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THE IMPACT OF GLACIAL PROCESS ON THE EVOLUTION OF POLJES IN MONTENEGRO

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Abstract

Poljes of Montenegro are formed within the Dinaric mountain system. These poljes are usually small surface, only several square kilometers. They are located at different altitudes from 6 to 1305 m a. s. l. The glacial process had direct and indirect impact in the development of poljes. The direct impact reflected in the fact that during the strongest glaciations, the absolute dating was established that occurred during the MIS 12, when many glaciers descended right into poljes, where they are deposited large amount of moraine material. Because of this some part of poljes were covered by moraines. During the Later glacial phase (MIS 6) scope of glaciations was significantly lower, and glaciers were not descended into poljes. The indirect impact reflected in the strength of river transport, which is increased by melting of glaciers. The consequence of increased power river was transporting glacial material, which infilling, uplifting and leveling bottom of poljes. All of this had a significant impact on water circulation in the karst. The recent period represents the end of transport of glacial material, dominance of karst processes and plunge of river flows.

Keywords*: glacial process, polje, glacial deposit, Montenegro, Dinaric karst*

INTRODUCTION

Montenegro is in the southeastern part of the Dinaric mountain system. The largest area builds carbonate rocks. The most abundant are Mesozoic limestones. Limestones are widely distributed, almost pure, reaching in thickness a few thousands meters [1]. Karst terrains extend from the sea-level to the highest altitudes (from 0 to 2528 m a.s.l.). Modern karst evolution is under the influence of different climate impacts. The average annual precipitation decreases gradually from the coastline and the coastline mountains (Crkvice – 4621 mm), over the mid-karst terrains (Žabljak – 1471 mm), towards the inner zone (Pljevlja – 802 mm) [2]. The highest average annual temperature is recorded in the lower coastline area (Herceg Novi –15.7°C). Temperature drops with elevation from 10.7°C (Nikšić – 647 m a.s.l.) [2] in mid-elevated karst areas and 4.7°C in mountainous region (Žabljak – 1450 m a.s.l.), to 0.3°C in the high-mountainous area (2450 m a.s.l.) [5]. The highest elevated karst terrains were imposed to glacial process during Pleistocene that considerably changed previous relief and played important role in the creation of modern relief. Glacial process took part in three stages [3], [4], [7], [8]. The oldest one took part during MIS 12 (470-420 ka), younger in MIS 6 (190-130 ka) and the cirque stage during MIS 5D-2B (110-11.7 ka) [7] [8]. Karst relief in Montenegro includes the smallest forms (kamenitze, karrens), various sinkholes and uvalas, and the largest forms – polje. The evolution of karst poljes was influenced by different geomorphological processes, which left behind significant traces to their present look.

GEOGRAPHICAL POSITION

Poljes in Montenegro are exposed at different altitudes, from 6 m a.s.l. (Skadar – crypto depression - 60 m) to 1305 m a.s.l. (Drobnjačko polje) (Fig. 1). Poljes are drained from different basins. The river Zeta supplies water to the poljes Ivanje (1090 m a.s.l.), Lukovsko (815 m a.s.l.), Nikšićko (595 m a.s.l.), Bjelopavlićko (35 m a.s.l.), Drezga (60 m a.s.l.), Kopilje (585 m a.s.l.) and Radovče (845 m a.s.l.).

Figure 1. Poljes in Montenegro

Downstream catchments of the river Morača discharge into the Cetinjsko (635 m a.s.l.) and Skadarsko polje (6 m s.l.). Catchment of the river Tara supplies Bitinsko (1180 m a.s.l.) and Drobnjačko poljes (1305 m a.s.l.), whilst Dragaljsko (600 m a.s.l.), Grahovsko (685 m a.s.l.) and Njeguško poljes (840 m a.s.l.) are drained by catchments of the Bay of Boka Kotorska. Finally, the river Trebišnjica provides water for the polje Velimsko (780 m a.s.l.).

METODOLOGY

Qualitative geomorphological analyses included analyses of aerial photographs (scale from 1:20 000 to 1:50 000) using remote sensing methods [6]. The main principles of geomorphological mapping were applied for the determination the boundaries between different types of relief, as well as for their graphic presentation [9]. Topographic maps in scale 1:25 000 served as the base for qualitative and quantitative geomorphological analyses. Distinct measuring parameters, prospection and separation of glacial and fluvial sediments including the volume and extent of their accumulation, were directly measured during fieldwork.

