Geological Quarterly, 2022, 66: 6
DOI: http://dx.doi.org/10.7306/gq.1638

Karst relief of the Mali me Gropa Massif, central Albania

Viacheslav ANDREYCHOUK[1, *], Romeo EFTIMI[2], Jerzy NITA[3] and Alexander KLIMCHOUK[4]

[1] University of Warsaw, Faculty of Geography and Regional Studies, Krakowskie Przedmieście 30, 00-927 Warszawa, Poland

[2] ITA Consult, Rr. Rreshit Çollaku, pll. 10/3/18, Tirana, Albania

[3] University of Silesia in Katowice, Faculty of Natural Sciences, Institute of Earth Sciences, Będzińska 60, 41-200 Sosnowiec, Poland

[4] National Academy of Sciences of Ukraine, Institute of Geological Sciences, Gonchara 55-b, 01-054, Kyiv, Ukraine

Andreychouk, V., Eftimi, R., Nita, J., Klimchouk, A., 2022. Karst relief of the Mali me Gropa Massif, central Albania. Geological Quarterly, 66: 6, doi: 10.7306/gq.1638

The mid-altitude mountain massif of Mali me Gropa is located in the central part of Albania, rises to an altitude of 1500–1800 m a.s.l., is composed mostly of Mesozoic limestone, and is characterized by extensive surface karst development. The karst relief is dominated by "doline" morphology including "polygonal" karst. Detailed geomorphological analysis of the western part of the Mali me Gropa massif (so-called Western Massif) by means of GIS methods is used to determine and explain the morphometric and morphological diversity of the area's topography. Based on a homogeneity criterion, a number of geomorphological units with specific kinds of karst relief have been distinguished within the massif. The differences in karst sculpture concern the size (diameter) of dolines and depressions, their depth, shape and symmetry, orientation, density of occurrence and spatial pattern, which provide the basis for distinguishing geomorphological units. The spatial differentiation of the karst relief is explained by the influence of factors which are evolutionary (geological and geomorphological evolution of the massif), hypsometric (altitude difference of terrains) and geomorphologic-structural (inclination of the slopes and layers). The relatively poor expression of open karst conduits (i.e. caves and vertical shafts) on the surface of the massif may result from the relative immaturity of the epikarst zone, the widespread occurrence of residual cover on the plateau, and the accumulation of large amounts of clay material in dolines and depressions. Detailed hydrogeological studies show, however, high karst permeability and dominance of conduit flow. Considering the high geomorphological landscape and ecological value of the area, it should be granted the status of a nature reserve or national park. Geomorphological and karstological research within the massif should be continued as it represents a type of karst found also in other parts of Albania. This type of karst area is of great economic (groundwater reserves) and natural protection (environmental) importance.

Key words: karst geomorphology, mountain karst, central Albania, Mali me Gropa massif.

INTRODUCTION

Karst landscapes in Albania cover 6750 km^2 (24% of the territory). Karst areas are distinguished on geomorphological and hydrogeological maps of Albania as 25 karst regions (Eftimi, 2020). Twenty-three of these, underlain by carbonate rocks, cover a total surface area of 6500 km^2, and 2 regions, comprised of gypsum, have a total surface area of 250 km^2. Mali me Gropa is one of the carbonate regions known for its well-expressed karst landscape. The karst of Mali me Gropa was first described by Desio (1960), who in his well-known Italian book "Manuale della Geologia Applicata" illustrated the karst chapter with pictures of Mali me Gropa. The mountain area of Mali me Gropa (in Albanian: "the mountain with holes") is located in central Albania, 20 km NE of Tirana. It rises to an altitude of 1500–1800 m a.s.l. and is composed mostly of Mesozoic limestone, the thickness of which reaches 800 m.

The area is an allochthonous block towering above the surrounding areas. The difference in relief, i.e. the difference between its largely flat upper part and its foot, is 550–800 m. This geomorphological condition, the clean and massive nature of the limestones, and the significant precipitation (slightly >2000 mm/year), are conducive to karst development. The karst morphology is diverse throughout the massif, both in types of karst forms and types (patterns) of karst landscape.

The study area, as in many other similar mountainous areas of Albania, was not previously studied geomorphologically. Earlier research were carried out mainly on hydrogeological aspects, aimed at resolving water supply issues to the capital of the country and other areas. These were accompanied by karstological observations necessary for the proper assessment of the massif's water resources. We provide the first detailed geomorphological characterization of the massif, in defining the morphometric and morphological diversity of the area, and revealing its causes. We also explain the relatively rare occurrence of open karst shafts in the bottoms of dolines and, in part, describe the nature and degree of the underground karstification of the massif.

* Corresponding author, e-mail: w.andrejczuk2@uw.edu.pl

Received: August 4, 2021; accepted: February 20, 2022; first published online: April 05, 2022

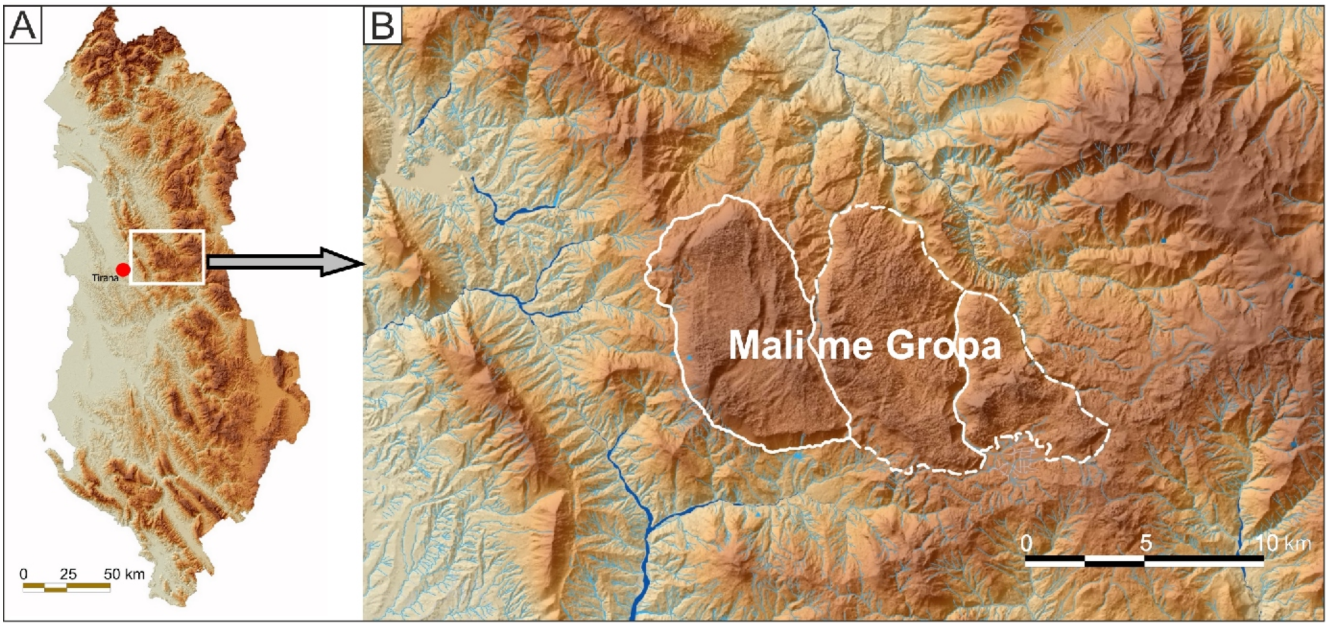

Fig. 1. Location of the Mali me Gropa area within a relief map of Albania (A) and the drainage basin (B)

The dashed line is the boundary of the entire Mali me Gropa area, the solid line delineates the separate massifs

STUDY AREA

LOCATION

Situated in the central part of Albania, the Mali me Gropa massif occupies the southeastern portion of the Skanderbeg Mountain range, extending from the valley of the Mat River in the north-west to the upper section of the Erzen River in the south (Fig. 1). To the north and east, the Mali me Gropa is drained by the western tributaries of the Mat River, to the west by the tributaries of the Tirana River, and to the south by the tributaries of the Erzen River. The massif extends 15–18 km from the west to the east, and 5–11 km from the south to the north, while its area is ~165 km^2. The Linos Valley separates the massif into two sub-regions: western and eastern. The surface of the western sub-region (often identified by the name Mali me Gropa) is ~55 km^2, with its highest summit Miceku Shenmeris at 1827 m, while the surface of the eastern sub-region is ~110 km^2 with the highest point being Noi Madh at 1846 m.

HISTORY OF RESEARCH

The Albanian karst has mainly been described by geographers; a first general description was made by Kristo (1973). He found that the karst in Albania is mostly developed in pure massive and thick-bedded Upper Triassic and Cretaceous limestone and classified it as typical classical Mediterranean karst (Bakalowicz, 2015). Different aspects of the Albanian karst are described in books by Krutaj et al. (1990) and Qiraizi (2001), as well as in some papers (Kristo et al., 1987; Parise at al., 2004, 2008). The geomorphological map of Albania, at scale 1:500,000 (Geomorphological Map of Albania, 1992) also gives some limited data about the karst of Albania. The Mali me Gropa area has not been the object of specific geomorphological investigation, but some karst phenomena have been described as part of hydrogeological investigations. In 1951 the Selita spring was investigated in relation to the Tirana water supply and surface karst phenomena of the Mali me Gropa karst plateau were described by Kalinina (1951). She was the first to establish that the basement of the western block of the Mali me Gropa massif, consisting of volcanic and sedimentary rocks, comprises three synclinal surfaces which control the spring's location. This conclusion was supported by subsequent hydrogeological investigations (Pali, 1973).

Kessler (1958) further investigated the karst phenomena of the Mali me Gropa karst plateau. He described the Mali me Gropa karst landscape as very rich in karren fields, sinkholes, uvalas, poljes, blind valleys, vertical shafts and caves (Fig. 2). In the western block (Western Massif), he described eight vertical caves with depths varying from 28 to 50 m, plugged at their bottoms by boulders, debris and soil. The longest cave he visited was the Vali Cave located in the eastern bloc (Fig. 3). This cave is 250 m long, gently sloping to the east at ~15°. Later this cave was measured by Donneborg (1993) to be 330 m long.

A Dutch expedition in 1993 noticed the high degree of surface karstification of Mali me Gropa and hoped to find large caves there, but found only some small vertical and horizontal caves, the longest being 117 m. They noted innumerable dolines with vertical channels at their bottoms, favouring percolation of rainwater into the karst massif (Speleo Netherland, 1993).

Some hydrogeological investigations, including the Hydrogeological Map of Albania sc. 1:20,000 (Eftimi et al., 1985), contributed to the recognition of the intensive karst development of this area, both at surface and at depth. The effective infiltration in Mali me Gropa comprises ~55% of the precipitation, or ~1100 mm/year (Eftimi, 2010); the spring's water is undersaturated in calcite and dolomite, thus facilitating karstification (Eftimi, 2010, 2020). As a result of intense karstification and focused discharge through karst depressions, groundwaters forming in Mali me Gropa are highly vulnerable (Eftimi and Zojer, 2015; Eftimi and Malik, 2019).

GEOLOGY

Albania is part of the Mediterranean Alpine Folded Belt and the Dinaric-Hellenic range. The Mali me Gropa massif belongs to the Mirdita Zone, which is an equivalent of the Serbian Zone in the Dinarides and the Subpelagonian Zone in the Hellenides

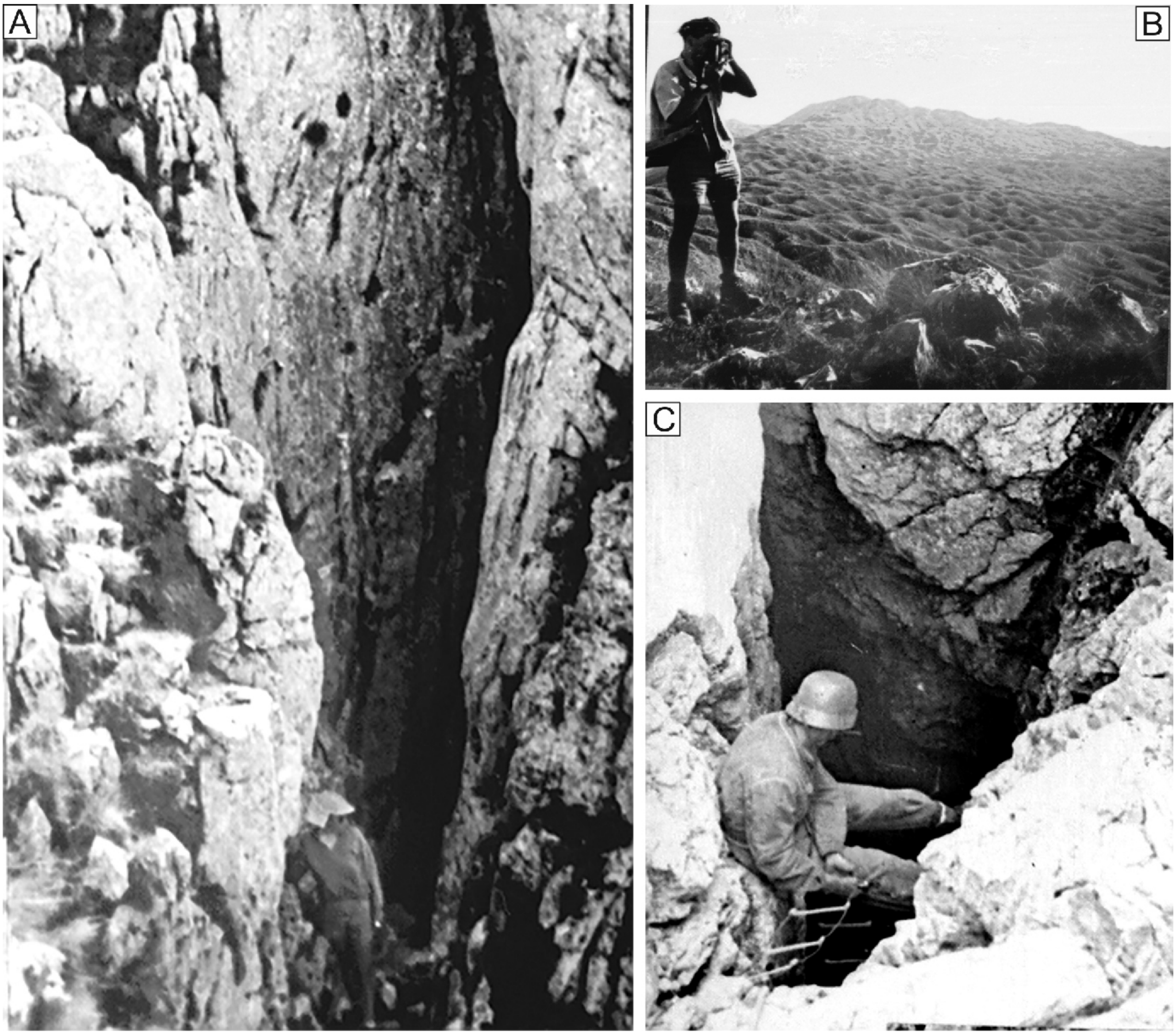

Fig. 2. Some examples of the karst forms shown by Kessler (1958)

