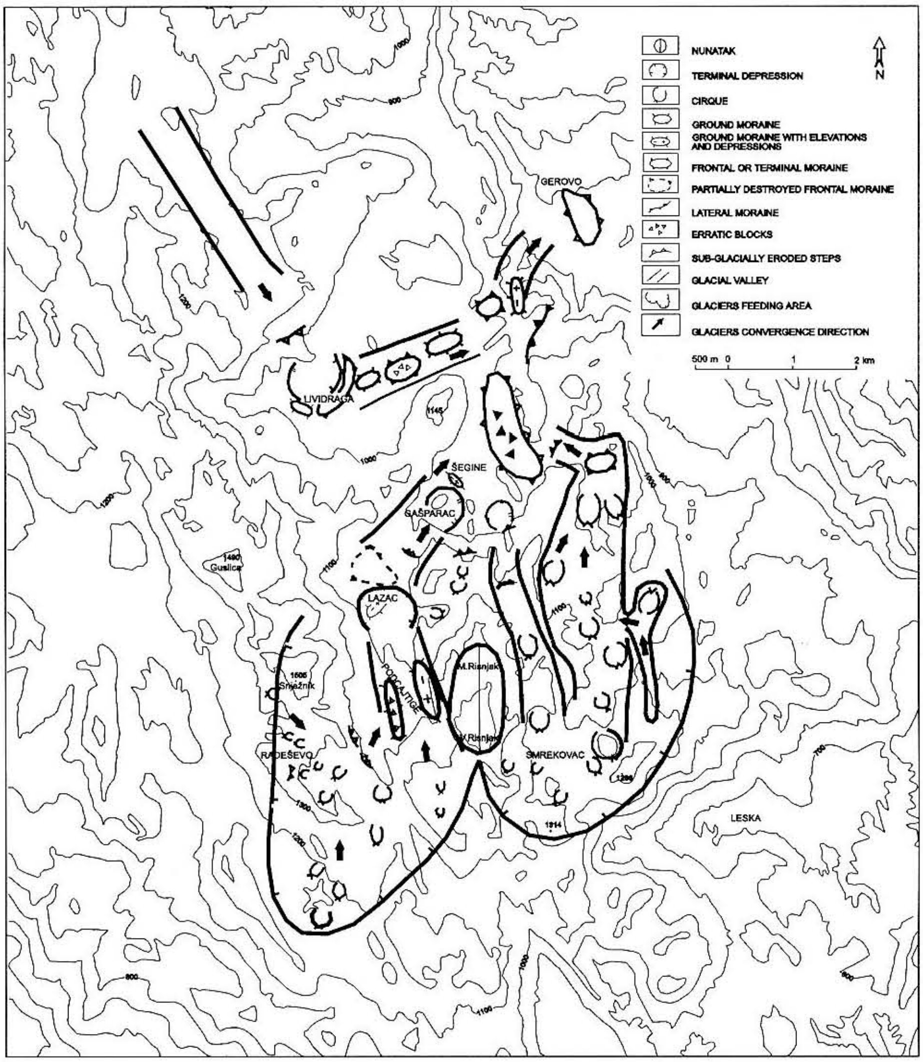

Fig. 3 Glaciation traces of the Risnjak - Gorski Kotar region.

by the interplay of deep glacially remodelled dolines, escarpments and more or less erosion surfaces.

2. GEOMORPHOLOGICAL TRACES OF GLACIATION

Mapping of the area of the Risnjak mountain massif ascertained for the first time the corresponding geomorphological and geological traces of the Pleistocene glaciation (Fig. 3).

2.1. GLACIAL RELIEF FORMS

The glacial forms in the area of the Risnjak mountain massif developed during the activity of four glaciers, three descended from Risnjak Mt. and one from the Slovenian Snežnik Mt. The sources of the so-called Risnjak glaciers are the Smrekovac and Radeševo (Croatian Snježnik) plateau and the range of Veliki and Mali Risnjak, while the source of the so-called Snežnik glacier was the plateau at the foot of the Slovenian Snežnik (Table 1).

The glaciation traces include the existence of glacial erosion (cirques, nunatak, sub-glacially eroded steps [1], terminal depressions, glacial valleys) and accumulative (moraines, erratic blocks) glacial relief forms.

