

**REGIONAL GEOMORPHOLOGICAL MAPPING OF MONTENEGRO:
LANDFORM GENESIS AND PRESENT PROCESSES**

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Abstract

As a contribution to the joint geomorphological research carried out by Ghent University and the University of Montenegro (<http://geoweb.ugent.be/physical-geography/research/western-balkans>) the main geomorphological features of Montenegro will be characterised and mapped. The main geomorphological regions were identified based on past research in the different geomorphological regions. A polje (Njeguse), a canyon (Kanjon Starobarske) and a debris fan and fluvial terraces (Moraca - Podgorica) will be mapped in detail using GPS measurements, topographic maps (1:25 000) and GIS software. Additionally, a large-scale geomorphological map of the Montenegrin territory will be created using existing literature, DEM, GIS software and soil samples. Homogeneous geomorphic units will be mapped using the geomorphon approach. Another aspect of this research concerns the formation of Skadar Lake, since existing literature shows contradictory theories: subsidence, or a rias coast that was isolated by the Bojana alluvial deposits, or a combination of both. Therefore, this region (including Bojana river alluvial plain and Ulcinj coastal dunes) will be subjected to sedimentological research. The resulting maps and sedimentological data will be used to fully understand the different formation processes of the present-day geomorphology. Furthermore, measurements and photographs will be used to assess the influence of land use changes on gully erosion.

Introduction

The fieldwork is performed in 2013 in order to map the most important geomorphological landforms in Montenegro. With these maps, an interpretation will be made of the landform genesis in addition to a clear visualization of the different geomorphological regions and features in the country. Furthermore, research is dealing with the main current erosion processes.

From a geographical point of view, three regions more or less homogenous – concerning climatology, lithology, hydrography and vegetation – can be described. Starting from the south, the Mediterranean coastal part (Coastal Montenegro), the Submediterranean central part (Central Montenegro) and the mountainous northern – north eastern part (Northern Montenegro) are discerned.

Geomorphological regions

Coastal Montenegro. Three north west – south east oriented (typical for Dinaric alps) units are aligned next to each other: the High Karst consists of Mesozoic carbonates, the Budva zone consists of Triassic limestone and the Dalmatian zone represents different linear structures consisting of Cretan-Eocene limestones (anticlines) and flysch deposits (synclines). The combination of these three zones results in quite a differentiated topography.

The High Karst zone and Skadar Lake. This limestone structure has been unequally uplifted; the altitude varies between 1300 m above Kotor to 200 m in the east. Apart from there, the

topography is karstic, with many dolines, sharp ridges and residual reliefs in the weathered limestones. On the bottom of the dolines and karstic depressions, small villages, farms and rural communities are concentrated. The High Karst zone consists of limestones and dolomites, heavily fractured by tectonic events.

In the southeastern part of this region the High Karst Zone borders Skadar Lake. Skadar Lake lays in a graben, filled with alluvial sediments from the Drin River, the longest river of Albania. For this reason, the lake is generally quite shallow (4 m), except for the part where the lake meets the valley of Rijeka Crnojevica. In this area the bottom of the lake gets very ragged with dolines, uvalas and sub-lacustrine sources (Nicod, 2003). Another theory about Skadar Lake states that the area was originally part of the Adriatic Sea (similar to Kotor Bay). The only connection with the Adriatic Sea would have been closed by a combination of alluvial sedimentation of the Drin and supply of aeolian from the coast to form dunes (Nicod, 2003).

The inland depression - Niksic Polje. In the inland depression 3 different regions are discerned: the plain of Podgorica on the debris fan of the Moraca River, the Zeta-valley and Niksic polje.

Durmitor. The Durmitor massif is one of the highest in the Dinaric Alps and very characteristic for its glacial and karst morphology and deep canyons. It dominates the surrounding karst plateaus: Jezera in the east and Piva in the North West, which are demarcated by the canyons. Durmitor consists of Triassic and Jurassic carbonates and late-Cretaceous flysch. Tectonic uplift is estimated to be quite slow (6 m/ka), with clear traces of past activity. The Bobotov Kuk fault is clearly visible in the relief, determining the orientation of the cirques and canyons. In the massif, numerous cirques are to be found, formed in the flysch rocks on the one hand and glacial karst cirques formed in the carbonates and dolomites on the other hand (Nicod, 2003).