A and **C** – vertical shafts in the western block, **B** – a view of the intensively karstified surface of the karst plateau, western block

Fig. 3. A large ponor where the Vali River disappears, forming the Vali Cave (the eastern block; photo by V. Andreychouk)

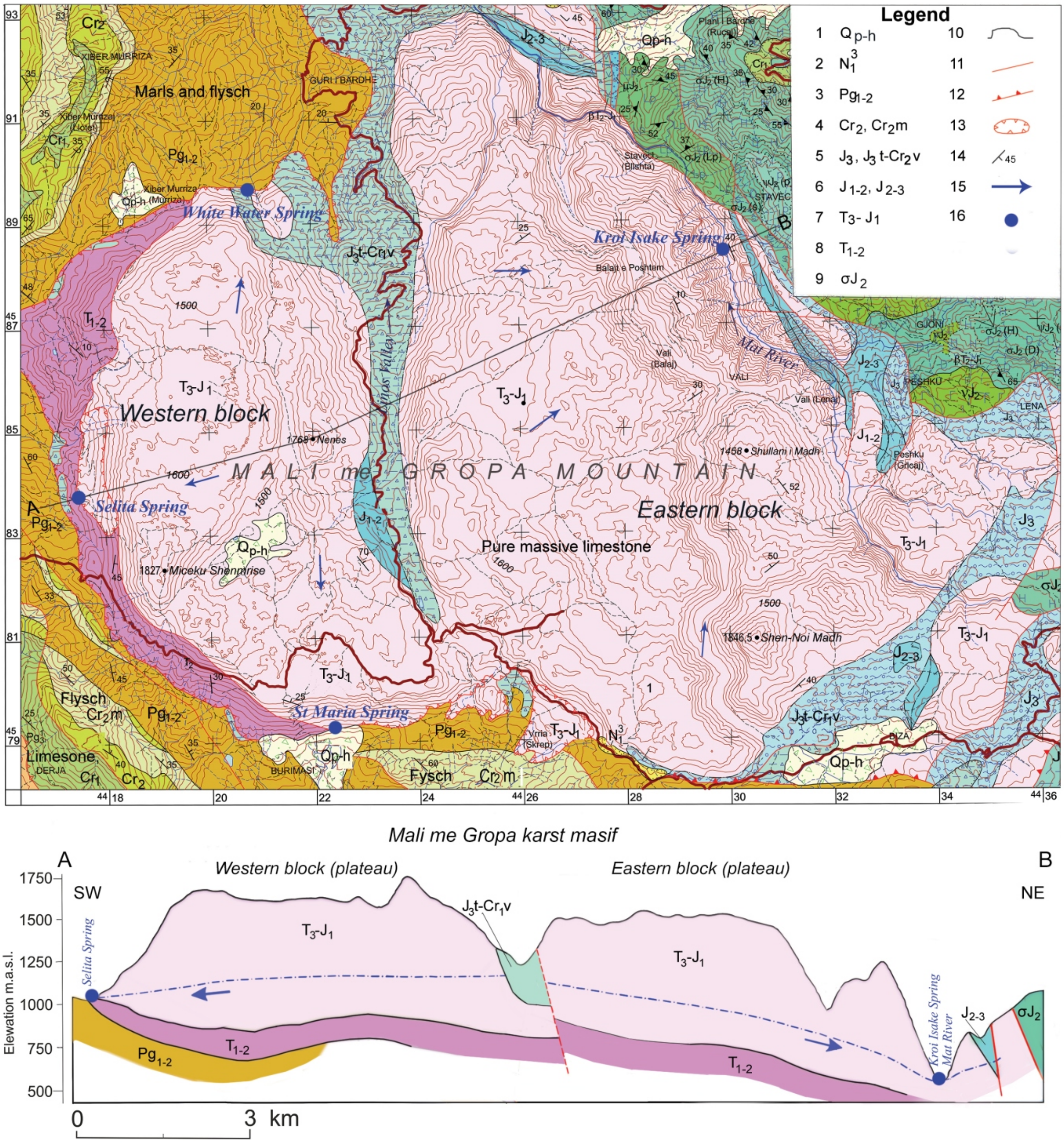

Fig. 4. Geological map and section of the Mali me Gropa area, central Albania (after Xhomo et al., 2002, modified by R. Eftimi)

1 – heterogeneous deposits, 2 – molasse, 3 – Krasta flysch, 4 – limestone and flysch, 5 – mainly breccia, 6 – limestone and siliceous rocks, 7 – pure massive limestone, 8 – volcanic and sedimentary rocks, limestone, 9 – various intrusive rocks, mainly serpentinites, 10 – geological boundary, 11 – tectonic fault, 12 – limit of overthrust, 13 – gravitational block, 14 – strike and dip of beds, 15 – direction of groundwater flow, 16 – karst spring

(Meco and Aliaj, 2000; Xhomo et al., 2002). The Mirdita Zone has an allochthonous character (Aubouin and Ndojaj, 1964; Hoxha and Avxhiu, 2000; Frasheri, 2000; Aliaj and Bushati, 2019) and comprises ophiolites of Middle and Upper Jurassic and Triassic age (Gjata and Kodra, 1999; Frasheri et al., 2009). The Mali me Gropa massif is situated in the western periphery of the Mirdita Zone and represents a large, slightly raised allochthonous block. It consists mainly of Upper Triassic to Lower Jurassic pure limestone, which rests on volcanic and sedimentary rocks, with Middle Triassic limestone and siliceous rocks comprising its basement (Liko, 1962).

The Mirdita Zone, or more precisely its upper part consisting of older (T_3-J_1 and J_3-Cr_1) Mesozoic carbonate strata of Triassic and Jurassic age, experienced an intense compressional phase during the Eocene, which caused overthrusting towards the west onto younger Paleogene flysch deposits (Pg_{1-2}) of the Krasta geological zone (Meço and Aliaj, 2000; Aliaj and Bushati, 2019; Fig. 4). The Linosi Valley incises the area to a depth of 250–350 m in the central part of this area, reaching sedimentary rocks (J_3-Cr_1) at its bottom. In the northeast, the Mali me Gropa area comes into contact with intrusive rocks of the Bulqiza ultrabasic massif (J_{1-2}). The greater susceptibility to erosion of these rocks compared with the Upper Triassic limestones was decisive in the development of the Linosi valley.

The Upper Triassic limestones are generally pure, massive, and fractured. The fractures are widened in their upper parts due to weathering. Because of the lack of pronounced deformation (folds), the tectonic fracture systems show a more or less even distribution within the massif.

With few exceptions, there are no noticeable lineaments on the surface that might relate to smaller or larger faults. This character of fracturing facilitates the development of karren and rock rubble (karst-weathering) in the upper part of the limestones.

CLIMATIC CONDITIONS

The study area is distinguished by favourable climatic conditions for the development of karst. It has a moderately warm and humid climate. In the cool season, when air temperatures drop below zero (mid-November to mid-March, generally ~50–60 days, sometimes more), the plateau is snow-covered. As for the thickness of the snow cover, the data are very limited, but according to our sporadic observations its maximum thickness does not exceed 50–70 cm.

The area receives relatively high precipitation (>2000 mm), but its annual distribution is uneven. For the 6-month-period October-March the average precipitation is 1470 mm, or 68% of the yearly sum and for the period April-September it is 680 mm, being 31.5% of their annual quantity (Fig. 5). The non-uniformity of the precipitation indicates that the climate of the area has the character of a Mediterranean climate.

RESEARCH METHODS

The geomorphological study of the massif comprised GIS-based mapping and field observations. The area was “manually” divided into geomorphological units according to the homogeneity of the relief, on the basis of clear visual differences evident on detailed (1:25,000) topographic maps, orthophotos, satellite photos, and drone photos. The units distinguished and the corresponding types of relief were ground-truthed during the fieldwork within selected transects across the massif in various directions.

Then, the typologically homogeneous geomorphological areas distinguished were subjected to GIS analysis in order to calculate basic parameters and indicators, and to generate appropriate models and maps.

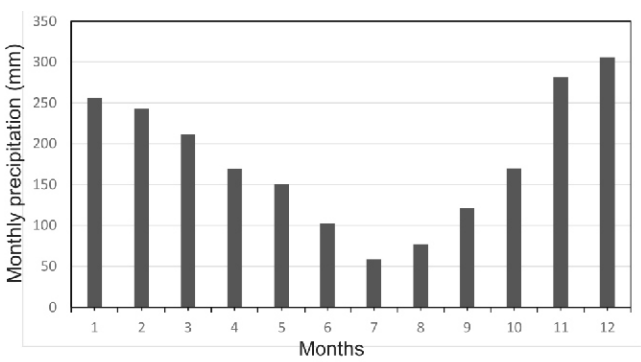

Fig. 5. Average monthly precipitation in the western foot of the Mali me Gropa Massif, Selita point (Jaho at al., 1980)

The following maps and orthoimages were acquired for the purpose of the study:

– 1:25,000, 1:50,000 and 1:100,000 scale topographic maps;
– orthophotomaps and satellite images;
– data for the DEM and DSM;
– 1:50,000, 1:100,000, 1:200,000 scale geological maps;
– 1:50,000 scale hydrographic maps;
– corinne maps of land management and urbanization, forests and land use;

The following *GIS* software was employed to process the data: *Global Mapper*, *QGIS*, *MapInfo* and *ArcGIS*. With this software, thematic map compilations and spatial analyses related to the inventory and interpretation of karst features were carried out. The employment of DTM and orthoimages enabled obtaining a detailed spatial inventory of karst features in the area designated. Based on Digital Elevation Model images, detailed analyses of slope and slope aspect, as well as calculations regarding the dimensions of the features, were performed. Spatial data were processed using the following projection: EPSG: 28404 (Pułkovo, 1942) and Gauss-Kruger zone 4.

The orthophoto data obtained, of accuracy of 20 cm per cell, came from 2015–2016. Mosaics of super-high resolution orthoimages (from 2.5 m to 1 m) from the Copernicus information services were also utilized. In addition, data from LandSat8 was used for general visualization (output format GeoTIFF, UTM projection, output data WGS 84). Numerical data for the Digital Terrain Model (DTM) and DSM came from 2015–2017, the size of cell on the model is 0.1 m (DTM) and 0.1–0.2 m (DSM). Moreover, the EU Digital Elevation Model (EU-DEM), which combines data from various sources (Copernicus on SRTM and ASTER data), was employed for general purposes.

Photographic documentation took place during field observations, including drone photography.

RESULTS

DIVISION OF THE MASSIF INTO GEOMORPHOLOGICAL UNITS

The analysis of the relief of the Western Massif allowed the recognition of relatively homogeneous areas, both within the plateau and on the slopes of the massif (Fig. 6). These areas, both of higher and more detailed rank, were contoured on the basis of the morphological homogeneity of the units, clearly visible on the different maps generated by digital models.

The karst plateau of the massif was divided into four large areas that refer to particular parts of the massif: north-west (AP-1), south (AP-4), east (AP-3), and a belt of elevations and depressions (AP-2) that separates these areas (Fig. 6A). The AP-1 and AP-4 areas represent an undulating karst plateau, diverse as regards relief, while the AP-2 and AP-3 areas exemplify typical chains of hills and depressions embedding karst dolines. Within the *massif slopes,* three areas different in relief character were distinguished: northwestern (AS-1), western and southwestern (AS-2), and eastern (AS-3; Fig. 6A).

These large areas were further divided into basic geomorphological units of homogeneous relief. Within the northwestern area, i.e. plateau AP-1, eight basic units were distinguished (AP-1.1 to AP-1.8); within the southern area (AP-4), five units (AP-4.1 to AP-4.5); within the eastern area (AP-3), two units (AP-3.1 and AP-3.2); and within the area AP-2, three units (AP-2.1-AP-2.3; Fig. 6B). Three slope areas were additionally

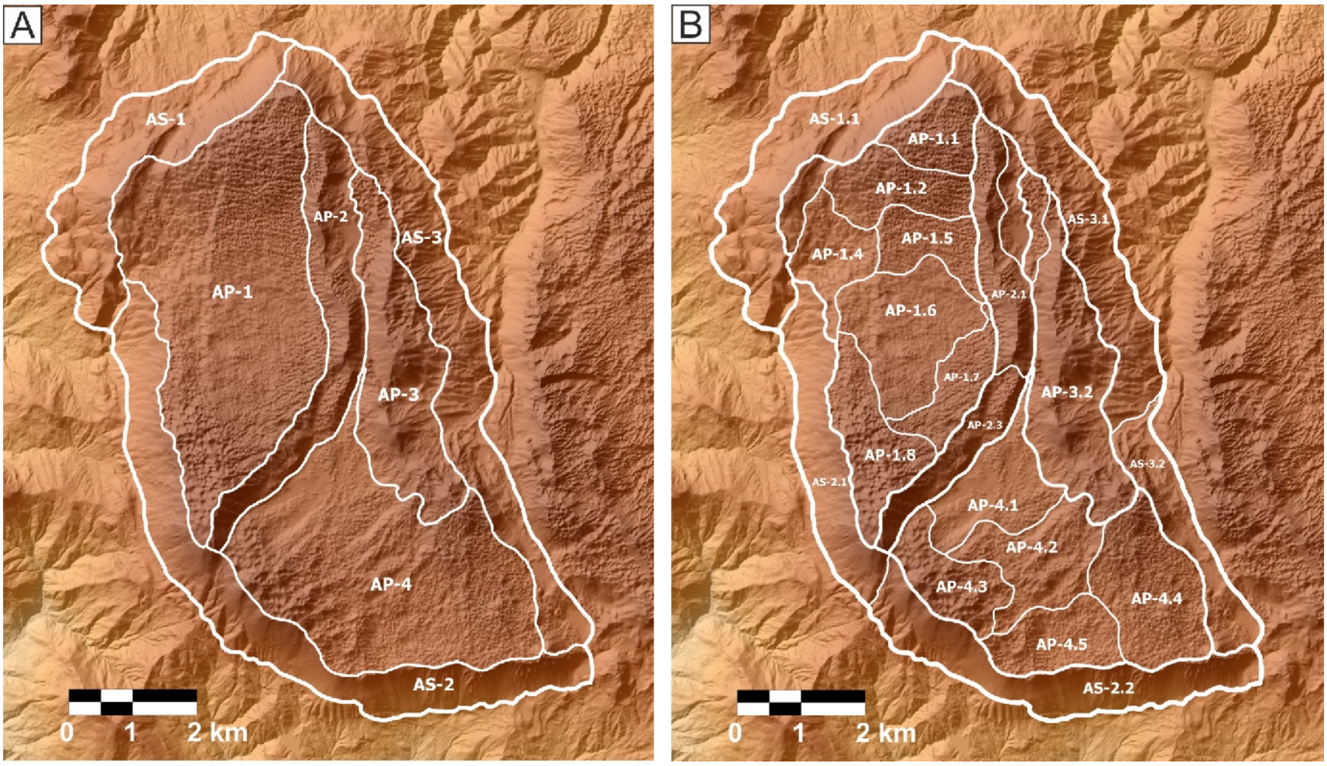

Fig. 6. Division of the Western Massif into geomorphological units

A – division into units of higher rank: a thicker line means border of the slopes of the massif and plateau while a thinner line means border of the main parts; **B** – division into basic geomorphological units; symbols AP and AS stand for plateau and slopes, respectively; the numbers next to the symbols indicate individual units of different rank (see Table 1)

divided: AS-2 into AS-2.1 (west) and AS-2.2 (southern), AS-3 into AS-3.1 (northeastern) and AS-3.2 (southeastern), whereas the slope area AS-1 remained undivided due to its geomorphological homogeneity.