2.1.1. Glacial erosion forms

In the Risnjak region, the glaciers source area is represented by systems of glacially remodelled dolines - cirques, which were mutually connected by ice in the Pleistocene.

Smrekovac is an "older" erosion surface which was later microtectonically broken, and today has the features of the plateau formed by exogenic processes (primarily by glacial and corrosion processes). This is a more-or-less hilly region characterized by the interplay of deep glacially remodelled dolines [2], escarpments and uneroded parts of the erosion surface. The whole Smre-

[1] Sub-glacially eroded steps are destructional forms developed by selective glacial erosion.

[2] Glacially remodelled dolines are pre-glacially formed sink-holes being filled with ice and snow during glaciation.

Glacier	Glaciation time	Length in km
Radeševo - Podcajtige	late Würm	2.5
Radeševo - Lazac	late Würm	4.5
Radeševo - Gašparac	late Würm	7.0
Smrekovac - Šegine - Zelinski lug	late Würm	5.5
Smrekovac - Šijska cesta - Zelinski lug	late Würm	7.0
Slovenski Snežnik - Lividraga	late Würm	18.0
Slovenski Snežnik - Mali klanac	Würm	22.5
Slovenski Snežnik - Gerovo	older Würm or Riss	24.5

Table 1 Estimated lengths of the glaciers in the area of the Risnjak mountain massif, of the Croatian Snježnik mountain range and Slovenian Snežnik.

kovac area is situated 1,150 m above sea-level (above the Pleistocene snow-line) and is, considering its relief, open towards the north (Fig. 4).

Radeševo - today a plateau (erosion surface) on the mountain range of Croatian Snježnik, like Smrekovac represents a system of glacially remodelled dolines and escarpments, but located higher above sea-level (over 1,200 m). These dolines - cirques, considering relief, are "open" towards the east and north-east (the ice "was flowing" towards the uvalas Lazac, Gašparac and Šegine). The glacially remodelled dolines - cirques, were pre-glacially formed by corrosion, but by the activity of ice, meltwater and snow-water they were deepened and widened, and today their depths vary from several tens of metres to 209 m (Viljska doline). Particular cirques-dolines are a hundered metres in width.

In the Pleistocene between the accumulation areas of the Risnjak and Snježnik glaciers, the Sjeverni Mali Risnjak - Veliki Risnjak - Južni Mali Risnjak range, most probably stuck out above the ice like nunataks, among the plateau glaciers formed on the Smrekovac and Radeševo plateau. Proof that the very summit of Risnjak was above the ice includes the periglacial rock erosion and microrelief dissection which couldn't be possible if the area had been under the ice (Fig. 5). Cryofraction produced rock cracking, rock-fall, stone stripes and migrating turfs. Except in the topmost parts, such microrelief dissection can't be found either on the Smrekovac (excluding Bijele Stijene) and Radeševo plateaux, or in the systems of the Lazac, Gašparac, Šegine, Zelinski lug uvalas-terminal depressions, and Gerovsko polje.

In motion, ice with eroded material encounters different obstacles and forms the so-called sub-glacially eroded steps. These forms have been established in front of the terminal depressions and moraines (Podcajtige, Gašparac, Šijska cesta, Zelinski lug, etc.). Furthermore, in addition to glacial erosion, the sub-glacially eroded steps between particular sink-holes were remoulded by corrosion processes. With regard to the

Fig. 4 A view from the summit of Veliki Risnjak towards the east, on a part of the system of the glacially remodelled dolines - cirques of Smrekovac.

Fig. 5 A glacially remodelled doline in upper part of Veliki Risnjak, with periglacial stone stripes and blocks at the bottom.

Fig. 6 A terminal depression with an erratic block (foreground) and the frontal moraine in Šegine (in the background).

chiefly carbonate structure and strong corrosion processes, it is understandable that the traces of the glacial striae (furrows) and of the ice smoothed surfaces have not been found.