RESULTS

The primary (tectonic) phase in generation of the polje considers to pre-Quaternary evolution. Large areas of Dinaric Alps were affected with tectonic movements related to ascending and splitting. The rise and subsidence of limestone masses led to complete or partial destroying of certain valley systems. Surface links being broken in river system due to replacement of surface flows with underground ones. In the proceeding (erosion phase) in subsided fluvial, fluvial-karst and karst valleys re-modeling, widening and deepening of the primary tectonic landforms took part. Fluvial and karst processes on carbonate basement could not produce large amounts of sediments thus the feeding of poljes was minimal in given phase. Global climate changes during Quaternary caused the alternation of different geomorphological processes: glacial and fluvial, i.e. karst process. Yet in the beginning of researches was emphasized that the small elevation of the Dinaric Alps disabled glaciation, which became a significant geomorphological process in this area when the Dinaric Alps considerably ascends [3]. In the Montenegrin Dinaric Alps two glacial phases, during which glaciers advanced far from their cirques and one, actually two phases when glaciers retained in their cirques, took part [11], [4], [7], [8]. Quaternary sediments of glacial origin at Orjen, Durmitor and Sinjajevina mountains were dated using Th/U ratios [7], [8]. Cold periods, when glacial material is producing, alternate with warm pluvial periods during which a glacial material will be removed and transported to the lowermost levels – polje bottoms.

The amount and kind of material is different, as well as the velocity of the polje filling up. During cold phases, when glacial processes did not take part (before MIS 12) the cryo-nivation process was intensive. Although sediments formed by these processes could be transported to poljes, it was not discovered in poljes yet. Significant fill-up of poljes and ascend of bottoms started after the first glacial phase. During the first, the earliest and the most extensive glacial phase, the glaciers had much more extent and retreated further downward then will during the subsequent phase. Such conditions supported the formation of greater amount of moraine material at relatively low heights.

Glacial process is going to be replaced with fluvial-karst and karst at the end MIS 12. Re-transportation of material and consequent filling-up of poljes with rise of their bottoms have happened. The alternation of very coarse grained, fine grained and very fine grained, well-sorted material is obvious at opened profiles. The force of river flows varied: from strong torrential streams to weak and peaceful. Sorting of the mentioned material indicates on possible forming of lakes. The next climate change and the repeated alternation of the most dominant geomorphological processes (MIS 6) brought a moraine accumulation at higher elevations than earlier. The extent of glaciation was considerably lower. During the post glacial period the glacial material has been certainly re- transported supporting the continuation of filling-up of the karst fields and rise of their bottoms.