Each basic unit defined has specific, relatively homogeneous (in morphological and genetic terms) relief. Each unit is characterized by a specific hypsometric and expositional location, a specific range of hillside inclination (slopes) and specific karst landforms, considered below. Basic morphometric parameters for the Western Massif and its individual geomorphological units of various ranks are shown in Table 1.

MORPHOMETRIC CHARACTERISTICS OF THE UNITS

The Western Massif rises to an altitude of 1330–1820 m a.s.l. The highest point is Necekul të Shënmërise with an altitude of 1827.1 m a.s.l. The average elevation of the plateau is 1561.8 m (weighted average – 1560.9 m; Table 1). The denivelation, i.e. the difference between its highest and lowest parts, reaches almost 400 m, although within the units specified it is much smaller.

The altitude parameters vary between the plateau parts (Fig. 7). The area of AP-1, including its eight basic units (AP-1.1 to AP-1.8), spreads over an area of ~1400 ha, covers the north-western part of the plateau, and is characterized by extreme elevations ranging from 1300 to 1820 m. The average denivelation of the relief for all the 8 basic units is 190 m. The average elevation of this part of the massif is 1568.8 m a.s.l. (Table 1). The area is relatively flat: the average inclination of the slopes located there varies within the range 4.9–12.7°, while the average inclination is 8.3° (Table 1 and Fig. 8). As regards the exposure of the slopes, the NS direction is dominant (Fig. 9).

Another "flat" area, AP-4, occupies the southern part of the plateau (basic units: AP-4.1–AP-4.5) and has an area of 1186.72 ha. The elevation of the terrain within it ranges from 1330 to 1715 m (for all units), while the average leveling is 240 m. The average elevation of the surface is 1520.8 m (Table 1). The average inclination of the surface in individual units varies between 6.4 and 9.8° (Table 1 and Fig. 8)[1]. NS–NNS exposures of the slopes dominate in this area (Fig. 9).

The other two areas of the plateau, AP-2 and AP-3, constitute its most mountainous parts. The area of AP-2 extends first sub-meridionally and then meridionally across the entire massif, thus separating the north-western plateau (AP-1) from the southern plateau (AP-4; Figs. 6 and 7). Its lower section (AP-2.3) extends from the southwest to the northeast and represents mainly a NW–SE-inclined (Fig. 9) slope of the plateau AP-1, with a fragment of flattened and karstified surface in its northern part (Fig. 7). The elevation of the terrain within the slope decreases from its edge to the foot from almost 1800 m to 1500 m. The averaged inclination of the slope is ~17°, though in the southern part of the area it is much higher (25–30°): the lower average inclination results from the levelled surface in the northern part of the area.

In the centre of the massif, the AP-2 area "turns" northwards in the form of a belt consisting of an elevation (AP-2.1) and an adjacent depression (AP-2.2) to the east (Figs. 6 and 7). The

[1] These numbers refer to the average inclination of the surface in general and do not reflect variations of the inclination on the scale of smaller karst forms.

Table 1

Morphometric characteristics of the geomorphological units of the Western Massif of the Mali me Gropa area

Units	S [ha]	H_{max} [m]	H_{min} [m]	Denivelation $D = H_{max} - H_{min}$ [m]	$H_{average}$	Slope inclination average	A° Slope exposure average
AP-1.1	145.62	1720	1565	155	1642.5	7.7	155
AP-1.2	190.02	1710	1455	255	1582.5	9.6	204
AP-1.3	59.28	1580	1385	195	1482.5	12.7	152
AP-1.4	159.68	1525	1295	230	1410.0	10.8	191
AP-1.5	143.72	1610	1505	105	1557.5	4.9	191
AP-1.6	342.60	1682	1545	137	1613.5	5.4	182
AP-1.7	141.15	1682	1552	130	1617.0	5.7	170
AP-1.8	239.71	1820	1490	310	1645.0	9.4	198
Average for AP-1	177.72	1664	1474	190	1568.8	8.3	180.4
AP-2.1	21.07	1710	1545	165	1627.5	13.7	224
AP-2.2	63.37	1665	1515	150	1590.0	11.8	160
AP-2.3	167.07	1800	1490	310	1645.0	16.8	145
Average for AP-2	147.84	1725	1517	208	1620.8	14.1	176.3
AP-3.1	51.42	1585	1515	70	1550.0	5.8	193
AP-3.2	457.76	1745	1485	260	1615.0	14.0	207
Average for AP-3	254.59	1665	1500	165	1582.5	9.9	200.0
AP-4.1	230.76	1610	1450	160	1530.0	6.4	149
AP-4.2	252.00	1659	1424	235	1541.5	8.9	192
AP-4.3	180.60	1693	1476	217	1584.5	11.04	158
AP-4.4	337.51	1715	1380	335	1547.5	8.2	157
AP-4.5	185.80	1473	1328	145	1400.5	7.9	198
Average for AP-4	237.34	1630	1411	218	1520.8	8.5	170.8
Arithmetic average for plateau AP	197.84	1664	1460	204	1561.8	9.4	179.6
Weighted average for plateau AP	204.4	1670.2	1469.4	200.7	1569.8	10.1	182.2
Median AP	178.5	1682.0	1487.5	180.0	1570.0	8.9	183.0
Geometric average AP	170.5	1661.6	1457.6	187.4	1560.1	8.80	178.2
Average deviation AP	78.4	68.5	67.6	70.9	57.9	2.73	20.0
Standard deviation AP	104.6	88.4	81.9	82.8	74.5	3.40	23.3
AS-1.1	522.85	1665	1020	645	1342.5	20.2	171
Average for AS-1	522.85	1665	1020	645	1342.5	20.2	171
AS-2.1	325.42	1740	1040	700	1390.0	23.8	261
AS-2.2	428.36	1650	890	760	1270.0	29.2	199
Average for AS-2	376.9	1695.0	965.0	730.0	1330.0	26.5	230.0
AS-3.1	489.17	1635	1160	475	1397.5	18.1	168
AS-3.2	229.93	1660	1280	380	1470.0	15.2	178
Average for AS-3	359.5	1647.5	1220.0	427.5	1433.8	16.6	173.0
Arithmetic average for slopes AS	399.15	1670	1078	592	1374	21.3	195.4
Weighted average for AS	419.8	1669.2	1068.3	600.8	1368.8	21.1	191.3
Median AS	428.4	1660.0	1040.0	645.0	1390.0	20.2	178.0
Geometric average AS	382.6	1669.6	1069.9	573.3	1372.4	20.78	192.7
Average deviation AS	97.2	28.0	113.6	131.6	54.2	4.16	27.7
Standard deviation AS	120.8	40.8	148.1	159.2	73.9	5.41	38.6
Arithmetic average AP+AS	241.6	1665.2	1376.8	288.3	1521.0	12.0	183.0
Weighted average AP+AS	296.7	1669.7	1297.5	372.2	1483.6	14.8	186.1

S – area of the geomorphological unit; H_{max} – maximum surface height above sea level; H_{min} – minimum surface height above sea level; $H_{average}$ – average surface height above sea level

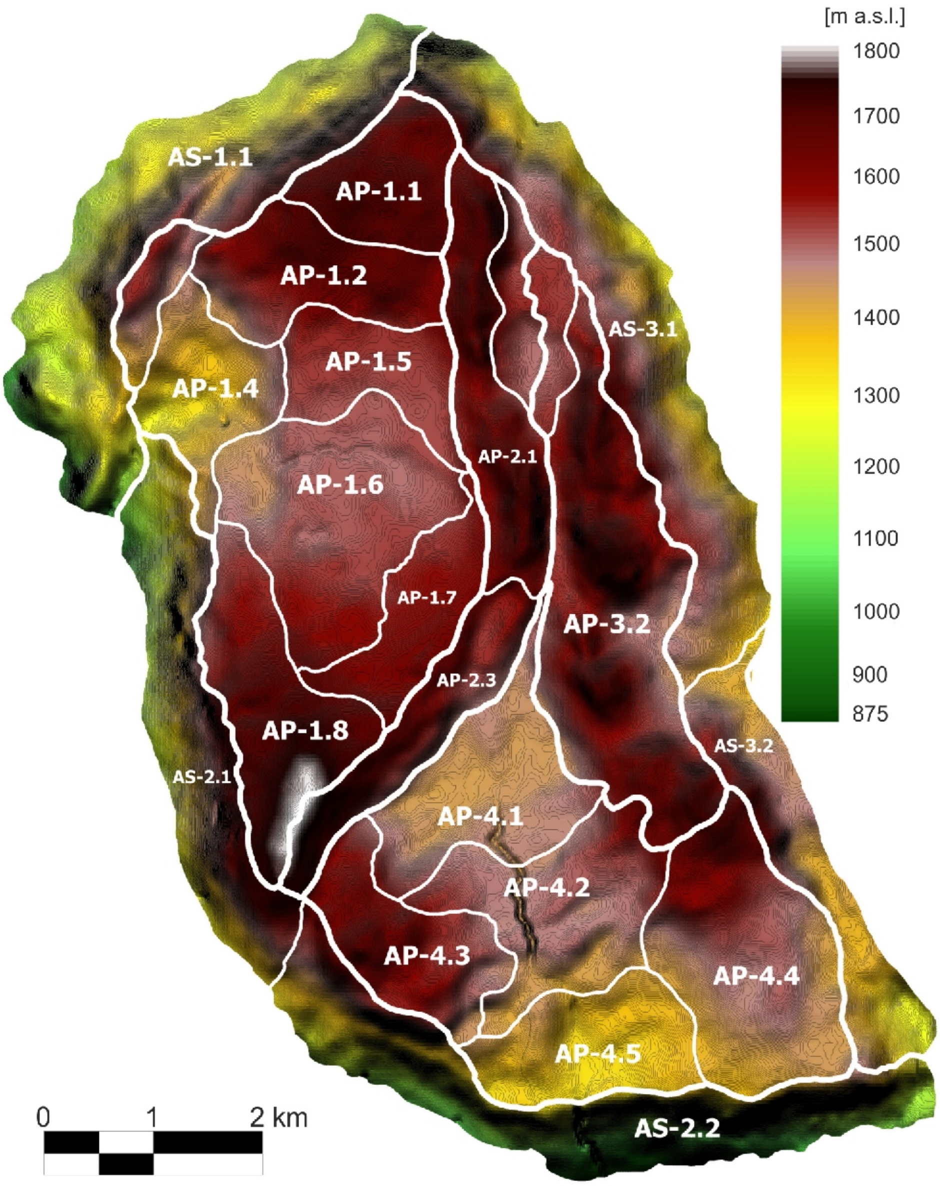

Fig. 7. Hypsometric map of the Western Massif

denivelation of the terrain within them is not large (165 and 150 m, respectively). The average elevations of the areas are 1635 and 1585 m a.s.l., whereas the average inclinations of the slopes are 13.7° and 11.8°, respectively (Table 1). Slopes with 224° (SSW) and 160° (SSE) exposure are predominant (Fig. 9).

The other mountainous area (AP-3) extends along the eastern periphery of the massif and consists of several hills (culminations) and depressions between them (AP-3.2). It is generally characterized by an undulose relief; however, in its northern part there is a plateau, which was distinguished as the basic unit (AP-3.1) within AP-3 due to the distinctiveness of its relief, especially its karst landforms. The elevation of the terrain in the AP-3 area ranges from 1485 to 1745 m, the average elevation being ~1585 m (Table 1). The denivelations are 70 m for the AP-3.1 unit, and 260 m for the AP-3.2. The average slope inclination is 7.1° for AP-3.1, and 12.8° for AP-3.2, and the dominant exposure of the slopes in both areas is northern and southern (Fig. 9).

The areas of the AP-2 and AP-3 mountainous terrains are 443.51 ha and 509.18 ha, respectively. In total, the area of flat and mountainous areas, i.e. of the entire plateau of the Western Massif, amounts to 4982.97 ha.

The slopes of the Western Massif cover an overall area of 1915.73 ha. The north-western slope AS-1 (522.85 ha) is concave: its upper part is steeper than the lower one, due to the accumulation of slope material (diluvia, etc., moved by gravity) at the foot. The average inclination of the slopes within the unit is ~20° (Table 1). The elevation difference between the foot (1020 m) and the edge of the plateau (1665 m) reaches 645 m.