Each of the four quoted glaciers has formed glacial valleys. These are documented at least in part by the "U" shaped transverse profile. This especially relates to the Podcajtige glacial valley and the glacial valley of the Snežnik glacier north-east and north-west from Lividraga. Two glacial valleys on the Smrekovac plateau are not so prominent (the Šija glacier valley and the Gašparac glacial valley). They represent linear elongated valleys marked by a series of dolines-cirques, mutually divided by little sub-glacially eroded steps.

Terminal depressions represent glacial erosion forms surrounded by frontal (final or terminal) moraines. They are shallow, by glacial erosion deepened areas where the glaciers melted. Their final forms appeared after the outflow of meltwater. Terminal depressions, today karst uvalas - Lazac, Gašparac, Šegine and Lividraga were formed in basic rocks (in the Jurassic limestones: Dogger and Malm - Lazac; in the Jurassic limestones: Malm, and Triassic dolomites: late Triassic - Šegine; in the Jurassic dolomites: Lias and Jurassic limestones: Malm - Lividraga; SAVIĆ & DOZET, 1984). They are of different dimensions: Lazac - 900 x 700 m, Gašparac - 600 x 500 m, Lividraga 800 x 750 m. As a rule, terminal depressions are full of glacial accumulative material (from 2-5 m diameter blocks to silt with diameters from 0.01-0.05 mm), and partly of fluvioglacial material (chiefly subangular, from 2-4 mm to approximately 20 cm) (Fig. 6). Till or glacial material is very poorly sorted. Fluvioglacial material is connected only with terminal depressions and sometimes appears in fragments. It is thought that the majority of fluvioglacial material is to be found outside the studied area, in the direction of the river Kupa plain.

2.1.2. Accumulation forms of glacial relief

When a glacier reaches the equilibrium-line between the ablation/accumulation of ice, melting begins as well as the accumulation of the eroded material which forms frontal (final or terminal moraines). Drumlins and kames haven't been observed.

We can distinguish accumulations of the ground, end and frontal or terminal moraines. In the Risnjak area, examples of the ground moraines include: Podcajtige - where the ground moraine appears in two forms - one with elevations and depressions (the eastern side of the glacial valley), and another with erratic blocks (the western side of the glacial valley); the Lazac ground moraine, Šegine moraine and a series of ground moraines at Lividraga. In Mali Klanac the ground moraine has fallen in, probably due to road excavations, so its structure can be seen clearly. Like till, in the previously mentioned terminal depressions, compositionally moraine is represented by a very heterogenous material, from blocks (with diameter of 1 m) to silt.

Frontal or terminal moraine has the form of an elongated (Zelinski lug) and half-moon (Gerovo, Gašparac, Lazac, Lividraga and Šegine) wall (deposit) surrounding the terminal depression. The Gašparac frontal moraine was made by a glacier the source of which was probably in the area of the modern Radeševo plateau. The moraine is covered with vegetation and is 250 m long and 150 m wide. The glaciers from the Smrekovac area formed two moraines: Šijska cesta (dimensions 500 x 300 m) and the largest, probably terminal moraine of the Risnjak glaciers - Zelinski lug (1,800 x 500 m) (Fig. 7). The ice which "was flowing" from the Slovenian Snežnik, formed a series of frontal moraines of different dimensions: between Lividraga and Gerovo (the frontal moraine Lividraga 1,000 x 150 m, the frontal moraine at the foot of Šeginščak: 600 x 300 m).

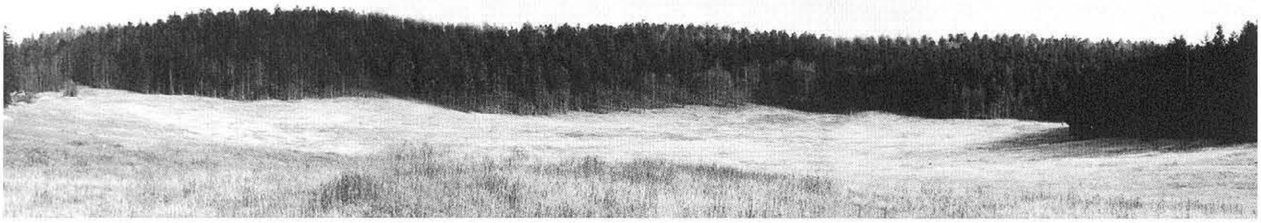

Fig. 7 The Zelinski lug frontal moraine with the Mašeničak Terminal depression.

