Large Canyons in Dinaric and Prokletije Mountains Region of Montenegro

Predrag Djurović,
Aleksandar Petrović

Abstract
Montenegro occupies relatively small, southeastern part of the Dinaric mountains. Geological composition, which is predominantly carbonate, enabled formation of a great number of deep canyons and gorges. Canyons of Montenegro were formed in several ways, during multiple phases.
Regardless of polygenetic and polymorphic character of the canyons, they can be classified into three main groups.
By incision of melt-water rivers of Pleistocene glaciers, deep and particularly narrow canyons of small width were formed. The rivers that presently flow through these canyons have a nival regime – during the summer, their discharge is minimal, or they completely dry out. Depths of these canyons are up to 500 m.
Rivers that directly feed into the Adriatic sea are of torrential character. They have pluvial regime, and dry out during the summer. Their canyons are short, several hundreds of metres deep.
Deepest and longest canyons have been formed by incision of rivers that have changed their regimes during a longer period of time. Melt-water of Pleistocene glaciers has incised the greatest parts of canyons at the beginning of Holocene. Presently, river courses have nival-pluvial regime. In this group, single-phase and multiple-phase canyons can be distinguished (alteration of erosional and accumulation processes). Depths of these canyons exceed 1000 m.
Key words: canyons, Montenegro, Dinaric, Prokletije

Geography faculty, University of Belgrade, Studentski trg 3/III, 11000 Belgrade, Serbia

Introduction

Dinaric Mountains occupy considerable part of Montenegro. This mountain system extends from north-western to south-eastern part of the country, where it turns to mountains of Prokletije system (Fig. 1).

In south-western part of the country, the Dinaric Mountains rise from the sea-level and make a range of coastal mountains (Orjen, Lovćen, Rumija, etc.). Further towards the hinterland, there are ranges of mountains which stretch in the direction north-west – south-east. These mountains are of medium altitude (up to 2000 m a.s.l.) and they represent dissected remnants of upthrown Pliocene plateaus (mountains Njegoš, Prekornica, Garač, etc). Further on, in the direction of internal parts of the Balkan Peninsula, there are the highest mountains of Montenegro. They maintain the same direction as two previously mentioned ranges, but the altitudes are between 2000 and 2500 m a.s.l. (mountains Volujak,

Figure 1 Geotectonic relations in south-western part of the Balkan Peninsula

Durmitor, Ljubišnja, etc.), and Prokletije mounts (Žijovo, Bogićevica, Visitor, Zeletin, etc.) (Petrović, 1985). Big canyons of the Dinaric and Prokletije mountains are parts of valley systems in the basins of the Adriatic and the Black Sea (Fig. 2).

Conditions for Genesis of the Canyons

Three factors had the main impact on the genesis of big canyons. Those are: characteristics of the respective rivers, geological composition, and tectonic movements.

Characteristics of the rivers have been constantly changing during a longer time span. There have been changes in discharge, in conditions of feeding, in types of river courses, etc. Repeated and strong climatic changes during the whole Quaternary have considerably influenced formation of canyons, mostly their depth and length, but also their general appearance. In the glacial phases of the Pleistocene, great quantities of water were accumulated as glaciers in mountainous areas. Therefore the discharges of rivers were smaller. The rivers were formed mostly from glacier meltwater, during short cold summers, when the discharge was in maximum. During the interglacial phases of the Pleistocene, the water accumulated in glaciers was quickly melting, which resulted in multiple increases in discharges. In this period, the river courses were fed both by meltwater and rain. Consequently, the erosion increases and in these phases reaches its maximum. The greatest incision took place in this period. During the Holocene, after melting of glaciers, feeding of river courses considerably changed, depending on the location. In coastal mountains, the precipitation is in the form of rain, so there is no retention in the accumulated snow. Precipitation maximum, as well as discharge maximum, occurs in winter. Long summer droughts have negative impact on discharges. Therefore the erosional activity is takes place in relatively short, winter part of the year. In high mountain areas, the precipitation maximum is also in winter, but in form of snow. In spring, the river courses are fed by meltwater, and also by rainwater due to second precipitation maximum. The discharges are considerably increased, as well as the erosional effect – much more than in the coastal area. Present climatic conditions, influenced by Mediterranean climate, great altitude and dissection of relief, have caused great quantities of precipitation in this area. In hinterland of the Boka Kotorska Bay, on Mt.Orjen, the average precipitation quantity exceeds 4500 mm, while the maximum reaches 8000 mm. Towards the continental area, the precipitation decreases, although the yearly averages are still high – about 2000 mm (Fig. 3).