The western (AS-2.1) and southern (AS-2.2) slopes of the massif, comprising the AS-2 slope area of total area of 753.78 ha), are characterized by steep inclinations (23.8 and 29.2°). Both basic units are distinguished by a dominance of steeply inclined slopes, precipitous in places. The slopes within the AS-2.2 unit are additionally affected by rock landslides. The average altitudinal differences between the foot of the massif and the plateau edge within the units are 700 m (1040–1740 m) for AS-2.1, and 760 m (890–1650 m) for AS-2.2 (Table 1).

The last slope area of the massif – AS-3 (eastern), covers an area of 719.1 ha) and consists of two basic units: AS-3.1 (northern part, 489.17 ha) and AS-3-2 (southern part,

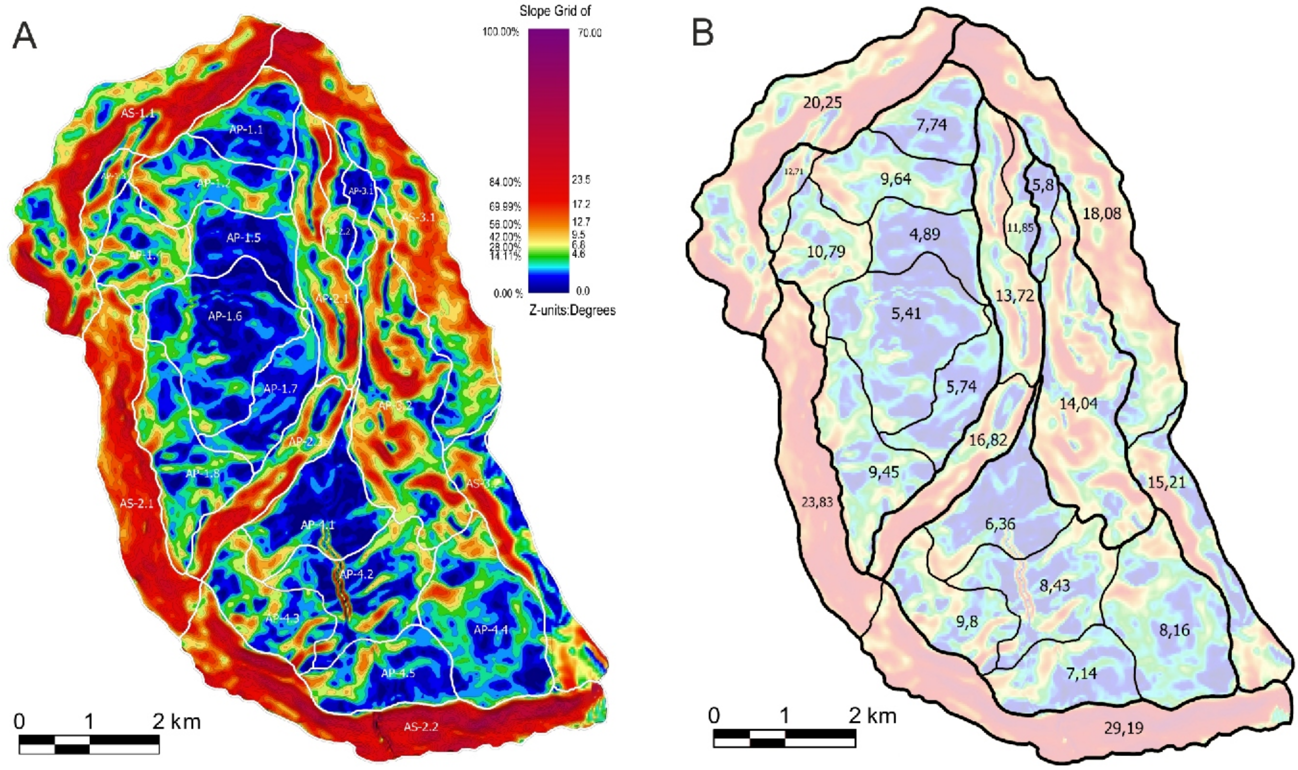

Fig. 8. Maps of the inclination of the terrain within the Western Massif of the Mali me Gropa area

A – actual map; **B** – averaged map (numbers are given in degrees)

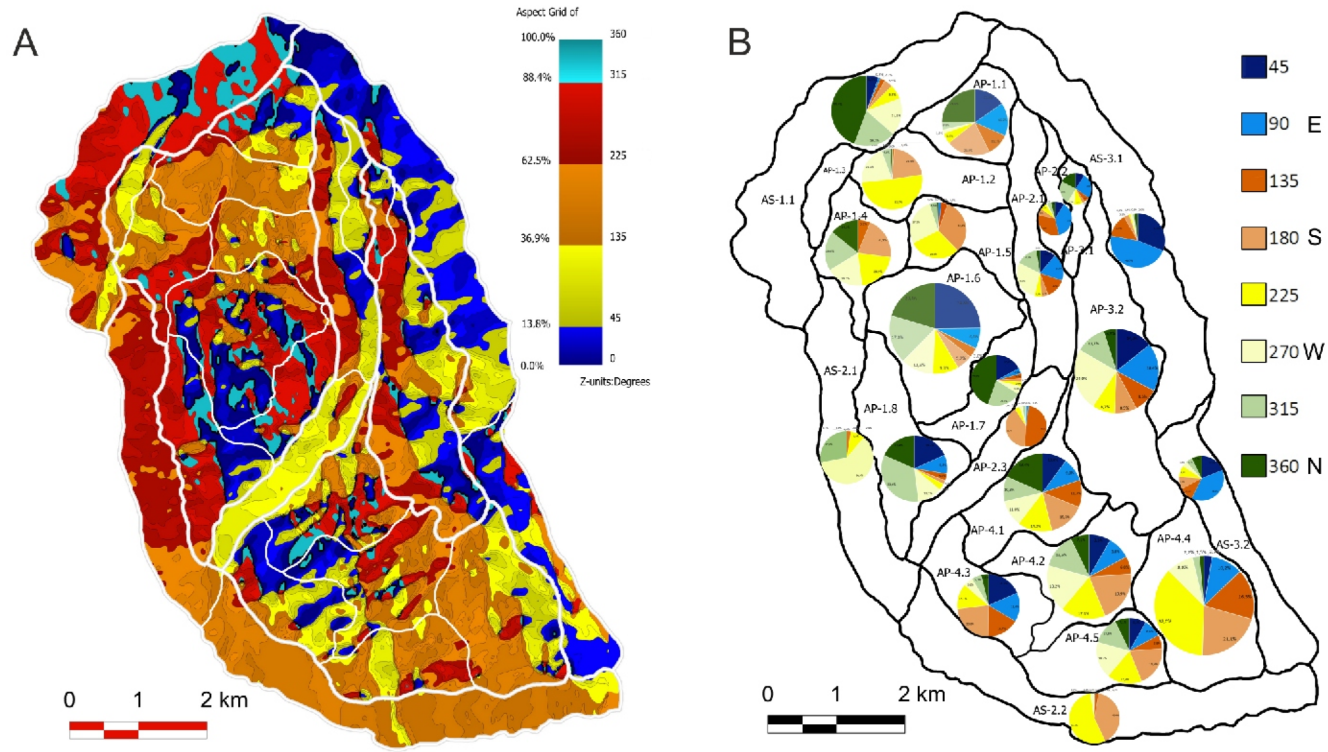

Fig. 9. Map (A) and diagram (B) of exposure of slopes within the Western Massif of the Mali me Gropa area

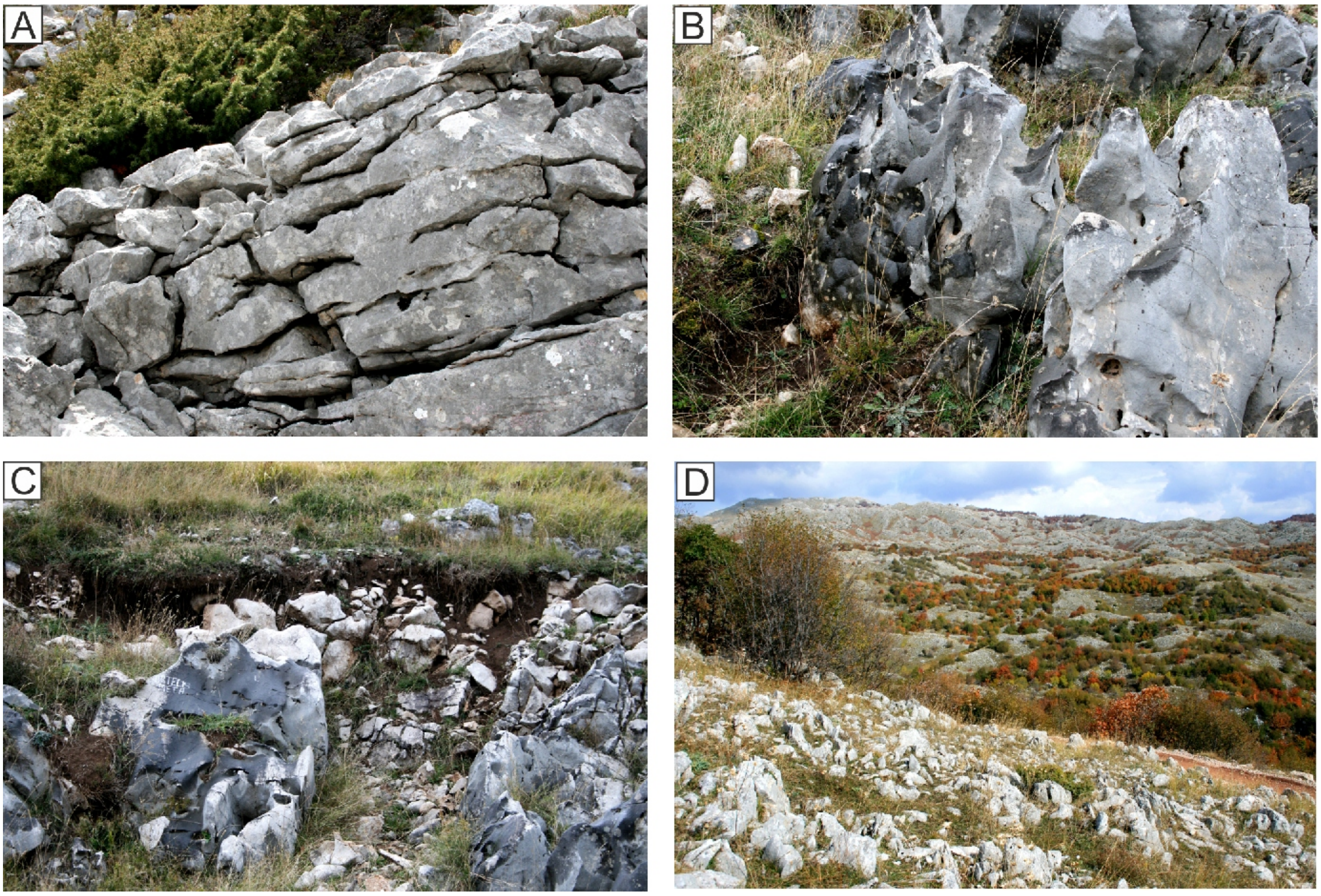

Fig. 10. Examples of karren occurring on limestone surfaces on the Western Massif plateau

A – karren developing along bedding fissures opened by weathering; **B** – sharp-edged karren on exposed limestone blocks; **C** – irregular smoothed subsoil karren; **D** – general view of a karstified surface with limestone blocks protruding from the soil (photo by V. Andreychouk)

229.93 ha). The denivelation of the relief within the AS-3.1 and the AS-3.2 slopes is 475 m (1160–1635 m) and 380 m (1280–1660 m), respectively. The denivelations are smaller than in the case of the other slopes because the eastern slope constitutes the slope of the Linosi valley, the bottom of which is located much higher than the foot of the periphery slopes of the massif. The average inclination of the eastern slope is 18.1° for AS-3.1, and 15.2° for AS-3.2 area (Table 1 and Fig. 8).

KARST RELIEF

The plateau area is an impressive arena of karst development characterized by a large morphogenetic diversity of features and landscapes. This diversity may be considered in two aspects: the diversity of karst forms and the diversity of types of landscape (geomorphological units).

Karst features on the plateau surface can be conventionally divided according to their size into small (microforms), medium (mesoforms) and large (macroforms). Microforms (karren) are developed on the surface of the limestone and show the effects of aqueous corrosion on the rock. Within the plateau, karren features are most prevalent, including subsoil and exposed varieties.

Because of the horizontal or only gentle inclination of the limestone strata, classic linear forms such as rillenkarren are almost absent on exposed surfaces. Grikes or kluftkarren in the form of networks of karstified fractures also occur to a very limited extent. More common are corroded bedding fissures (Fig. 10A) and irregular, in places "punctured", sharp-edged microforms of *cutters* type (Fig. 10B). Smoothed, irregularly shaped microforms occur beneath the soil-silt cover (Fig. 10C). On exposed convex surfaces, i.e. ridges separating adjacent karst dolines, there are widespread rock-grass-soil limestone surfaces with protruding corroded fragments of the rock substrate (Fig. 10D).

Karst mesoforms are represented by dolines and convex forms (hillocks and smoothed ridges between them) which constitute a characteristic regular pattern. This is the most widespread type of karst landscape on the plateau. Usually, dolines are concave forms with more or less expressed edges and a flattened (Fig. 11A) or flat (Fig. 11B) bottom filled with residual and soil material to varying degrees. Open cracks in the bottoms of the dolines are extremely rare. Locally, at the bottoms of larger dolines, there are ponds artificially created by shepherds, to collect rainwater for use for watering sheep grazing on the plateau (Fig. 11D). The diameter of the dolines on the plateau usually varies within 15–50 m, and their depth within 3–10 m, although deviations from these figures are very common. The depth is difficult to measure, inter alia, because the dolines are developed not on flat but on inclined (to varying degrees) surfaces. Therefore, their depth, as measured along the highest and the lowest slopes, may differ significantly. This pattern (vertical asymmetry) refers to the majority of forms occurring within the plateau. The dolines are usually separated by inter-doline ridges and hillocks (Fig. 11A).