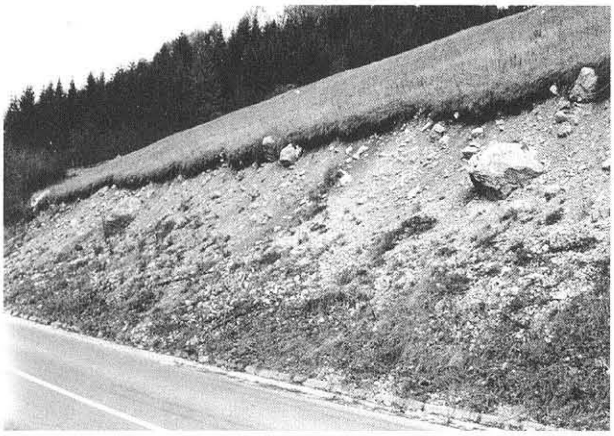

Fig. 8 A profile of the frontal moraine in Gerovo. Typical heterogenous till where huge blocks of several hundreds of kilograms mix with tiny karst material.

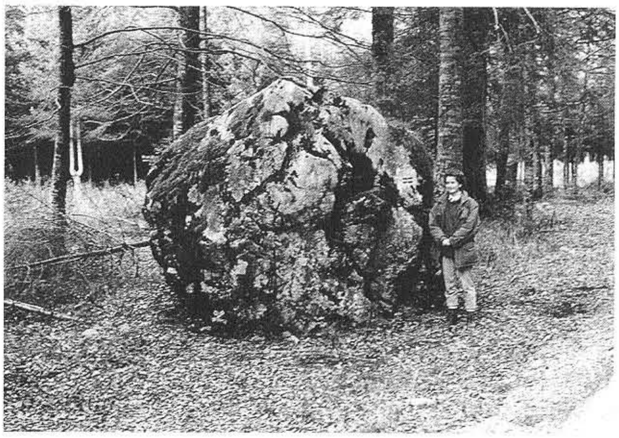

Fig. 9 Erratic block near Lividraga (its mass exceeds several tens of tons).

The Gerovo terminal moraine represents the final reach of the Snežnik glacier and forms a wall 500 m long and 300 m wide (Fig. 8). In the glacial material in the Lividraga doline and in the area of the frontal moraine discovered in Gerovo, a somewhat greater proportion of dolomites has been noticed. It can be explained by a greater volume of dolomite in the structure of the Slovenian Snežnik area. Between Lividraga and Gerovo, the Snežnik glacier also formed a lateral moraine, above Mali Klanac. All moraines are today covered with vegetation, which is probably the reason for their late discovery.

Erratic blocks represent the moraine material which is, because of its large dimensions, often accumulated in terminal depressions or in glacial valleys. Examples of these can be found in the terminal depression Gašparac and Šegine, but the largest examples of erratic blocks have been found in the area of frontal and ground moraines of Lividraga. Erratic blocks are mainly composed of the limestones (Jurassic limestones). Their mass exceeds several tens of tons. The relative roundness of the erratic blocks shows erosion as the consequence of transport (Fig. 9).

3. PALAEOCLIMATIC RECONSTRUCTION

Besides relief conditions the climatic ones had a great influence on the development of glacial processes. Here we shall primarily regard the air temperatures and the quantity of precipitation. As a base for reconstruction of the palaeoclimate of the Risnjak mountain massif, we have taken the data of the following meteorological stations: Delnice (698 m of the height above sea-level), Lokve-dam (723 m above sea-level), Parg (863 m above sea-level), Lividraga (935 m above sea-level), and data of the totalizer on Risnjak (1,420 m above sea-level). The air temperature and the quantity of precipitation were observed in the period from 1981 to 1994, and the average values relate to that period. The exceptions are the meteorological station Lividraga which stopped working in 1984 and the data of the totalizer on Risnjak for the period 1963-1993.

3.1. PALAEOTEMPERATURES

On the basis of Poser's mathematical reconstruction for the Pannonian plain[3], KLEIN (1953) calculated the average monthly and annual temperatures of Zagreb during the maximum of the Würm glacial. The difference between POSER's (1947) and KLEIN's (1953) reconstruction of the temperatures are presented in Table 2.