Figure 2 Positions of large canyons in the Montenegrian part of the Dinaric and Prokletije mountains

In geological composition of the mountains in Montenegro, carbonate rocks dominate (Fig. 4). Large areas of limestone of considerable thickness and purity enabled the development of karstic process and formation of karst relief in large part of Montenegro. Non-carbonate rocks occur in isolated patches, and are represented by clastic, metamorphic and igneous rocks (Bešić, 1969). Such geological composition had a favourable impact on canyon formation. Resistance of limestone to fluvial erosion enabled the incision of valleys with vertical sides. Furthermore, sinking of precipitation waters on limestone has prevented (or considerably decreased) the denudational processes on valley sides and thus preserved their vertical inclination.

The whole Dinaric and Prokletije mountains area is characterized by strong tectonic activity (Ivanović, 1991). The consequences of these activities are considerable vertical displacements – uplifting and downthrowing of relief. Except the parts around Skadar basin and Boka Kotorska Bay, which are being downthrown, all other areas are being uplifted. Mountainous areas are being particularly uplifted, with determined recent upthrows of 2, 4 and more millimeters per year (Fig.5). These recent uplifts, which are the continuation of

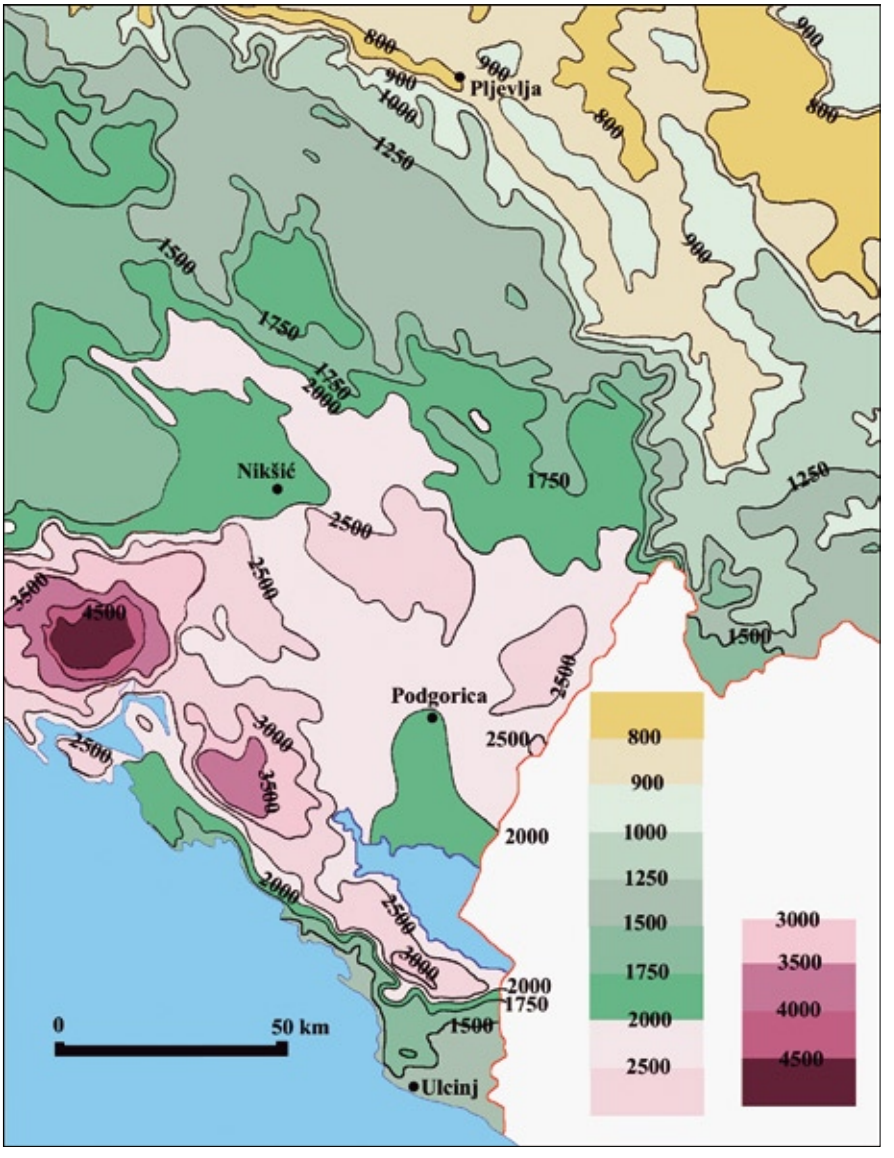

Figure 3 Yearly precipitation (after: Atlas klime SFRJ, 1969)

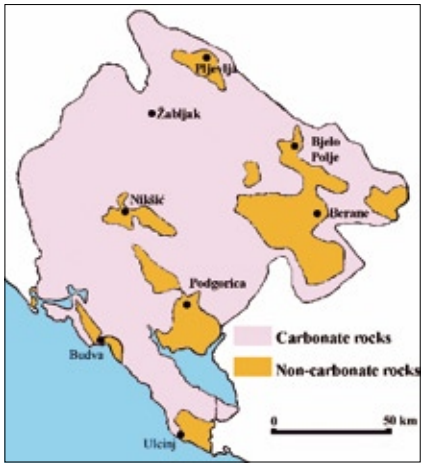

Figure 4 Extent of carbonate rocks in Montenegro

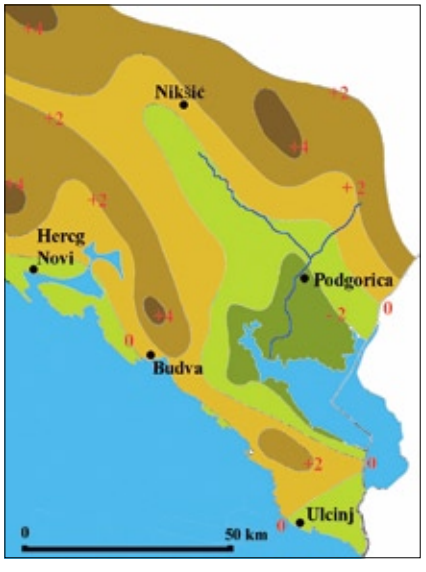

Figure 5 Recent vertical movements in Montenegro

Table 1 *Large canyons in Montenegro*

№	Name of the canyon	River	Length (m)	Depth (m)
1	Kazani	Ćehotina	1790	300
2	Kanjon Pive	Piva	31240	1034
3	Kanjon Sušice	Sušica	9200	684
4	Kanjon Komarnice	Komarnica	25150	761
5	Kanjon Tare	Tara	79400	1341
6	Kanjon Drage	Draga	5905	855
7	Kanjon Lima	Lim	3005	517
8	Đalovića klisura	Bistrica	8520	627
9	Kanjon Pridvarice	Pridvarica	3710	300
10	Kanjon Bukovice	Bukovica	3050	535
11	Kanjon Mrtvice	Mrtvica	6667	1247
12	Kanjon Morače	Morača	31676	1168
13	Kanjon Trebješnice	Trebješnica	2580	320
14	Kanjon Kruševačkog potoka	Kruševački potok	4400	1008
15	Kanjon Male Rijeke	Mala Rijeka	11391	814
16	Žljeb	Žljeb	1680	310
17	Kanjon Radmanske rijeke	Radmanska rijeka	1480	200
18	Kanjon Ibra	Ibar	7100	151
19	Kanjon Škurde	Škurda	840	907
20	Kanjon Cijevne	Cijevna	12400	903
21	Brcki kanjin	Brcka rijeka	1450	516
22	Kanjon Rikavac	Rikavac	370	130
23	Kanjon Vruće rijeke	Vruća rijeka	3260	970
24	Kanjon Starobarske rijeke	Starobarska rijeka	1530	344
25	Kanjon Grlje	Grlja	420	120