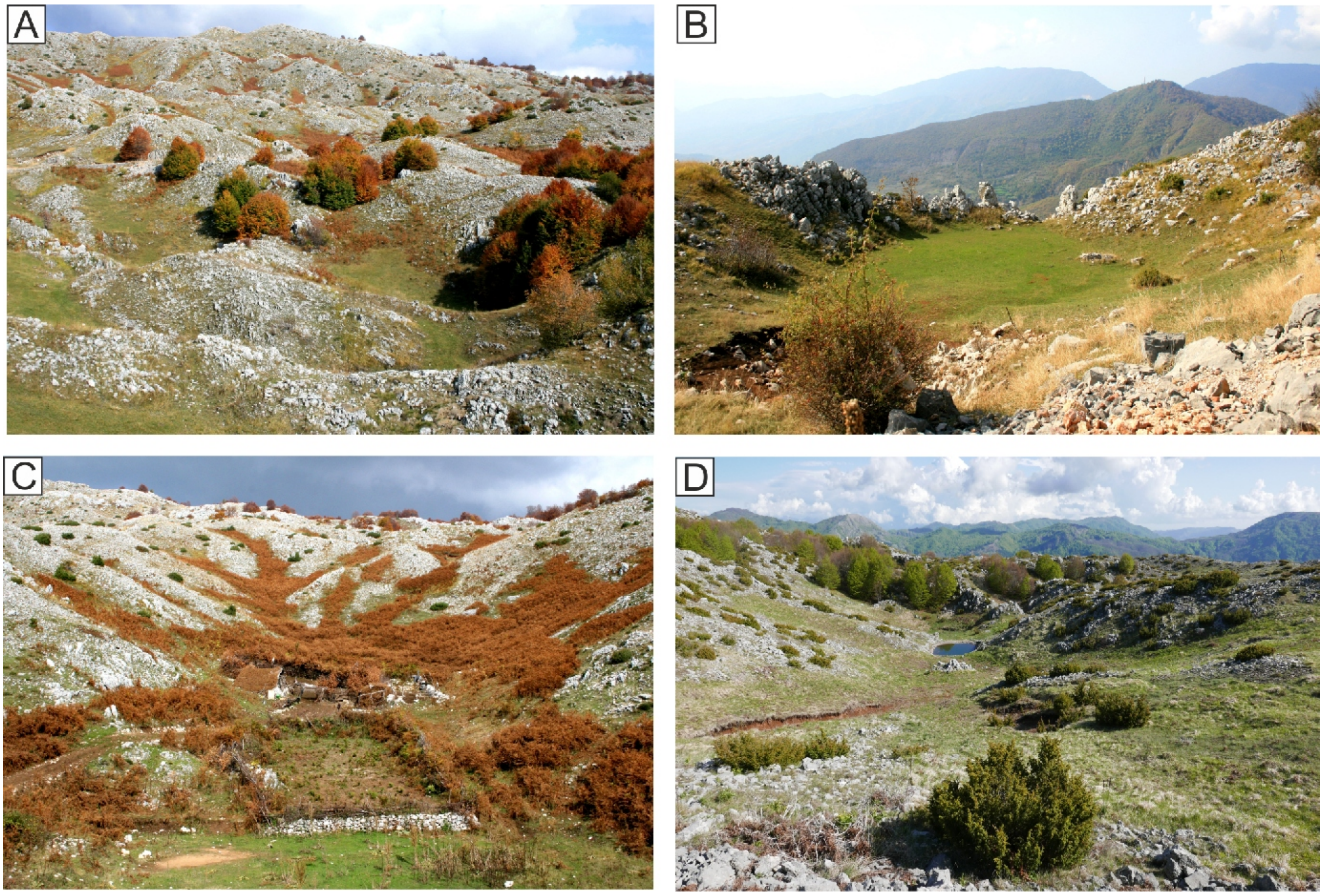

Fig. 11. Characteristic examples of mesoforms (dolines – A, B) and macroforms (depressions – C, D) occurring on the plateau of the Western Massif (photo by V. Andreychouk)

In many places within the plateau, especially in its lower parts, there are karst forms larger than dolines, which may be qualified as macroforms (Fig. 11C and D). These are karst depressions classically developed by merging of adjacent dolines. The depressions are usually oval, elongated, or irregular in shape.

These main types of karst forms of various sizes constitute morphogenetic complexes (landscapes) characteristic of geomorphological units, i.e. areas with a relatively uniform karst landscape (Fig. 12).

The most impressive and clearly outlined karst landscapes occur in the areas of flat plateau units, i.e. in AP-1 (northwestern part of the massif) and AP-4 (southern part). Within these areas, the relief takes on the features characteristic of highly karstified surfaces with the development of a "countless" number of contiguous dolines. Regardless of their plateau-like nature, the surfaces of both these units are not even but hypsometrically differentiated (Fig. 7). The altitudinal variations within them range between 535 m (northeastern plateau) and 387 m (southern plateau; Table 1). Taking into consideration the differences in the altitude of the areas, together with the characteristic types of karst relief, allowed the distinction of karst-geomorphological sub-units (Figs. 7 and 12). The hypsometric variation within the individual sub-units is significantly smaller, i.e. from 105 to 310 m in the case sub-units of the AP-1 area, and from 145 to 335 m in the case sub-units of the AP-4 area (Table 1).

Within the sub-units, the relief is homogeneous in terms of the size and shape of the dolines, the density of their occurrence and spatial arrangement (patterns, structures, etc.). This homogeneity, manifesting in the karst relief pattern preserved within a sub-unit, constituted the main criterion for distinguishing the sub-units. Below, a brief description of the karst relief of the individual sub-units in the AP-1 and AP-4 areas is given.

The elevated (above the average altitude of the plateau) northern verge of the AP-1 area (Fig. 13A) constitutes the landscape of the AP-1.1 area (Fig. 12). The terrain is gently convex on the peripheral part of the massif, the slope of which includes slightly elongated corrosion dolines of asymmetrical profile that results from their development on the convex slopes. The location on the slope is also the reason why the forms are shallow, i.e. their depth does not exceed a few meters. When looking at the area from above, one can see elements of the arrangement of the forms in the shape of an emerging (though not yet fully developed) network of a micro-catchment, with the shallow forms arranged into local series.

The relief of the AP-1.2 area (Figs. 12 and 13A) is characterized by the occurrence of shallow corrosional dolines with conspicuous bottoms, flattened in places. As in the previous case (AP-1.1) the dolines are asymmetrical due to their location on an inclined (towards the inner part of the plateau) surface. Deeper dolines are filled with residual soil material, covered with grass, and clearly stand out as such against the background of the terrain surface. A characteristic feature of the landscape of the area is that dolines are arranged in chains of more or less latitudinal (E–W) trend. The limestone ridges separating dolines are of varying width, asymmetrical (with an extended southern slope) and almost completely devoid of vegetation.

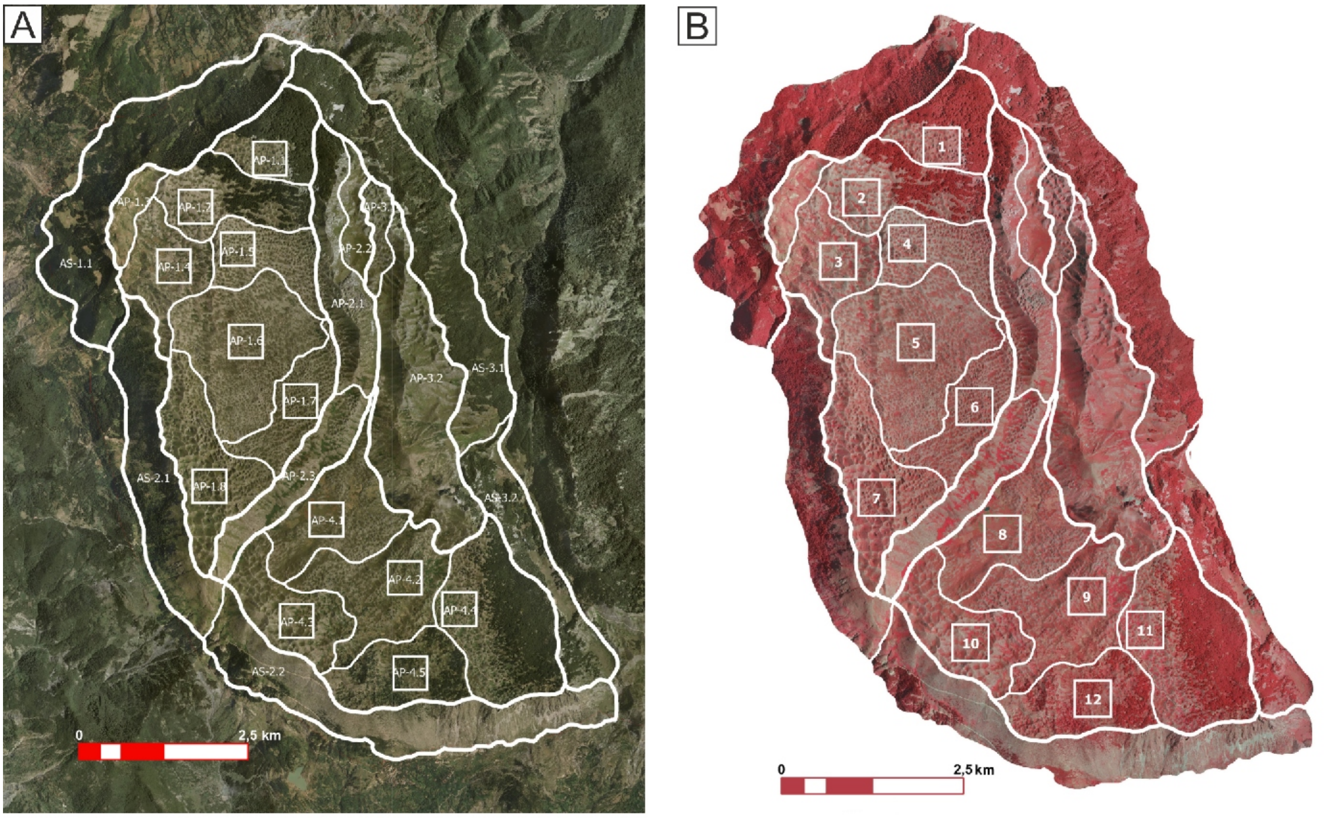

Fig. 12. Location of chosen patches (0.25 km^2) within which the density of doline occurrence was calculated in relation to the basic geomorphological units of the Western Massif

A – map of the units; **B** – map with the patches marked (1–12) within the areas described

The area of 1.3 is represented by a small range surrounding the massif on the northwestern side. It is a little elongated convexity with no typical corrosion dolines. It has a well-developed eluvial-soil cover (Fig. 13C).

The area of AP-1.4 (Figs. 12 and 13C) is characterized by the occurrence of larger ovoid (convex) hillocks cut by valleys and small dolines with flat bottoms, and larger depressions with flat bottoms. The elongated shapes of the forms indicate that the role of erosional processes is greater here than in the previous cases. This is due to the location of the area at the western edge of the plateau and the overall inclination of the surface towards the edge.

The AP-1.5 area (Figs. 12 and 13C,D), located in the central part of the plateau, is characterized by a relief dominated by well-developed corrosion dolines with grass-covered bottoms. Unlike in the higher (northern) area of AP-1.2, karst dolines are smaller, and their abundance across the entire area is greater (compare in Fig. 12). The arrangement of the dolines in chains is also less pronounced. The ridges separating the dolines are narrow and, because of their adjacency, they form a fairly regular "dense mesh" network. Such a landscape corresponds largely to the term "polygonal karst" (Williams, 1971, 1972; Ford and Williams, 1989, 2007).

The area of AP-1.6 (Fig. 12) is characterized by similar relief but which is less well-ordered and has a less regular pattern. Both the dolines with the grass-covered bottoms and the limestone ridges separating them are distinguished by their irregular shapes. They are also comparable in terms of their size and area occupied. Any attempt to graphically connect the ridges into polygonal networks would be difficult. And even if possible, the contoured polygon units would commonly have irregular shapes and dimensions.

The AP-1.7 area (Fig. 12), in terms of morphology, is somewhat transitional between the highly ordered relief of the AP-1.5 area and the less ordered relief of the AP-1.6 area. Features of specific, but difficult to define, regularity can be seen in it regarding the distribution of both the dolines (chains) and networks (polygons).

Area AP-1.8 (Figs. 12 and 13A) is distinguished by a relief with morphological features similar to those of area AP-1.1. The area represents the highest part of the north-western plateau (Fig. 7 and Table 1) and forms a convex hill in its southern part. The forms developed on its slopes are relatively large but asymmetrical (due to the slope of the surface) and do not always have well-formed bottoms. The slopes of the forms cover the greater part of the area.

The southern (lower) plateau (AP-4) of the massif is located slightly (50–100 m) lower than the north-western (upper – AP-1) plateau (Table 1 and Fig. 14A). The plateau karst sculpture (AP-4) generally resembles that of the north-eastern plateau but has more mature features. This concerns both the degree of development (depth) of the karst dolines and the occurrence of the major depressions, including those with flat bottoms and "inselberg" hills (Fig. 14B).

Area AP-4.1 (Figs. 12 and 14B) is distinguished by the presence of segments of fairly regular relief similar to that of area AP-1.6. Most of the area, though, is an elongated (towards the SW–NE) flat-bottomed depression with hillocks in the form of islands and islets. In its entirety, the karst landscape of the area can be characterized as the least regular ("degraded") of all.