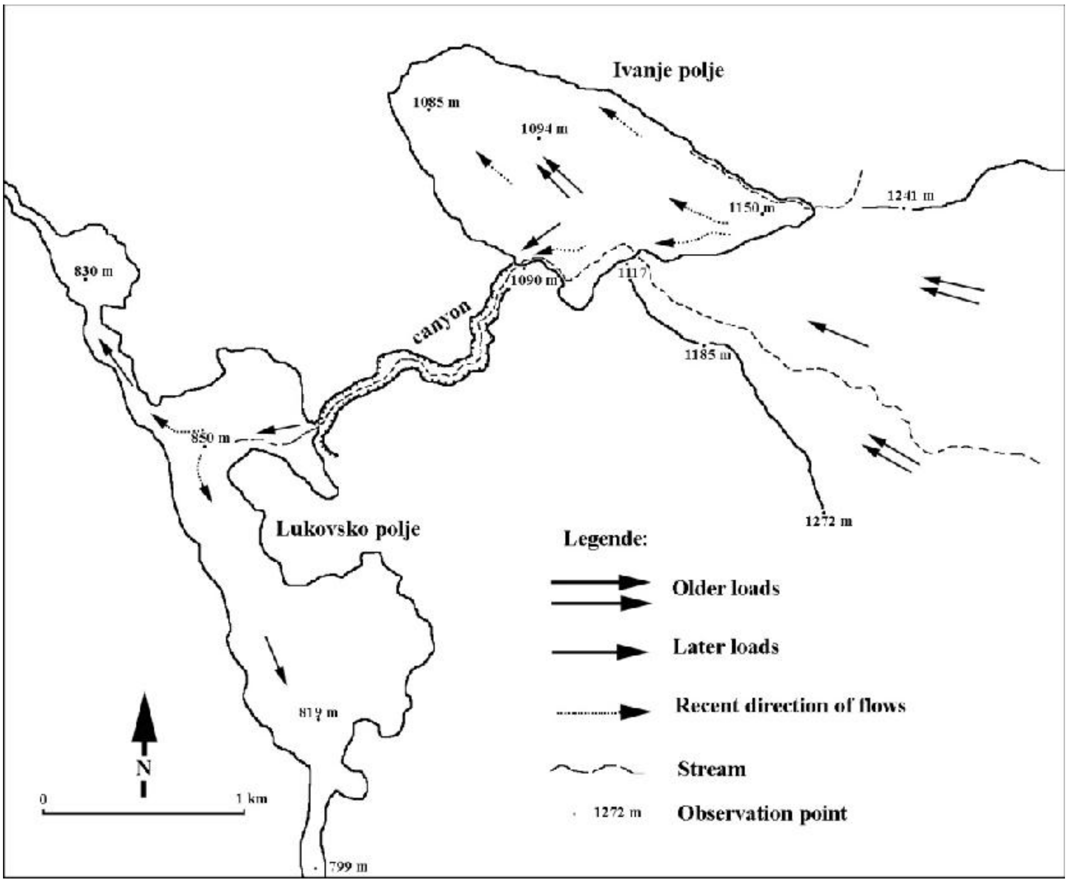

Figure 2- Lukovsko and Ivanje poljes

Step-sided, opened and mutually connected poljes (Ivanje – Lukovsko – Nikšićko) (Fig. 2) are in the catchment of the river Zeta. Bottoms of these poljes are covered by thick sedimentary layers and are more elevated than used to be primarily (since the erosion phase). The most elevated the polje Ivanje is largely covered by sediments, and is opened towards the lower positioned the Lukovsko polje. The first loading phase took part from the southeast and ended in the lowermost southwest. Loading included the remobilization of glacial material, which has been formed during the first glacial phase (Ninkovići Member ice masses 470-420 ka ~ MIS 12: Durmitor). The new phase of loading occurred after the second glacial phase (Zabljak Member ice masses, 190 - 130 ka ~ MIS 6: Durmitor) [7], when in the highest southeastern part in the polje Ivanje evolved a flooding fan. Flooding sediments built at the bottom a very low watershed from where surface waters are still flowing throughout the narrow canyon on the west towards the Lukovsko polje as well as on the northwest towards the lowermost point in the polje to disappear. The Lukovsko polje has been completely filled-up by re-transported glacial material from the polje Ivanje. The new-formed watershed within the accumulated sediments at the bottom pushed surface water on south towards the river Gračanica and to northwest towards the river Surdup.

Poljes Radovče and Kopilje were filled up similarly. Sediments from the higher-positioned the polje Radovče were after the already mentioned glacial phases re-transported through short and narrowed valleys into the polje Kopilje and further to the lower, Bjelopavlićko polje.

Loading with glacial sediments and rise of bottoms have experienced closed poljes: Dragaljsko, Njeguško, Grahovsko (Fig.3). Such, closed polje forms and evolves just like the presented opened poljes. However, the intensity of their fill-up with glacial material was of low intensity. Vast amounts of moraine material were noted along margins of Dragaljsko [7] and Njeguško poljes [10].