similar displacements from the latest geological past (Pliocene – Pleistocene) are determining the fluvial process. In riverbeds the vertical incision is dominant, while lateral erosion occurs only in smaller portions. These portions are mostly composed of non-carbonate rocks, or belong to the areas of neotectonic downthrow. Therefore, such a great number of river courses have incised canyons and gorges.

Genetic Types of Canyons

Various characters of river courses and their changes during longer periods of time have influenced the formation of three types of canyons:

1. Canyons formed directly by glacial meltwater streams
2. Canyons formed by river courses with glacial-nival regime
3. Canyons formed by torrent streams

1. Canyons formed directly by glacial meltwater streams

The end of the Pleistocene marks withdrawal of glaciers in high mountains of Montenegro (Cvijić, 1899, 1903, 1913), until their almost complete disappearance (the only example of a small recent glacier is Debeli Namet on Mt.Durmitor) (Djurović, 1999). Some glaciers, moving down the mountain sides, have particularly carved some parts of glacial valleys (Fig. 6a). Therefore, the glacial valleys do not have continual inclination, but a number of higher and lower parts of the valley bottom. During the glacial retreat, the downstream end of glacier is situated in various parts of previously formed glacial valley. In higher parts of the valley bottom, the meltwater stream starts to incise the bed in the valley bedrock. The critical moment for formation of this kind of canyons is when the glacier ends on the upper point of the high part of the valley bottom (Fig. 6b). Previously formed stream bed retreats simultaneously with the final part of the glacier, thus incising into the high (convex) part of the valley bottom. By further retreat, the glacier end becomes lower than the upper point of the high part of the valley bottom (Fig. 6c). This is when formation of the canyon actually starts. The glacier continues with retreat down the high part of the valley bottom, while meltwater stream continues to incise the canyon. The incision contin-

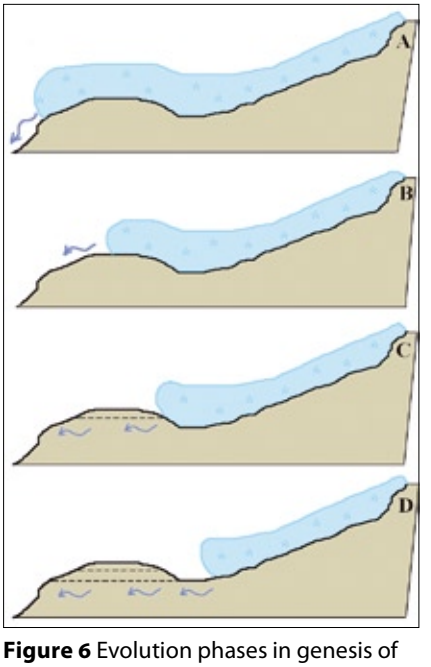

Figure 6 Evolution phases in genesis of the canyons formed directly by glacier meltwater streams

ues even after the glacier retreats far from the entrance to the canyon (Fig. 6d). After complete withdrawal of the glacier, erosional activity of meltwater stream turns to fluvial erosion. Due to mountain climate, the stream has the nival regime. The complete incision reduces the altitude differences between the entrance and exit part of the canyon, thus contributing to the balance of the longitudinal valley profile.