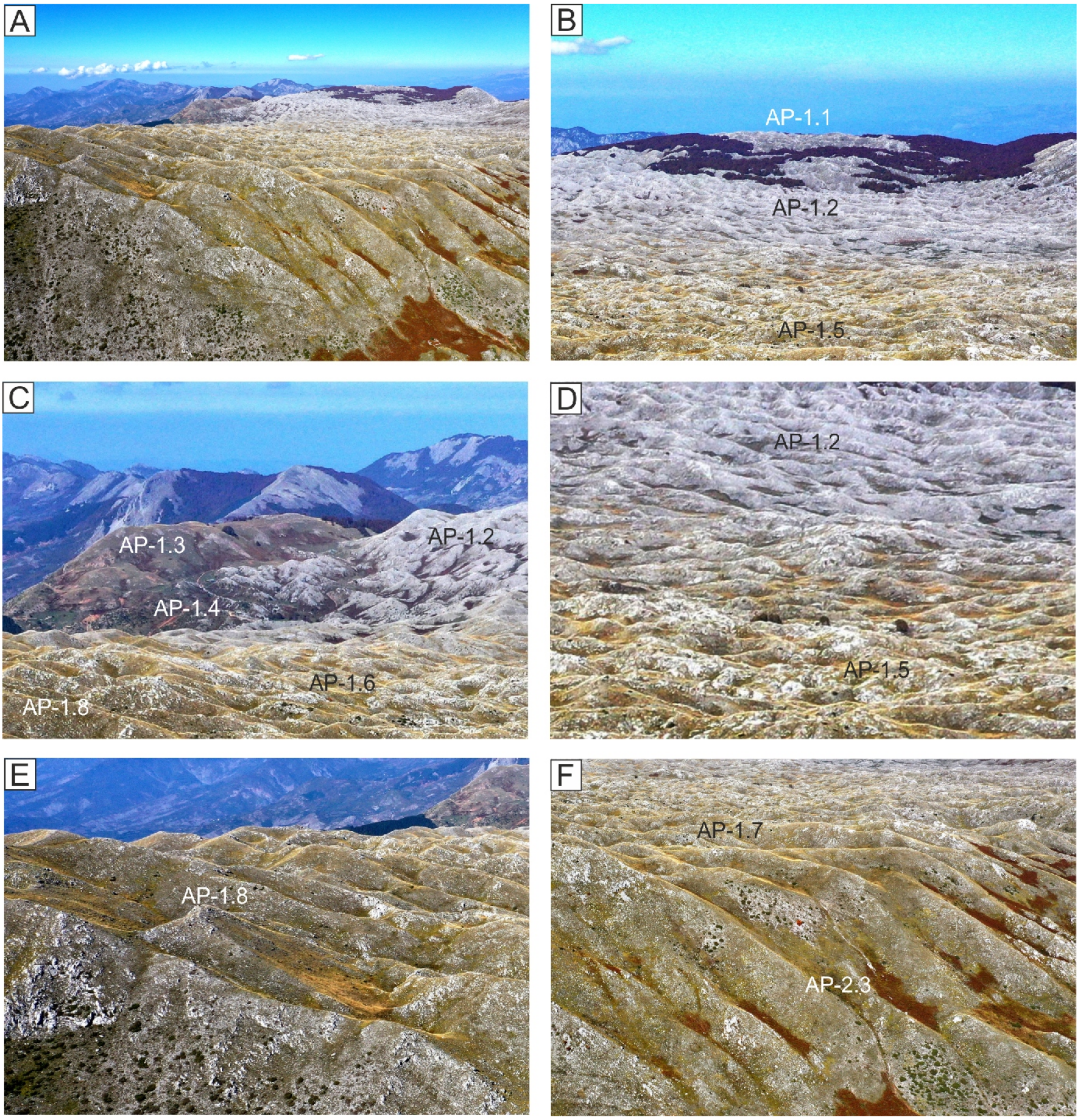

Fig. 13. Some views of the northwestern plateau with marked areas described in the text

A – general view of the plateau; **B** – view of the northern part of the plateau; **C** – view of the northwestern part of plateau; **D** – the boundary between areas AP-1.2 and AP-1.5 visible due to change in colour of terrain' surface; **E** – view of the southeastern slope of area AP-1.8; **F** – linear corrosion-erosional forms on the eastern slopes (AP-2.3) of the plateau (drone photos by A. Klimchouk)

Area AP-4.2 (Fig. 12) is represented by a strongly karstified hilly plain, which is slightly inclined towards the SW, and has widespread flat-bottomed small depressions, complex in shape due to their merging. The distribution of hillocks and depressions displays some pattern, i.e. chains of NE–SW trend. In general, however, the karst landscape of the area does not show clear patterns.

The AP-4.3 area (Figs. 12 and 14C) is characterized by a fairly regular relief with morphological features similar to those in the areas AP-1.8 and AP-1.1. These features are particularly visible in the highest (convex) part of the area, the altitude of which reaches over 1600–1700 m (Fig. 7). Corrosion dolines developed here are larger and have asymmetrical profiles, due to their development on hillslopes.

The AP-4.4 area (Fig. 12), slightly inclined in general to the south, morphometrically resembles the AP-1.5 area with a well-ordered karst relief. Within it, especially in the eastern (wooded) part, there are numerous karst dolines separated by limestone ridges, whose connection reveals a regular polygonal network which allows classifying the area as polygonal karst.

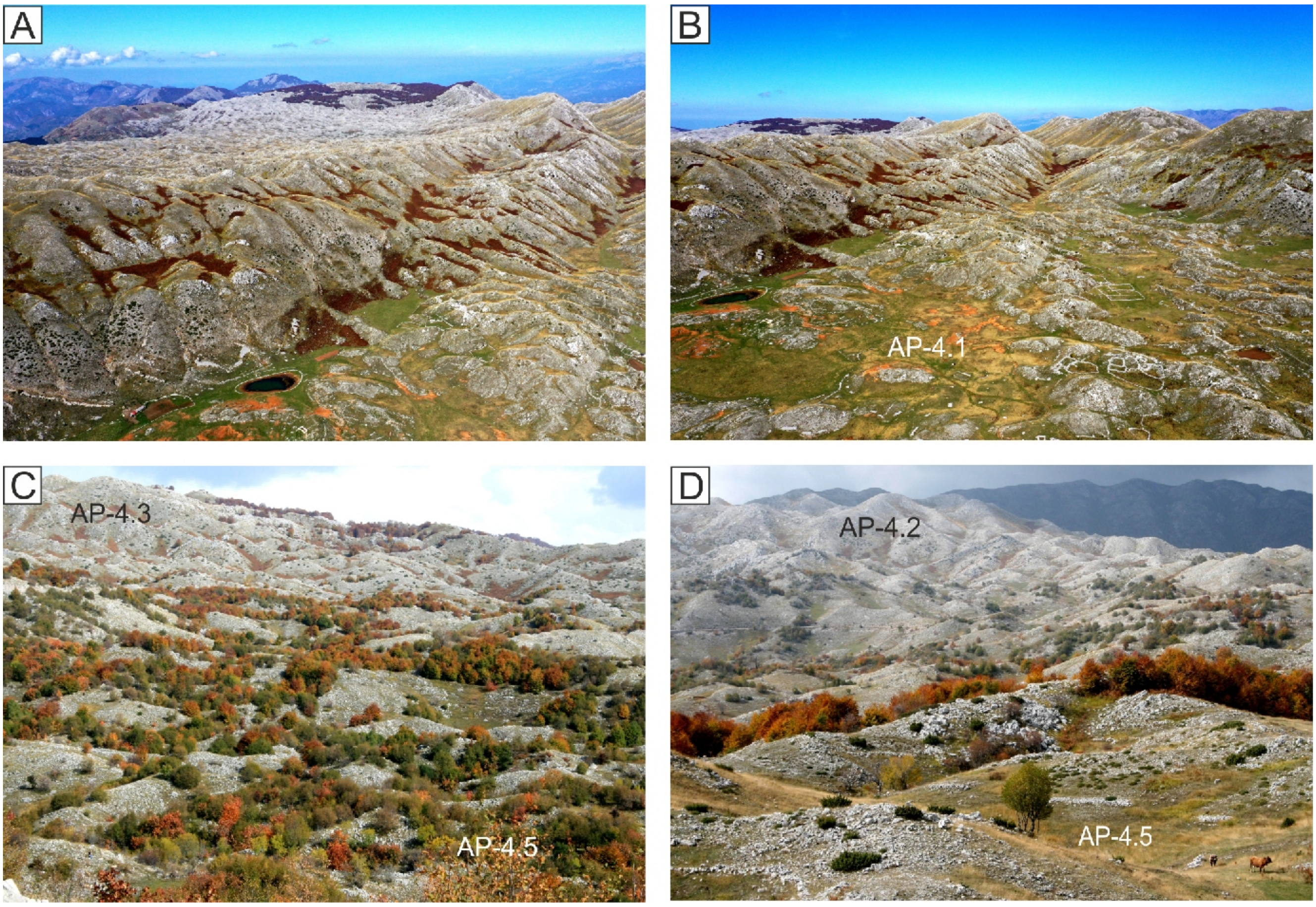

Fig. 14. Views of the southern plateau

A – view of the entire northwestern plateau and transitional (to the southern plateau) area from the south; **B** – the large depression in the northern part of the southern plateau generally corresponding to the area AP-4.1; **C** and **D** – views from the southern periphery (AP-4.5) of the southern plateau to higher parts located to the north-west (AP-4.3) and north-east (AP-4.2, the highest part). A and B – drone photos by A. Klimchouk, C and D – photos by V. Andreychouk

However, in contrast to AP-1.5, the net meshes or its conventional polygons here are more diverse in terms of size and morphology, whereas their distribution does not show any chains or other ordered patterns. Regular traits are also seen in the karst relief of the western, unforested (Fig. 12) part of the area but, due to surface inclination (towards the SW), karst dolines here are shallower and have asymmetrical vertical profiles.

Area AP-4.5 (Figs. 12 and 14D) is located in the southernmost near-edge part of the southern plateau. It is the lowest part of the southern plateau, and respectively of the whole massif (of its plateau-like part; Table 1). Just as in the case of the previous area, it is distinguished by the presence of a large number of karst dolines and morphological homogeneity. The difference is that the bottoms of the dolines here are better developed. The arrangement of the dolines and ridges retains the features of a polygonal network; however, the relief of the area has more mature features (more smoothed ridges between the dolines, a larger area of the doline bottoms, and so on).

DISCUSSION

Our morphological and morphometric analysis of the Western Massif plateau and comparison of basic geomorphological units has revealed some patterns that help explain the diversity of this karst relief.

The basic karst areas distinguished within the plateau differ in the morphology of karst forms, the density of their occurrence and the degree of ordering of the relief (its uniformity, homogeneity). The karst relief of almost all geomorphological units analysed generally shares certain morphological similarities. Within the karst plateaus, the widespread occurrence of corrosion dolines and depressions represent characteristic patterns of highly karstified areas with a high density of concave forms. Nevertheless, both on the maps and in the field, one may easily observe certain differences in karst morphology that constitute the basis for distinguishing separate karst-morphological units. These differences are related to the diameter of the forms (dolines and depressions), their depth, shape and symmetry, orientation, density of occurrence, and to the spatial pattern created by concave forms. For example, within the AP-1.8 area (one of those located at highest altitude) there are relatively large though shallow asymmetrical (in vertical profile) dolines separated by gently bulging "ridges" that – when looking at the orthophotomap – create the illusion of the hilliness of the relief. The same is the case with the AP-4.3 area within the southern plateau. In turn, the AP-1.2, AP-1.7, and AP-4.2 areas are distinguished by the dolines occurring in chains (latitudinal series).

Central areas of the northwestern plateau (AP-1.5, AP-1.6, and AP-1.7) and the southern areas of the southern plateau (AP-4.2, AP-4.4 and AP-4.5 are characterized by the highest density of dolines (204–328 forms per km^2; Table 2) and by the

Table 2

Density of dolines within areas of the northwestern (AP-1) and southern (AP-4) parts of the plateau

AP-1.1	AP-1.2	AP-1.4	AP-1.5	AP-1.6	AP-1.7	AP-1.8	AP-4.1	AP-4.2	AP-4.3	AP-4.4	AP-4.5
200	172	96	274	204	328	164	112	236	120	240	284

highest degree of ordering (regularity or irregularity) of the karst relief. The most ordered character (uniformity, homogeneity) is observed in the landscapes of the areas AP-1.5 (patch 4, Fig. 12), AP-4.4 (patch 11, Fig. 13), and, to a slightly lesser degree, in AP-1.2 (patch 2, Fig. 12), AP-4.5 (patch 12, Fig. 12), and AP-1.7 (patch 6, Fig. 12). The type of landscape in these areas, especially in the first two, can be referred to as polygonal karst, represented by the presence of many karst dolines separated by relatively narrow ridges (Fig. 15).

The area of AP-4.1 within the southern plateau is distinguishable by the presence of extensive flat-bottomed depressions filled with residual material (Figs. 12 and 14B) that cover a large part of its surface.

These and other differences in the karst relief within the karst-geomorphological units distinguished can be explained by several factors, such as:

1. *Geological and geomorphological evolution of the area*. The analysis revealed the relationship between the types of karst relief and the altitude of the terrain. We do not know what the nature of the relief of the massif at the earlier (pre-karst) stage was, when the gradually rising massif was still covered by non-karstic strata. It cannot be ruled out that some elements of the relief, especially large ones, such as the long slope dividing the surface of the massif into two parts (the north-western and southern plateaus), or the ranges surrounding the massif from the eastern side, may have an inherited (structural, denudational) character. However, it can be inferred that after the non-karstic cover had been removed by denudation, a leading role in shaping the relief started to be played by the karst processes taking place inside the massif. The internal structural differentiation of the massif may have contributed to intensified internal denudation within its more fractured parts. This resulted in the formation of a denser network of meteoric water infiltration points on the surface (hence a denser network of dolines and smaller dimension of polygons), and increased infiltration of rainwater. This, in turn, led to faster lowering, by surface chemical denudation, of their surface. This explains why the central parts of the north-western plateau are located lower in relation to the periphery (Fig. 13A), and are distinguishable by the most developed karst relief characterized by the highest density of dolines and their smaller diameter but greater depth. This may be the reason why the "polygonal karst" developed and occurs just in this part of plateau (Fig. 13B, D, area AP-1.5 and Fig.15).

This mechanism may also have contributed to the variation in altitude, and to the character of karstification of the terrains within the southern plateau (see Fig. 12, areas AP-4.1, AP-4.2, AP-4.5 and Fig. 14).