The temperatures for the meteorological stations of the Risnjak area (Table 3) have been calculated on the same principle (taking into account differences between today's and the Würm temperatures of Zagreb).

It is necessary to point out that this reconstruction is based upon today's relief forms and altitude relations which were considerably changed in the Würm because the sea-level was about 100 metres lower. A greater degree of continentality conditioned lower air temperatures, and the ice itself with its mass and thickness in the top part of the Risnjak mountain massif, caused a decrease of the air temperature.

In order to get a more complete picture of temperature relations today and in the Würm, the average annual temperature of the Veliki Risnjak summit has been calculated for today and for the age of the last glacia-

[3] Having observed the intensity of the frozen soil melting in the Pannonian plain, POSER (1947) calculated the average monthly air temperatures during the Würm glacial. The average annual temperature amounted to -2.0°C, which shows that in the Pleistocene the Pannonian plain belonged to the periglacial zones. Later research of PÉCSI (1961) in Hungary, KAISER (1961) in the neighbourhood of Belgrade, MALEZ (1965) in Slavonia, BOGNAR (1975, 1976) and ZEREMSKI (1977) affirmed the results of Poser's analysis.

Zagreb	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Today	0.6	2.2	7.4	11.3	16.2	19.3	21.5	20.7	16.8	11.7	6.2	2.8	11.4
Würm	-13.0	-12.0	-8.0	-3.0	3.0	8.0	11.0	9.0	3.0	-2.0	-8.0	-12.0	-2.0
Differ.	13.6	14.2	15.4	14.3	13.2	11.3	10.5	11.7	13.8	13.7	14.2	14.8	13.4

Table 2 Differences between mathematical temperature reconstruction of the maximum Würm and today's temperatures of Zagreb, after BOGNAR et al. (1991).

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Delnice													
Today	-1.3	-1.7	2.4	6.9	11.6	14.6	17.3	16.9	13.3	8.8	2.9	0.2	7.1
Würm	-14.9	-15.9	-13.0	-7.4	-1.6	3.3	6.8	5.2	-0.5	-4.9	-11.3	-14.6	-6.3
Lokve-dam													
Today	-1.7	-1.8	2.1	5.7	10.8	13.9	16.8	16.2	12.7	8.1	2.7	-0.1	7.1
Würm	-15.3	-16.0	-13.3	-8.6	-2.4	2.6	6.3	4.5	-1.1	-5.6	-11.5	-14.9	-6.3
Parg													
Today	-1.2	-1.7	2.3	5.8	10.9	13.7	16.9	16.2	12.7	7.9	2.5	0.1	7.2
Würm	-14.8	-15.9	-13.1	-8.5	-2.3	2.4	6.4	4.5	-1.1	-5.8	-11.7	-14.7	-6.2
Lividraga													
Today	-3.7	-4.5	0.9	4.0	8.9	12.5	15.4	14.0	12.0	7.7	1.0	-1.1	5.8
Würm	-17.3	-18.7	-14.5	-10.3	-4.3	1.2	4.9	2.3	-1.8	-6.0	-13.2	-15.9	-7.6

Table 3 Average monthly and annual air temperatures for the meteorological stations Delnice, Lokve-dam, Parg and Lividraga (1981-1994 and the last 1981-1984) today and during the Würm glaciation.

tion by means of the vertical temperature gradient[4] (Table 4).

3.2. PALAEOPRECIPITATION

Using the same actualism principle according to which today's climatic circumstances are the key for reconstruction of the climate in the past, the quantity of precipitation can also be calculated. On a map of Europe, KLEIN (1953) presents the quantities of precipitation during the maximum of the Würm glacial related to today's quantity. Differences for the area of the Risnjak mountain massif was about 70%, i.e. the quantity of precipitation was about 30% less (Table 5).

Over the broader Risnjak region, precipitation has been measured by means of a classic rain-gauge, and the quoted values obtained in that way. By use of a rain-gauge with a net (in the Velebit area - Zavižan) the average value increases for 249% (KIRIGIN, 1967). If we suppose that the increase on Risnjak was approximately the same, the quantity of precipitation would be as presented in Table 6.