Basic morphometric characteristics of the canyons formed by meltwater streams are extremely small width (10 to 50 m), and totally vertical sides, which are at some places exceeding 90°. In the sides of the canyons, there are remnants of erosional pots, formed by whirlpool flow of meltwater streams. These remnants can be seen on the cross sections from top to bottom of the canyons. Longitudinal profile of the canyon shows numerous escarpments, which are actually the sides of present erosional pots, still being formed at the bottom of the canyons. These canyons are of relatively small depth, because it is determined by vertical difference between high and low parts of glacial valley bottom. In post-glacial period, entrenchment of the canyons continues, but due to carbonate composition and sinking of waters, the discharge is considerably reduced. It often happens that the river courses dry out during the summer. This interrupts the yearly continuity of the fluvial process, as the dominant geomorphological process. In Montenegro there are two canyons formed directly by meltwater streams (Tab.1). Nevidio Canyon is situated in Dinaric Mountains (Fig. 7), while Grlja Canyon is on Mt. Prokletije (Miljković, Petrović, 1990). Both canyons were formed in the same way. They have been incised in the last phase of the Pleistocene and during the whole Holocene, and are the youngest canyons in Montenegro.

Figure 7 Cenyon Nevidio and Komarnica river canyon

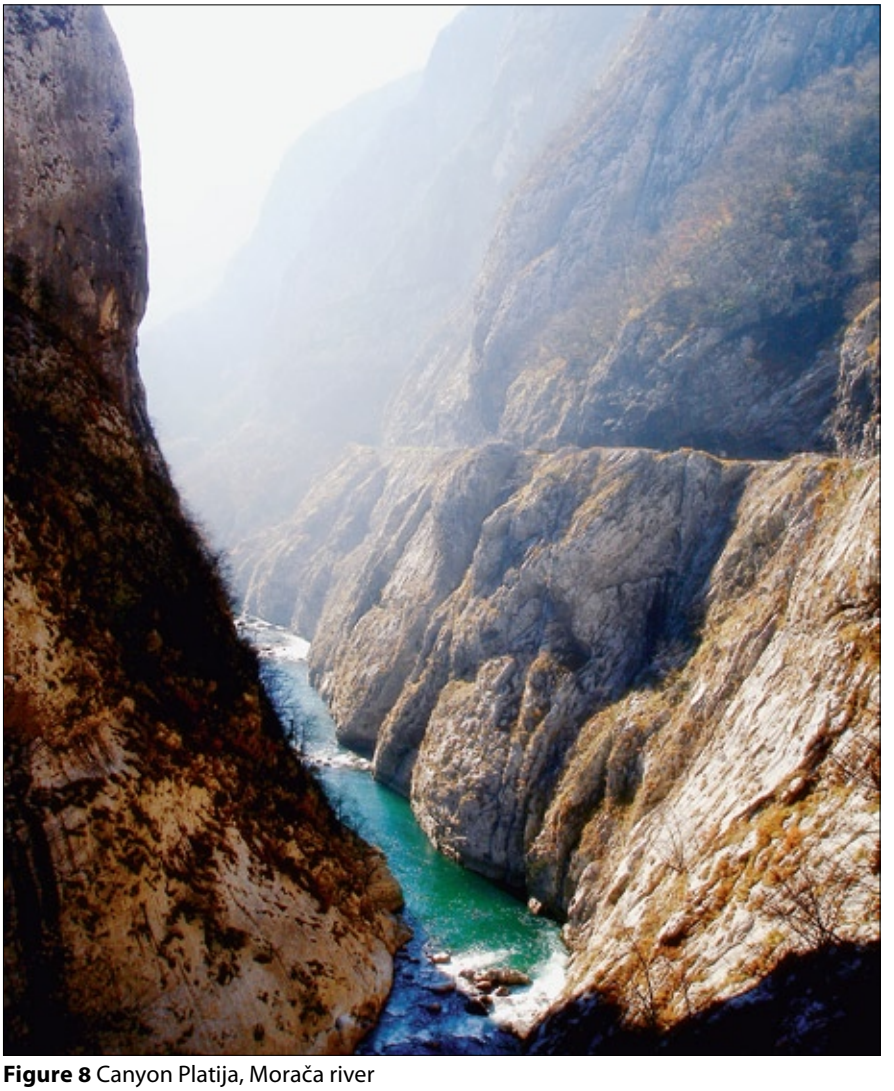

Figure 8 Canyon Platija, Morača river

2. Canyons formed by river courses with glacial-nival regime

Incision of deep and long canyons took part in longer time span, with considerable changes of climatic conditions and tectonic movements in their basins.