Prokletije. Many authors have studied the physical-geographical characteristics of this area. Cvijic (1921) called attention to the geographical individuality of the Region, with special emphasis on the Prokletije mountain group. The major part of this massif lies within the territory of Albania and a smaller part in Kosovo, but still a considerable part of the area lies within Montenegrin territory. This part is one of the National Parks of Montenegro, alongside Biogradska Gora, Durmitor, Lake Shkodra and Lovcen. The Prokletije mountains are the highest massive of the Dinaric Alps, reaching a height of 2694m (Maja e Jezercë) in Albania and containing Zla Kolata, the highest peak of Montenegro at a height of 2534 m. The area has only recently been explored due to political instability and poor accessibility.

Across the border, in Albania, some still active glaciers were discovered on 15 september 2007, making it one of the southernmost glaciers of the European continent. In the Montenegrin part plenty of cirques, glacial valleys (e.g. Ropojana and Grbaja) and other periglacial evidences are found (Milivojevic *et al.*, 2008).

The northern crystalline hills. The only region not yet covered in this overview is the northern of Montenegro, including Biogradska Gora and the municipality of Bijelo Polje. Paleozoic clay and sand, Triassic red sandstone and dark ophiolites, are found (Ager, 1980). This geology is reflected in the landscape, where smooth hills and valleys are formed due to higher vulnerability for lateral erosion. Furthermore, this part belongs to the catchment area of the Black Sea and was consequently less influenced by sea level changes in the Mediterranean.

Geomorphological phenomena

Karst. As Radulovic (2013) writes: “Karst is a geological term which refers to a set of specific morphological forms of landscape that are the result of interaction between a number of factors, primarily water and water-soluble rocks. Therefore, karst forms are developed only in terrains made of soluble rocks, commonly limestones and dolomites, but also in terrain made of gypsum, anhydrite and halite rocks. Due to the solubility of carbonate rocks (limestones and dolomites), tectonic faults are expanded and secondary porosity of rocks is increased.” A major part of Montenegro is part of the Dinaric karst. This part geologically consists of limestone and dolomite sedimentary rocks, formed in favourable climatic conditions. Due to tectonic activity, folding, faulting and overthrusting increased the porosity of the rock, intensifying the karst processes. That caused the present-day very complex karst landscape, marked by karren, sinkholes (dolines), uvalas, poljes, dry valleys and caves (Radulovic and Radulovic, 1997).

Canyons. Very impressive in the karst landscape, numerous steep and narrow canyons deeply incised the rocks. It is safe to state that such deep incisions (500m to over 1000m) are unlikely to be caused only in Quaternary times. Most probably, these incisions are mainly caused by a more extreme sea level lowering event such as the Messinian Salinity Crisis. Canyons are often – if not always – part of a karst landscape because of the strong resistance of carbonate rocks to erosion, resulting in a vertical incision and thus narrow valleys (Djurovic and Petrovic, 2007).

Rias. The term ‘ria’ is used to describe a former river valley system developed in a high relief coast that is drowned by sea level rise. The resemblance of the morphology above current sea level to a fjord could cause some confusion, but as a ria coastal system has nothing to do with glacial erosion, the morphology of the drowned parts is different (Castaing and Guilcher, 1995).

In Montenegro, Kotor Bay (*Boka Kotorska*) provides a typical example of this phenomenon. These valley systems were formed before the Holocene due to glacial and interglacial sea level changes and especially during the Messinian Salinity Crisis (ca. 5,5 million years ago), when the Mediterranean Sea was nearly completely dessicated because of tectonic and glacio-eustatic uplift of Gibraltar Street. As a result, sea level – thus erosion basis - lowered with probably more than 1000 meters (Krijgsman *et al.*, 1999) which allowed regressive erosion in the landscape. The result is a very deep incised morphology under the current sea level by a river flowing in NE-SW direction, orthogonal to the orientation of the anticlinal structures with its tributaries, parallel to the anticlines. In the hard carbonates, narrow and steep valleys were incised while in the soft flysch layers the river and tributaries formed wide valleys, causing the NW-SE orientation of the bays (Magas, 2002).