Very low temperatures in the Pleistocene, and a large amount of precipitation (mainly data of the rain-gauge with a net) had a significant influence on the development of glacial processes. When we take into account the northern exposure, and great relief dissection of Risnjak, it is understandable that there were all the necessary conditions for the accumulation of large quantities of ice, which, while moving, produced a series of accumulative and erosive glacial features.

4. THE PLEISTOCENE SNOW-LINE

For the area of the Risnjak mountain massif the Pleistocene snow-line has been calculated by means of Höfer's method, according to which the snow-line is fixed as the arithmetic mean between the average height of the ridge, limiting the glaciers accumulation area, and the lower height of the glaciers limit - moraines (HÖFER, 1879). This method is advisable for short glaciers, certain slopes or expositions, so we speak about a local topographic snow-line. In the studied region two glacial source areas have been fixed (Smrekovac and Radeševo), and the local topographic snow-line calculated for each of them according to the aforementioned approach.

[4] Vertical temperature gradient has been calculated by means of the known values of the air temperature for the meteorological stations Delnice (698 m above sea-level) and Lividraga (935 m above sea-level), and it amounts to 0.55°C for every 100 m of elevation.

Height (m)	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500	1,528
Today	7.65	7.10	6.55	6.00	5.45	4.90	4.35	3.80	3.25	2.70	2.55
Würm	-5.75	-6.30	-6.85	-7.40	-7.95	-8.50	-9.05	-9.60	-10.15	-10.70	-10.85

Table 4 Average annual air temperature of Veliki Risnjak (1,528 m) today and in the Pleistocene has been calculated by means of the vertical temperature gradient (0.55°C/100 m).

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Delnice													
Today	176.2	167.6	179.3	154.6	170.8	179.8	90.5	128.8	155.4	291.0	237.6	245.5	2,177.0
Würm	123.3	117.3	125.5	108.2	119.6	125.9	63.4	90.2	108.8	203.7	166.3	171.8	1,524.0
Lokve-dam													
Today	176.8	140.0	160.3	156.3	145.3	173.1	68.5	120.0	195.9	279.5	250.5	259.5	2,125.7
Würm	123.7	98.0	112.2	108.4	101.7	121.2	48.0	84.0	137.1	195.7	175.4	181.7	1,488.1
Parg													
Today	113.9	104.5	121.9	133.0	140.6	161.4	82.9	138.1	171.6	259.0	180.0	164.4	1,771.5
Würm	79.7	73.2	85.3	93.1	98.4	113.0	58.0	96.7	120.1	181.3	126.0	115.1	1,239.9
Lividraga													
Today	266.0	184.6	286.8	179.1	317.7	230.8	70.3	184.4	352.1	512.5	292.2	886.4	3,962.6
Würm	186.2	129.2	200.8	125.4	222.4	161.6	49.2	129.1	246.5	358.8	204.5	620.5	2,634.2
Risnjak													
Today													3,358.2
Würm													2,350.7

Table 5 Average annual quantities of precipitation today (Lividraga 1981-1984; Delnice, Lokve-dam, Parg 1981-1994; Risnjak 1963-1993) and reconstruction for the maximum of the Würm.

Meteorological station	Classic rain-gauge (today)	Rain-gauge with a net (today)	Rain-gauge with a net (reconstruction for the Würm)
Delnice	2,177.0	5,420.7	3,794.5
Lokve-dam	2,125.7	5,293.0	3,705.1
Parg	1,771.5	4,411.0	3,087.7
Lividraga	3,762.6	9,368.9	6,558.2
Risnjak	3,358.2	8,361.9	5,853.3

Table 6 Quantities of precipitation in the meteorological stations Delnice, Lokve-dam, Parg and Lividraga, and on the Risnjak summit measured by means of a classic rain-gauge, and reconstruction for measurments by means of a rain-gauge with a net (today and in the Würm).