During the whole Quaternary, climatic oscillations were conspicuous, which resulted in changing of the character of rivers. These changes lead to morphological changes in the canyons. Erosional effect of rivers differs throughout the year, depending on the discharge. The greater the discharge, the greater the mechanical strength of the river. For mountain rivers, increase in discharge occurs in spring, because the rainwater of the secondary precipitation maximum joins the meltwater of snow accumulated during winter. In this way, the quantity of precipitation collected during one half of the year performs the

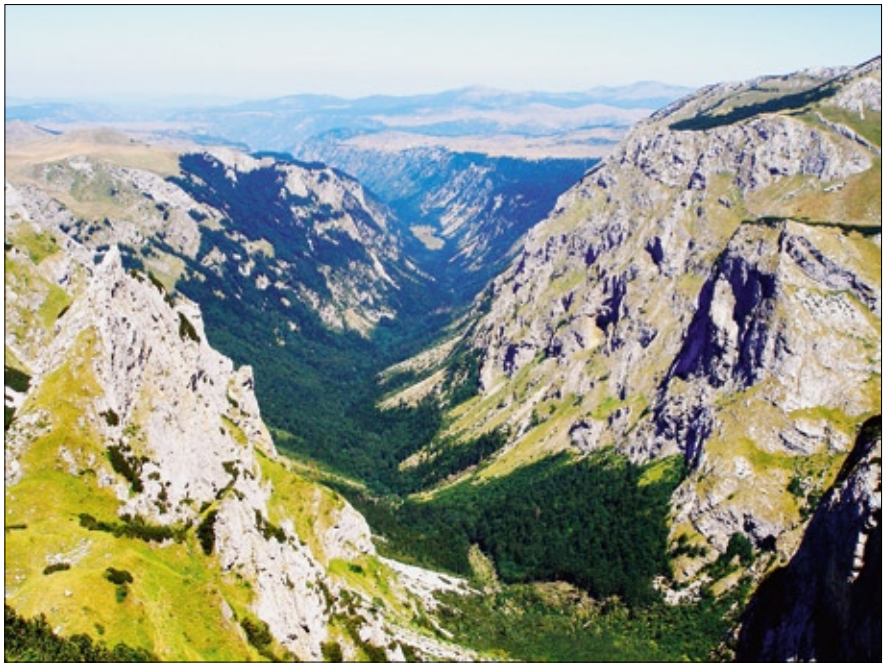

Figure 9 Sušica river canyon

fluvial erosional activity during only three months in spring. Therefore the erosional effect is considerably higher than in the areas with different climatic characteristics. Erosional fluvial activity was even higher when rainwater and winter snow meltwater were strengthened by glacial meltwater. Formation of glaciers and accumulation of water took place during the glacial phases, while rapid melting and erosion by meltwater followed during the interglacial periods.

Judging by the intensity of recent neotectonic uplift (2 to 4 mm per year), without the detailed analyses of tectonic activity during the Quaternary, we can say that the tectonic conditions have been almost ideal for formation of deep canyons. The uplift of the relief has been faster or slower, but constant.

Variations in discharges, as well as neotectonic lowering of downstream parts of some canyons have lead to sedimentation of great quantities of fluvial material. The bottoms of the river canyons of Tara and Morača (Fig. 8) (Milojević, 1938) were filled with pebble. The Tara river canyon was filled up to 120 m of relative height (in relation to the present level of river bed). Subsequent climatic changes have caused the changes in erosion, so these accumulations have been cut through and preserved as terraces.