2. *Altitude differences of the areas.* The differences in the height of the terrain (as well as in the nature and degree of its karstification), both inherited and developed during the karst evolution of the area, at some moment began to play the role of an independent relief-shaping factor. The terrains situated at a higher altitude can serve as supply areas for the lower ones, i.e. provide additional amounts of water flowing down during heavy rain. The presence of surface runoff is indicated by numerous karst-erosive forms developed on the slopes. The most spectacular examples occur in the zone between the north-western part located at a higher altitude and the southern part of the plateau located lower (Figs. 13F and 14A). It may be inferred that the runoff of water into the lower regions may have contributed to their faster karstification, and still does. This conclusion is

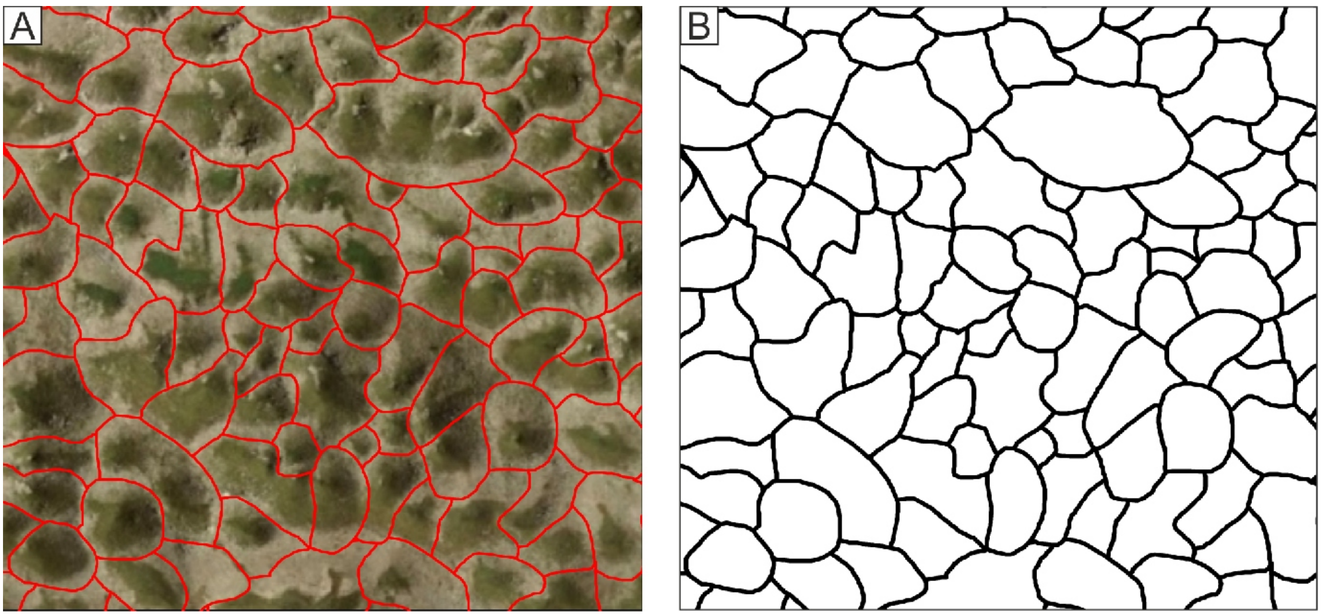

Fig. 15. Polygonal karst network built for patch 4 (0.25 km^2), central part of the AP-1.5 area

A – orthophotomap (the red lines show the boundaries of the concave forms); **B** – polygonal network derived from A

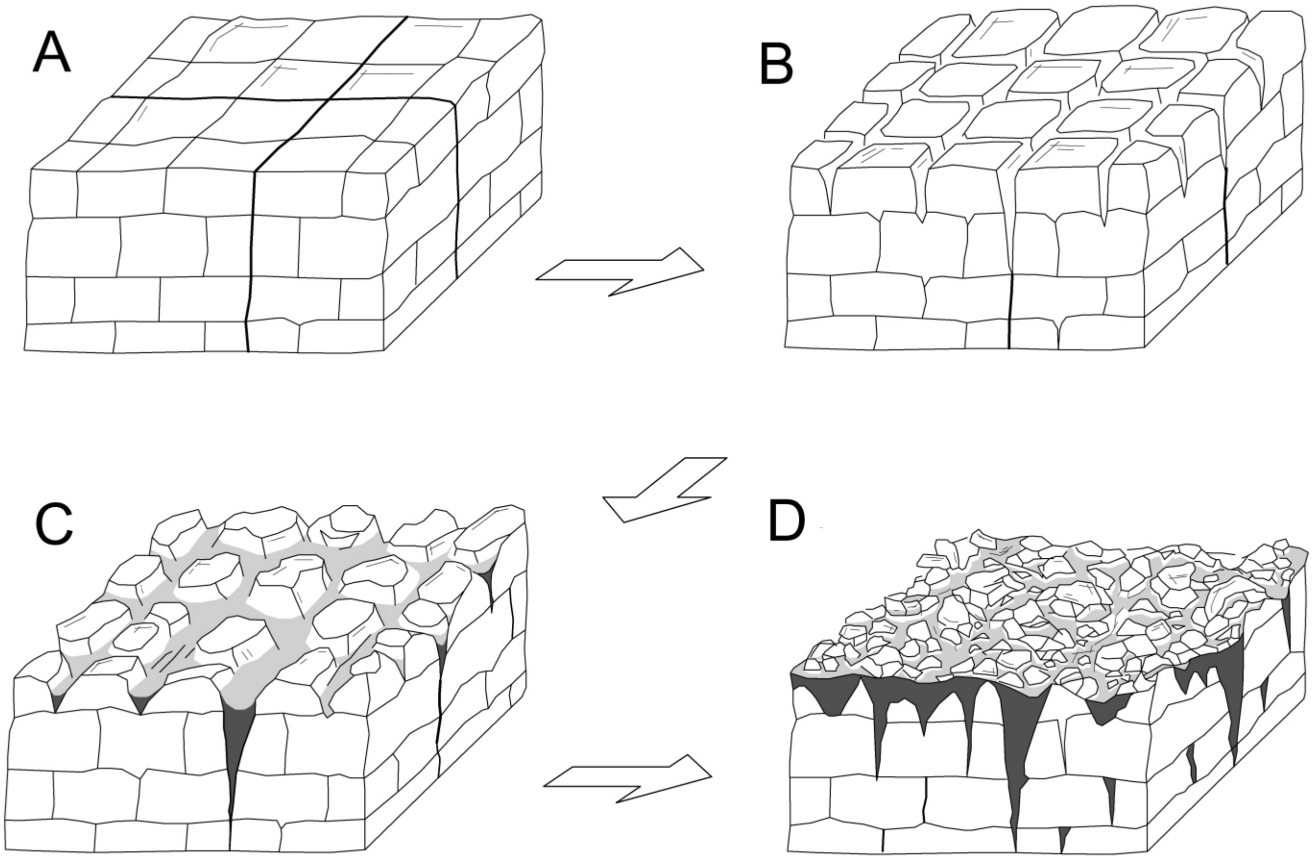

Fig. 16. Hypothetical scheme of the corrosive destruction of the network of fracture karren and the formation of the rubble and residual cover (black) on the horizontal or slightly sloping fissured limestone surface (mainly on the surfaces of ridges separating dolines)

A–D – hypothetical stages of transformation

prompted by the geomorphological situation in the AP-4.1 area surrounded to the east and west by higher-lying areas (Figs. 7, 12 and 14B). The inflow of waters from those areas may have played an important role in the faster karstification of this area and the formation of mature karst relief, with the presence of extensive flat-bottomed depressions and island hills. (Fig. 14B).

The altitude factor certainly works also in other parts of the area where altitude differences occur, but its impact there may be more "camouflaged" and more modest.

The altitude variations between the areas may have been enhanced by climate. Currently, the sub-units are distinguishable by specific elevation ranges. The average heights range from 1400 m a.s.l. (AP-4.5) up to 1645 m a.s.l. (AP-1.5; Table 1). The difference (~250 m), however, is too small to explain these or other distinctions in karst morphology by climatic factors such as precipitation, snow cover thickness, temperature, etc., although these may be of some significance.

3. *The inclination of slopes.* The influence of this factor can explain the larger dimensions, shallowness, slightly elongated shapes and asymmetry (in vertical profile) of the dolines developed on gentle slopes within the areas AP-1.2, AP-1.8 (Fig. 13E), AP-4.3 and in part AP- 1.4. The inclination of the limestone layers may be responsible also for the distribution of dolines into latitudinal series in the area of AP-1.2 (Figs. 12 and 13B, D). These elements of morphological "structuration" may be associated also with structural factors, but this question needs additional study.

The second aim of the study concerned some specific questions regarding the karst geomorphology of the massif, such as:

1. Why fissure karren (grikes, kluftkarren) do not occur in abundance on the exposed limestone surfaces and why there is a lack of distinct *karren fields*?

2. What is the reason for the relatively rare occurrence of *open karst shafts* at the bottoms of the dolines? What is the nature and degree of the *underground karstification* of the massif?

These two questions are obviously inter-related and pertain to peculiarities of the epikarst evolution (Klimchouk, 1995; Williams, 2008). As noted above, horizontal or only slightly inclined layering is characteristic of the Western Massif. Such an arrangement prevents the formation of slope karren (linear, hydraulically controlled). By contrast, a horizontal arrangement of strata intersected by a dense regular network of fractures is highly conducive to the development of a regular network of fracture-controlled types of karren (grikes, kluftkarren). Nevertheless, there is also a lack of such karren on the plateau, or they occur locally in an underdeveloped form. In places, the rock substrate is covered by residual clay material containing much limestone rubble. At the top of the residual and soil cover, there are many corroded rock fragments (Fig. 10D).

For pronounced development of epikarst and particularly of fracture-controlled karren, large "throughgoing" fractures are needed to connect the epikarstic zone with the bulk vadose zone below. Such major fractures, later evolving into vertical

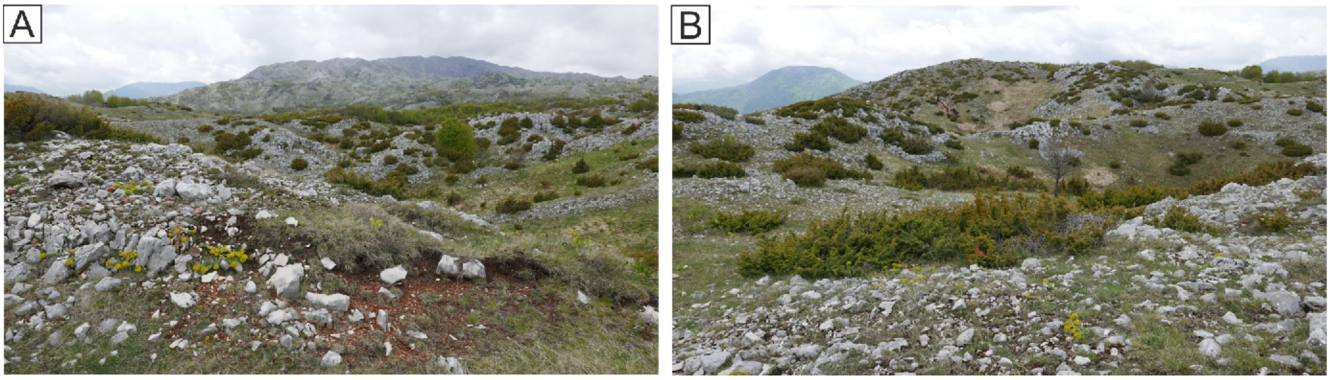

Fig. 17. Some typical examples of residual cover with many limestone blocks destroyed by karstification; the southern plateau (A and B – area 4.5); photos by V. Andreychouk

conduits (shafts), provide effective drainage of epikarst and the removal of insoluble residue (Klimchouk, 1995; Williams, 2008), facilitating the development of mature epikarst dominated by fracture-controlled karren. The lack of such karren on the plateau and the widespread occurrence of residual clay with limestone rubble suggests that throughgoing vertical fractures/conduits are scarce within the massif, leading to slower percolation from epikarst down into the vadose zone, the consumption of the most of the dissolution capacity of precipitation within the very top of the epikarstic zone, and accumulation of the residual products. This situation is illustrated in Figures 16 and 17.

The residual (karst-weathering) material that forms on the rock surface is washed out to the karst depressions, where it accumulates. As it builds up, it becomes a barrier for rainwaters to sink directly into the rock substrate. Accumulation of the low-permeability residue in karst depressions makes it possible to create artificial lakes here, in which the water is retained permanently or temporarily (Fig. 18).

The water slowly infiltrating the soil-residual layer in the bottoms of dolines is enriched in carbon dioxide and corrodes the limestone below, which causes further deepening of the karst forms. This, in turn, facilitates the accumulation of larger amounts of residual material at the bottom and the greater amounts of water draining into the depression. A similar principle (though less well developed) lies behind the interaction of the upper and lower parts of the plateau. Higher-lying hilly areas

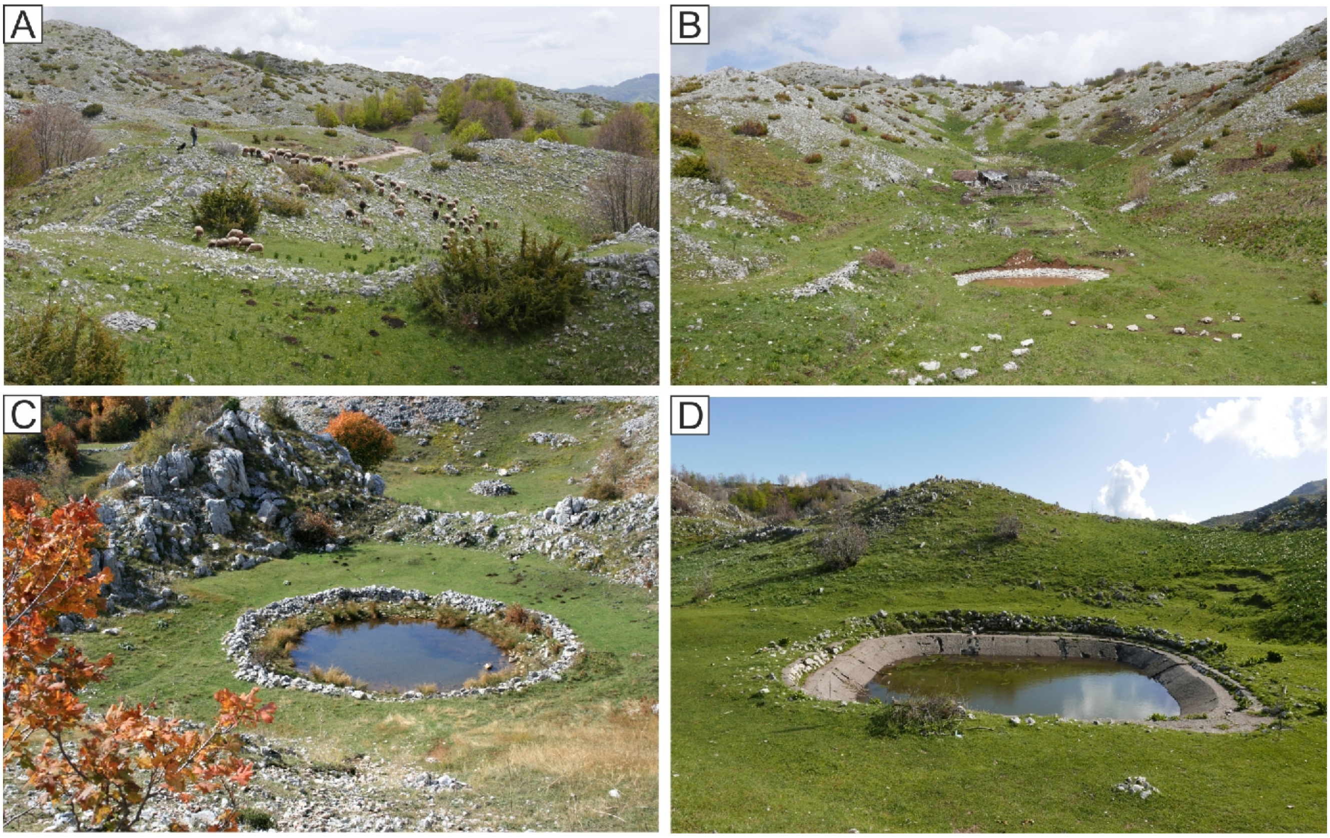

Fig. 18. Some examples of water retention in the bottoms of dolines and depressions (B, C and D)