4.1. THE SMREKOVAC AREA

Average height of the ridge: 1,349 m (Northern Mali Risnjak 1,434 m - Veliki Risnjak 1,528 m - Southern Mali Risnjak 1,448 m - Janjičarski vrh 1,314 m - Veliki Bukovac 1,266 m - Mali Bukovac 1,263 m - hill 1,190 m)

Lower height of the glaciers limit - moraine Šegine: 950 m

Local snow-line: 1,150 m

4.2. THE RADEŠEVO AREA
(chiefly the area of Croatian Snježnik)

Average height of the ridge: 1,412 m (Lazačka glava 1,426 m - Croatian Snježnik 1,505 m - Veliko Radeševo 1,363 m - hill 1,351 m - Cajtnik 1,416 m - Veliki Risnjak 1,528 m - Northern Mali Risnjak 1,434 m)

Lower height of the glaciers limit - moraine Lazac: 1,060 m.

Local snow-line: 1,236 m

Lower height of the glaciers limit - moraine Gašparac: 940 m

Local snow-line: 1,176 m

In the studied area some glacial erosion and accumulation forms, according to their location and exposition, suggest the conclusion that they are not the result of the glaciers with the starting point in the area of the Risnjak mountain massif, but their emergence is connected with the work of the glaciers from Slovenian Snežnik. As the research has so far been linked only to the Risnjak mountain massif, the local topographic snow-line of the Snežnik glaciers was taken from the work of ŠIFRER (1959) dealing with the problems of the Pleistocene glaciation on Notranjski Snežnik.

4.3. THE SLOVENSKI SNEŽNIK AREA

Snow-limit: 1,250-1,300 m (ŠIFRER, 1959)

The local snow-lines in the area of the Risnjak mountain massif in the Pleistocene were about 100-150 m lower than on the Slovenian Snežnik (according to ŠIFRER, 1959) and about 150-200 m lower than on Velebit (according to BOGNAR et al., 1991). Such a relatively lower snow-line can be explained by the northern exposure, relief protection and greater quantity of precipitation on Risnjak.

5. RECENT SNOW-LINE

On the basis of the previously defined Pleistocene snow-line and vertical temperature gradient, (between the meteorological station in the valley and the one placed very high, as close to the Pleistocene snow-line as possible), it is possible to calculate the Recent snow-line (the height above which conditions exist for glacial processes today). On the basis of observation, the snow-line of some glaciers in Europe (MESSERLI, 1967) has been defined, after that the average monthly temperature of the warmest month in the snow-line area was calculated, as 4.5°C. While calculating the average value, according to Messerli, a mistake from ±1.3 to ±1.4°C is possible, which corresponds to the height of +200 m of the snow-line. Following the same principle the Recent snow-line has been calculated for Risnjak.

The average value of the snow-line in the Risnjak area in the Pleistocene amounted to 1,190 m of the height above sea-level; the temperature of the warmest month in Lividraga (935 m) was 15.4°C, and by application of the already known vertical temperature gradient of 0.55°C/100 m, the temperature of the warmest month in the Pleistocene snow-line area was calculated. It amounts to 14.0°C. The Recent snow-line was calculated by means of the temperature fall of 0.55°C with every 100 m. Today, in the Risnjak area, it would be at the height of 2,890 m (then the temperature of the warmest month in the snow-line area amounts to 4.65°C - what corresponds to Messerli's method). As the Risnjak massif is far below that height, only periglacial erosion is possible in that area today.

6. CONCLUSION

New study in the area of the Croatian Dinarides discovered a series of traces of Pleistocene glaciation on many mountain ranges and massifs. The Risnjak mountain massif and the Croatian Snježnik mountain range are two of them.

By means of morphometric analysis, reconstruction of the palaeoclimatic conditions, and fixing of the spatial arrangement of the glacial relief forms, we can conclude that glaciation took place in the part of the Risnjak mountain massif above 1,150 m above sea-level, and in a part of the area of the Croatian Snježnik mountain range, then in a part of the Obruč range, and that it was in spatial connection with the glaciers from the Slovenian Snežnik.

This suggests the fact that the Pleistocene glaciation of the Dinaric mountain system in Croatia was far more wide-spread and prominent than was previously thought.

Therefore further research on all mountain massifs and ranges above 1,300-1,400 metres is necessary in order to complete the geoscientific and general natural-scientific cognitions about the form, intensity and temporal duration of the glaciation in Croatia.

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