Debris fan and river terraces. Many rivers developed in the Dinaric karst, often incising deep, narrow canyons, form wide alluvial fans when reaching alluvial plains close the sea (Djurovic, 2007). Upstream of Podgorica, the Moraca River has left a large debris fan.

During glacial periods in the Quaternary - meaning a lower sea level - the alluvial plain and fan were incised by the river due to regressive erosion. When sea level rose, aggradation took place, leaving a new layer of river sediments. In the alluvial plain of Podgorica and the debris fan, three or four (Keukelaar *et al.*, 2006) fluvio-glacial terraces can be recognized in the landscape caused by the interaction between the aggradation of the Moraca and Cijevna rivers and tectonic subsidence of the region (Nicod, 2003).

Coastal Dunes. Ager (1980) stated that an inlet of the Adriatic Sea would have been closed by dune formation as an explanation of Skadar Lake. Supporting for this theory is the present-day location of dunes in the area of Ulcinj (near the contact of the alluvial plain of Bojana river with the Adriatic) and the deep incised morphology in the north-western part of Skadar

Lake, very similar to the ria of Boka Kotorska. In addition to these findings, Google Earth shows the enormous alluvial cone from the Bojana River. More recent references are few but point out the fact that the lake is formed in a tectonic depression. The lack of more recent references about this subject makes it a potentially very interesting research object.

Glacial geomorphology. During several cold periods in the past a considerable part of Montenegro was covered by ice caps. The maximum extent of these ice caps is believed to be reached during the MIS (Marine Isotope Stage) 12, in the Middle-Pleistocene (ca. 470-420 ka). At that time, the Durmitor, Sinjajevina, Moraca, Magnanik and Prekornica massifs were covered by one huge ice cap with an area of nearly 1500 km². More recently, valley and cirque glaciers were formed in the Younger Dryas and some up-valley glaciers during the early Holocene (Hughes *et al.*, 2011). In Prokletije Mountains, three glaciation events with valley and cirque glaciers are recognised but no numerical dating has been done yet. Nevertheless it is assumed that the maximum glacial extent in this area took place in the Early- or Middle-Pleistocene, while the second event probably happened during the Last Glacial Maximum and the last during the Younger Dryas. The Orjen massif, close to the Adriatic coast (north of Herceg Novi) was regularly covered by an ice cap too (Milivojevic, 2008).

Since mapping and detailed description of the Durmitor and Prokletije regions with special attention for glacial geomorphology has already been done, these phenomena will not be part of the detailed geomorphological mapping.

Current erosion

Many factors have influenced the erosion processes in Montenegro. The most significant factors are the area's climate, relief, geological substrate and pedological composition, as well as the condition of the vegetation cover and the land use (Spalevi , 2011). Water erosion is the most important erosion type. It is caused due to precipitation and consecutive runoff primarily, but also by fluvial erosion in water streams (Kostadinov *et al.*, 2006). Kostadinov *et al* (2006) summarized erosion in Serbia and Montenegro using the categorization of Gavrilovi (1972). According to Spalevi (2011), Kostadinov (2006), Lazarevi (1996), water erosion has affected 13,135 km² or 95% of the total territory of Montenegro (13,812 km²). Given the extreme precipitation values in some parts of the country (the highest of Europe) the influence of this erosion type on the landscape is enormous. The erosion forms are often characteristic for karst regions, although other forms are observed as well. Following the categorization, almost half of the territory of Montenegro is exposed to medium (Spalevi *et al*, 2013, 2011, 2001) to excessive erosion, with highest values attained in the river catchments of Ibar and Piva and the coastal catchments (Spalevi *et al*, 2008, Kostadinov *et al.*, 2006, Lazarevi , 1996).

Geomorphological mapping methods

Geomorphological mapping is essential for us to be able to understand the landforms and their genesis. Pavlopoulos *et al.* (2009) explain why mapping of landforms can be very helpful. Probably the most important reason is that mapping gets you a precise visualization of the region, which helps to fully determine the underlying processes and formation history. Furthermore, landforms can be connected and compared to each other (Pavlopoulos *et al.*, 2009).

Naturally, the evolution of Geographic Information System (GIS) technology extends the possibilities to visualize and analyse landforms, using GPS and artificial intelligence (Bishop *et al.*, 2012). An advantage of the development of these techniques is that it allows a part of geomorphologic mapping to a certain level without being forced to visit or stay in the study area. As Poppe (2012) indicated, for recognizing landforms and patterns, free high-resolution

(until 30m) ASTER Digital Elevation Models can be downloaded and analysed using GIS-software and Google Earth can be used as well, albeit for small to medium scale.