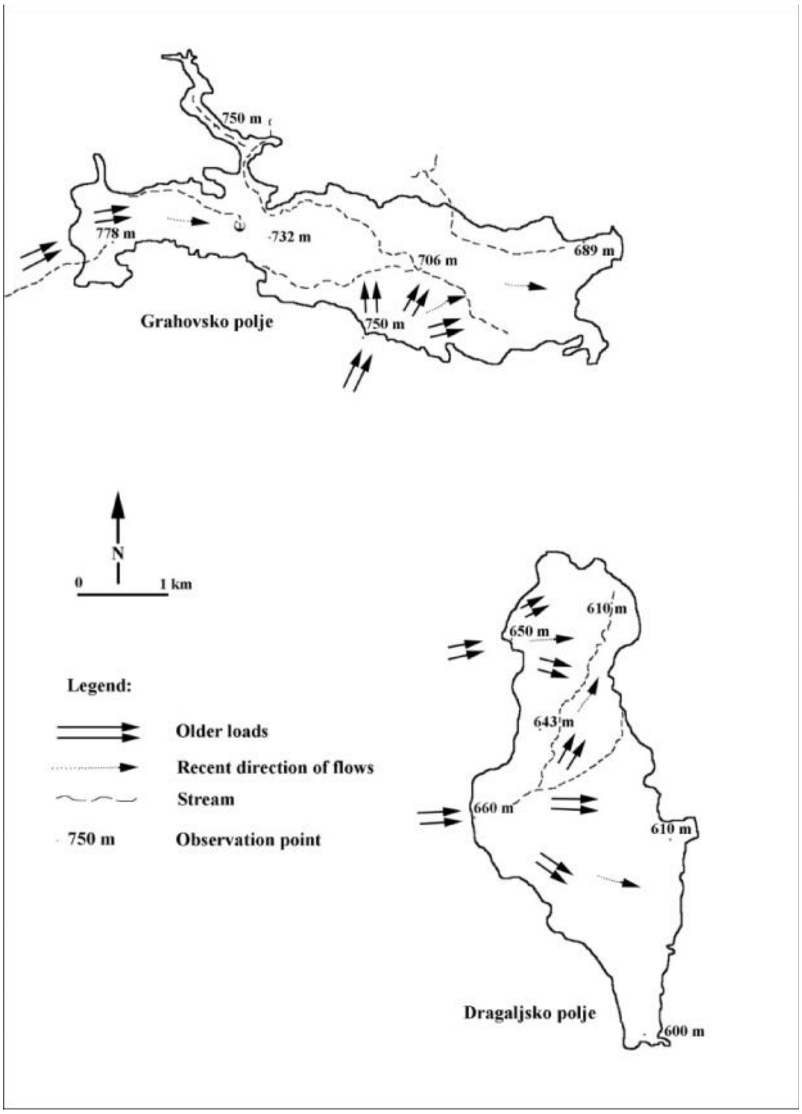

Figure 3- Grahovsko and Dragaljsko poljes

Correlation with the absolute age data [8], elevation and genesis of moraines on Durmitor and Sinjajevina indicated that these moraines were deposited during the strongest glaciation (MIS 12). Moraine material from the younger glacial phase (MIS 6) is exposed above. Although moraines in Dragaljsko and Njeguško poljes were deposited at their margins, they were not re-transported considerably. One of possible reasons for it is the high karstification, which forced a majority of surface water to sink and turn into the underground flows. Glaciers on Mount Lovćen produced the most distant moraines from the Cetinjsko polje [10], [12]. Consequently, the thickness of sediments, discovered in boreholes, is only 11 m.

Higher levels of the Drobnjačko polje were after the mentioned glacial phases covered with moraine material whose re-transportation led to covering and rise of bottom. Contours of the polje overlap with morphology of previous valley, which is still well-preserved. Considerable thickness of sediments, along with allogenic flows enabled preservation of watershed at the bottom and continual re-transportation.

The importance of glacial processes in filling of distinct poljes is either negligible, indirect or lack at all. The deposition of glacial material was disabled in the Velimsko polje due to distance from greater glacial centers. The Bitinsko polje, although located at the highest altitude, was not influenced by glacial processes. Accumulation in it was by fluvial processes. The lowermost Skadar polje is very far from glacial areas hence experienced only the indirect impact of glaciation. This could be inferred from larger amount of sediments that in a form of flooding fans carried the river Morača and deposited in its northeastern part.

CONCLUSION

The impact of glacial process on evolution of karst poljes in Montenegro is their filling and rise of their bottoms. In the opened poljes glacial material was transported from those at higher elevations into the lower ones. Certain poljes were completely filled with brought glacial material. Closed poljes, due to intensive karstification, have received considerably lower amount of glacial material. As the consequence, the less loading occurred. Transport of material took part during postglacial periods and after glacial phases MIS 12 and MIS 6. Poljes that are pretty distant from the glacial centers were instead directly influenced indirectly by glacial processes over larger amounts of sediments carried by rivers.

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