By combination of two most significant factors (permanent uplift of relief and great intensity of fluvial erosion), long and very deep canyons have been incised. Incision of the canyons took part in longer period of time, under the influence of climatic fluctuations during glacial and interglacial phases of the Quaternary. Depths of the canyons exceed 1000 m. Denudational processes on the sides of the canyons have lead to their considerable widening.

Taking into account that the studied area is relatively small (the whole Montenegro covers only 13812 km^2), the number of canyons with depths over 1000 m is significant. We can point out the canyons of the rivers Tara, Mrtvica, Piva, Sušica (Fig. 9), Draga, Morača (Platije), Cijevna (the last is in Mt.Prokletije). Apart from great depths, these canyons are famous for their lengths as well (Tab.1).

3. Canyons formed by torrent streams

Coastal part of the Dinaric mountains is characterized by vertical sequence of carbonate and non-carbonate zones. Great inclinations of the terrain (due to rapid uplift of coastal mountains from the sea level to about 1800 m a.s.l.) and great quantities of precipitation during winter have made the conditions for incision of relatively short, but deep canyons. Upstream parts of river courses are formed in impermeable Eocene clastic sediments, while downstream parts are composed of limestones. Considering the extremely high winter precipitation maximum, such geological composition causes the formation of torrent streams in upstream parts of drainage areas. These streams form short, several hundreds of meters deep canyons. During summer, flows in these canyons dry out. The sides of the canyons are very steep, almost vertical. Neotectonic uplift enables constant incision. Close to their mouths to the Adriatic Sea, these rivers have formed wide alluvial fans.

Conclusion

The most significant conditions for formation of big canyons of the Montenegrian part of the Dinaric mountains are characteristics of the river courses, geological composition and tectonic movements. By combined influence of these factors during various time spans, various canyons have been formed: those incised by direct erosion of glacial meltwater, those incised by rivers of glacial-nival regime, and those incised by torrent streams. The deepest canyons were formed during the whole Quaternary, and their morphology is a consequence of climatic changes in this period. The depths of the canyons exceed 1000 m. The canyons incised directly by glacial meltwater have been formed since the end of the Pleistocene. Their depths reach 500 m, but they are extremely narrow. The canyons incised by torrent streams are through gorges of coastal rivers. Their lengths are small, and the depths reach 500 m.

References

Atlas klime SFRJ, Savezni hidrometeorološki zavod, Beograd, 1969

Bešić, Z. 1969. Geologija Crne Gore - Karst Crne Gore, no. 2, Zavod za geološka istraživanja Crne Gore, Titograd, 1-304

Cvijić, J. 1899. Glacijalne i morfološke studije o planinama Bosne, Hercegovine i Crne Gore, Glas SKA 57, 1-196

Cvijić, J. 1903. Novi rezultati o glacijalnoj eposi Balkanskog poluostrava, Glas SKA 65, 185-333

Cvijić, J. 1913. Ledeno doba u Prokletijama i okolnim planinama, Glas SKA 109, 187-266

Djurović, P. 1999. Natural and athropogenic influences as threats to pits in the Debeli namet glacer (Durmitor nacional park, Montenegro), Contribuction del estudo cientifico de las cavidades karsticas al conocimiento geologico, Patronato de la Cueva Nerja, Instituto de Investigacion, Malaga, 579-585

Ivanović, S. 1991. Zemljotresi - fenomeni prirode, Crnogorska akademija nauka i umjetnosti, Građevinski fakultet Univerzita "Veljko Vlahović", Titograd, 1-207

Milojević, B.Ž. 1937. Visoke planine u našoj kraljevini, Državna štamparija, Beograd, 1-459

Miljković, Lj., Petrović, J. 1990. Dolina Vrulje sa posebnim akcentom na kanjon Grlje, 4. skup geomorfologa Jugoslavije, Geografski fakultet PMF u Beogradu, Beograd, 81-86

Petrović, J. 1985. Prokletije - geomorfološke odlike, Prokletije - zaštita i unapređenje Plavskog dela Prokletija, Republički zavod za zaštitu prirode Titograd, Skupština opštine Plav, Plav, 39-50