Research objectives

From the beginning of the 20th century, plenty of research has been done about the landforms in Montenegro. However, writing this literature review, it became clear that not all the landforms are described and explained adequately. An attempt will be made to answer the research question (1) “*How did the geomorphology of Montenegro develop and what are its main features?*” Some answers were already given in the literature review. However, knowing that mapping is quite essential to determine underlying processes of landscape formation (see before), this will be the main part of the fieldwork.

First of all, it will be very useful to map Montenegro as a whole, with the different geomorphological regions and landforms, the main hydrography and the relief all put together in a clear, obvious way. A lot of geomorphological features have already been observed in detail by other authors, but too often the larger picture is missing, increasing the need for an overview. Creating this map will create a new overview of the geomorphology of Montenegro. For this map, the ‘geomorphon’ method (Jasiewicz and Stepinski, 2013) will be applied and compared to classic GIS-based methods.

The next objective of this research will be the mapping of some of the mentioned landforms in detail. For each landform a typical example is chosen using Google Earth and literature.

Landform types and/or locations of which a geomorphological map already exists are excluded. Consequently, glacial valleys of Durmitor (Hughes et al., 2011; Djurovic, 2009) and Prokletije (Milivojevic, 2008) will not be taken into account. Additionally, landforms that are smaller than 1 meter (such as karren) will not be mapped either. Njegusi is chosen as research area for a polje and Brca kanjon as a typical example of a canyon.

As written before, Montenegro is subject to intensive water erosion and land abandonment is identified as an important aspect, either favouring or countering land degradation. An answer on the following research question will be sought (2): “*What is the influence of land use changes on gully development?*” Based on the findings of Jeroen Van den Branden (2010), a few locations that satisfy these conditions will be defined. Other potential sites, including repeat photographs, have been preselected by promoters Prof. Dr. Nyssen and Dr. Spalevi . The results of this assessment will be mapped as well.

This part of the fieldwork will be executed in collaboration with Annelies Kerckhof, a fellow master student of the Department of Geography of Ghent University handling the interaction between humans and physical geography based on interview.

Materials and method

For the small-scale map (overview) including the complete territory of Montenegro, the most important task will be to assemble all the existing literature and maps and put them together in one uniform map, using the legend proposed by Pavlopoulos *et al.* (2009). As geomorphologic information about the northern crystalline hills is quite scarce, it is necessary to do fieldwork there. A GPS will be used to determine the size and location of the major landforms. After the fieldwork GIS-software and Google Earth will be used to assemble and optimize these data in one map.

The detailed mapping of the smaller landforms and Skadar Lake will also be executed with the use of GPS. An additional aspect here will be the research of soil particles, i.e. qualitative recognition of soil texture. Therefore, it will be necessary to take samples of certain sediments. These samples will afterwards be investigated in the lab in Ghent to acquire a

better knowledge about the geomorphological history that explains the formation of the landforms. This will be useful for defining the origin of the different sediments present in the polje and canyons. Moreover, to develop a theory of the exclusion of Skadar Lake from the sea by the Bojana cone and dune formation, it will be essential to establish this theory with appropriate sediments. Similar to the small-scale map, the legend of Pavlopoulos *et al.* will be used to represent the landforms with GIS-software. For this part, Google Earth will be more difficult to use, taking into account its precision is approximately 40 meters (Chang *et al.*, 2009). Furthermore, the use of a digital camera will be useful to be able to investigate certain small landforms again if necessary.

The fieldwork of gully development changes (reactivation of stabilization) due to land use changes will be carried out together with Annelies Kerckhof. Again, use of GPS will be needed; however more precise measuring instruments could be necessary. For this part, the use of photographs will be essential.

Conclusion

A variety of different processes in the past resulted in the formation of the present-day geomorphology of Montenegro. Since the end of the 19th century, researchers have been trying to explain the remarkable landforms. In this review, this research has been summarized to serve as a background and as a guide to the fieldwork that is performed in 2013 in the context of the master thesis: ‘Geomorphological mapping of Montenegro: landform genesis and current processes’.

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