The reservoirs on figures B and C keep the meteoric water without any bottom isolation (except for the natural clay layer), while in the case of the reservoir on figure D a concrete layer is used for water retention; figure A shows that the plateau area is used as pasture

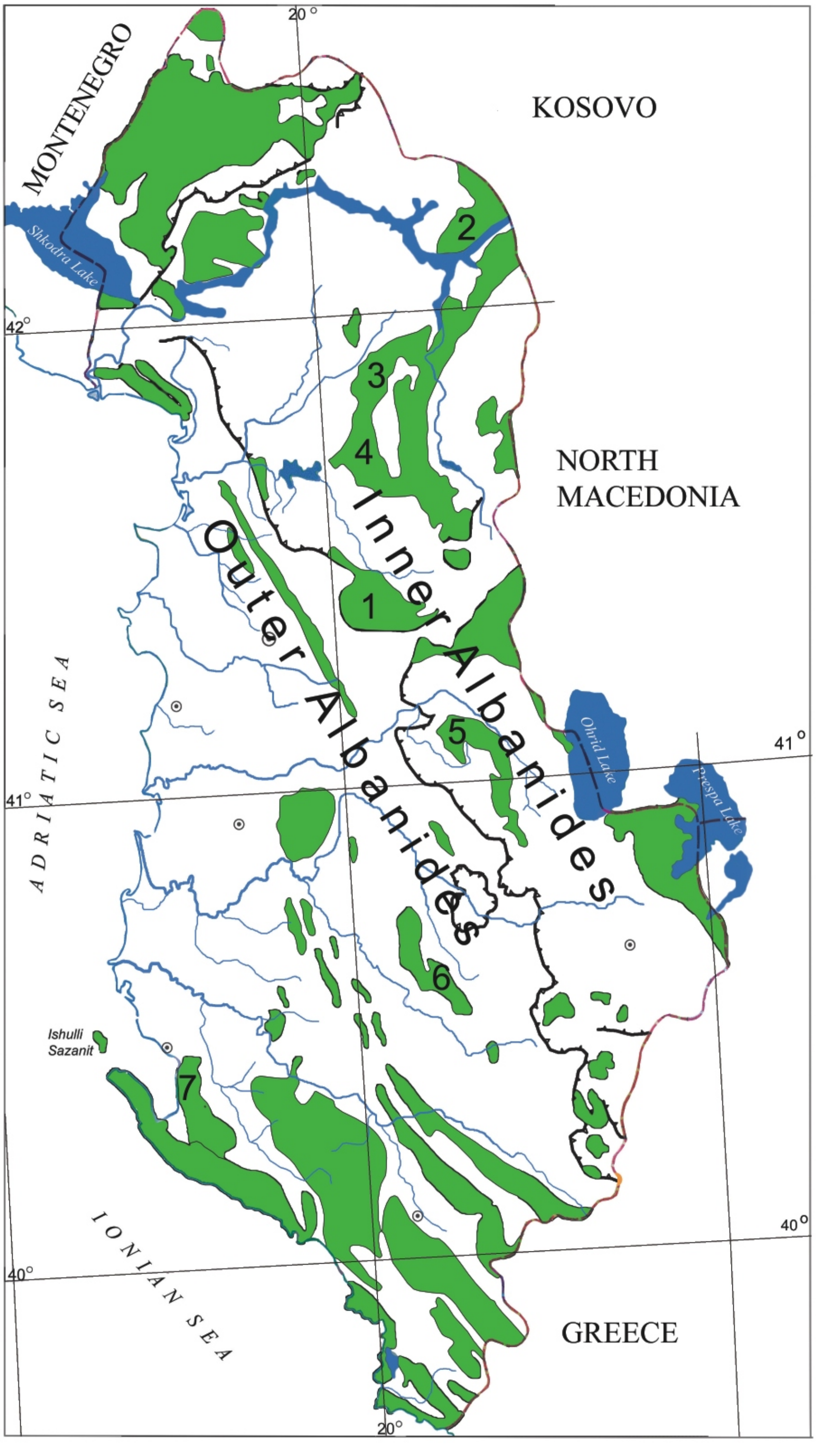

Fig. 19. The main allochthonous (1) and autochthonous (2–7) plateau-type karst massifs in Albania (after Eftimi, 2020)

1 – Mali me Gropa, 2 – Hasi, 3 – Zeba, 4 – Macukull, 5 – Berzeshta, 6 – Tomori, 7 – Shashica; the karst areas are shown in green

serve as the areas of supply of residual material for the lower areas – with a doline-like relief, and for those that are the lowest – where larger flat-bottomed depressions occur.

Detailed hydrogeological studies by one of the authors (Eftimi and Zojer, 2015; Eftimi, 2020; Eftimi and Malik, 2019) emphasize the strong karst permeability of the massif. These studies estimate that effective infiltration of precipitation into the massif is ~50 to 60%. They also show that conduit flow is the main hydrogeological feature of this karst massif, so that flow concentration effectively occurs in the epiphreatic/phreatic zone. The presence of large springs emerging at the foot of the massif (Selita Q = 507 l/s; St Maria Q = 894 l/s, Guri Bardhe Q = 250 l/s, and other) support this conclusion. Waters in springs remains undersaturated and shows periodic turbidity pulses. The latter may be result of concentrated intake of rain water into a few large open fractures and shafts. The high hydrogeological capacity of the massif makes it a significant reservoir of good-quality underground waters of great economic importance.

The Mali me Gropa is not the only karst massif of this type: in Albania there are other similar massifs (Fig. 19).

The massifs shown on Figure 19 have a similar structural-geological and geomorphological development to Mali me Gropa. They are blocks (not longitudinal structures) which lie on low-permeability rocks (mainly magmatic and metamorphic). The blocks consist of massive relatively pure and soluble Upper Triassic limestone or of generally horizontal Upper Cretaceous rocks. They are represented by generally horizontal high plateaus with very steep peripheries (as in the profile of Mali me Gropa). The plateaus are characterized by intense precipitation and very high effective infiltration. The infiltrated water recharge large-capacity springs. All of the massifs have a characteristic water cycle, similar to that in the Mali me Gropa massif. Therefore, the study of the karst of these massifs, especially the relief, which determines the conditions of water infiltration and circulation, is of great scientific and economic importance.

CONCLUSIONS

The Mali me Gropa limestone area in central Albania is a mid-altitude mountain massif typical of the Mediterranean, characterized by extensive karst development. The spectacular surface karst is represented by various forms that make up specific morphological complexes. Corrosion dolines of more or less the same size, forming characteristic spatial patterns, are the dominate forms. In some areas, the morphology of the surface strata corresponds to "polygonal karst".

Mapping of the plateau shows that the karst relief of the massif is generally characterized by a typological similarity (homogeneity) of karst relief. Nevertheless, in various parts of the plateau, the karst relief has undergone some modifications. These modifications concern the size and shape of karst forms (dolines and depression), their depth, symmetry-asymmetry, orientation, density of dolines, and the spatial pattern created by the forms. These differences are the basis for the distinction of geomorphological-karst areas with characteristic varieties of karst relief.

The spatial differences of karst relief within the plateau may be explained by several factors. The relationship between types of karst relief of particular areas and the altitude of the terrain may be the result of an uneven internal structure of the massif. After the emergence of the limestone from beneath the cover, the altitude differences may have formed as the result of the conjugated development of the relief and internal karst. Terrains with more intense internal karst denudation were lowered at higher rates, resulting in morphology different from terrains with less intense and more diffuse karstification.

The hypsometric differentiation of the plateau may also result in the redistribution of waters on its surface, causing its inflow from higher to lower areas. This may be reflected in the nature of the forms and the degree of karstification of areas surrounded by more elevated terrains.

The slight inclination of limestone bedding surfaces in some peripheral parts of plateau also influences the morphology and morphometry of the dolines, especially their asymmetry. The ordered character of the karst relief is primarily associated with its structural and evolutionary conditions.

The structural conditions i.e. horizontal (sub-horizontal) arrangement of the limestone beds, are the main cause of the poor development of typical linear karren, whereas the lack or poor development of fissure karren may result from their rapid development and evolutionary disappearance.

The relatively poor development of vertical shafts in the shallow subsurface may result from the structurally conditioned, very homogeneous structure of the epikarst zone, the scarcity of throughgoing vertical fractures, the widespread occurrence of residual cover on the plateau, and the accumulation of large amounts of clay material in depressions. This creates conditions facilitating a uniform, evenly dispersed character of rainwater infiltration (diffuse infiltration) deep into the karst massif.

This massif is currently an area subject to an increased human exploitation, particularly wood cutting and sheep grazing, the latter contributing to the pollution of water infiltrating the massif. Considering the fact that the massif is a habitat for many rare plant species for which elements of karst relief are a kind of ecological refuge, the best solution today would be to provide it with some form of legal protection, for example, by granting it the status of a National Park. As for the north-west plateau within the massif, it should be given the status of a nature reserve.

Acknowledgements. The authors would like to thank the reviewers: prof. M. Bąbel and an anonymous reviewer for their insightful analysis of this manuscript. Their suggestions were valuable and contributed to a significant improvement of the paper.

REFERENCES

Aliaj, S., Bushati, S., 2019. Look for the roots of the Mirdita ophiolites (Albania). JNTS, **49**: 3–47.

Aubouin, J., Ndojaj, I., 1964. Regards sur la géologie de l'Albanie e sa place dans la géologie des Dinarides. Bulletin de la Société Géologique de France, **VI** (97): 593–625.

Bakalowicz, M., 2015. Karst and karst groundwater resources in the Mediterranean. Environmental Earth Sciences, **74**: 5014.

Donneborg, M., 1993. Albanien expedition 1992 und 1993. Mitteilungen des Verbandes der deutschen Höhlen- und Karstforscher, **39**: 64–73.

Desio, A., 1960. Manual della Geologia Applicata. Hoepli, Milano.

Eftimi, R., 2010. Hydrogeological characteristics of Albania. AQUAmundi, Am01012: 79–92.

Eftimi, R., 2020. Karst and karst water resources of Albania and their management. Carbonates and Evaporites, **35** (69).

Eftimi, R., Malik, P., 2019. Assessment of regional flow type and groundwater sensitivity to pollution using hydrograph analyses and hydrochemical data of the Selita and Blue Eye karst springs, Albania. Hydrogeology Journal, **27**: 2045–2059.

Eftimi, R., Zojer, H., 2015. Human impact on karst aquifers of Albania. Environmental Earth Sciences, **74**: 57–70.

Eftimi, R., Bisha, G., Tafilaj, I., Sheganaku, Xh., 1985. Hydrogeological Map of Albania, sc. 1:200,000, Tirana. Printed in Nd, Mjeteve Mësimore H. Shijaku, Tirana-Albania.

Ford, D., Williams, P., 1989. Karst Hydrogeology and Geomorphology. Unwin Hyman Ltd., London.

Ford, D., Williams, P., 2007. Karst Hydrogeology and Geomorphology. John Wiley & Sons, Ltd., Chichester, England.

Frasheri, A., 2000. Temperature signals from the depth of Albanides (in Albanian). Bulletin of Geological Sciences 2000, Geological Survey of Albania: 57–66.

Frasheri, A., Bushati, S., Bare, V., 2009. Geophysical outlook of structure of Albanides. Journal of the Balkan Geophysical Society, **12**: 9–30.

Gemorphological Map of Albania, scale 1:500,000, 1992 (in Albanian). Centre of Geographical Studies Academy of Science of Albania, Printed in the Army Topographic Institute, Tirana.

Gjata K., Kodra, A., 1999. Albanian ophiolites: from rift to ocean formation. EUG 10: Journal of Conference, Abstracts. Symp. F04, Petrologic., 405, Strasbourg.

Hoxha, L., Avxhiu, R., 2000. Ophiolite volcano's sulphide potential assessment through integrated geological-geophysical and geochemical methods. In: Position of Albanides in Alpine Mediterranean Folded System, materials of 8th Albanian Congress of Geosciences, Tirana.

Jaho, S., Mici, A., Boriç, M., Mukeli, R., Naçi, R., 1980. Climate of Albania (in Albanian). Institute of Hydrometeorology, Tirana.

Kalinina, P., 1951. Geotechnical conditions of Selita spring area (in Russian). Vodokanalproekt, Leningrad.

Kessler, K., 1958. About the possibility increase the water supply capacity of Tirana (in Hungarian). Water Supply Directory, Ministry of Construction, Tirana-Albania.

Klimchouk, A.B., 1995. Karst morphogenesis in the epikarstic zone. Cave and Karst Science, **21**: 45–50.

Klimchouk, A.B., 2004. Towards defining, delimiting and classifying epikarst: its origin, processes and variants of geomorphic evolution. In: Epikarst (eds. W.K. Jones, D.C. Culver and J.S. Herman), Special Publication, **9**: 23–35. Charles Town, WV, Karst Waters Institute.

Kristo, V., 1973. Some aspects of karst in Albania (in Albanian). Collection of Studies, **1**: 67–79.

Kristo, V., Krutaj, F., Mezini, B., 1987. Karst landscape of Albania and the problems of its rational exploitation (in Albanian). Studime Gjeografike, **2**: 257–268.

Krutaj, F., Gruda, Gj., Kabo, Gj., Mecaj, N., Qirjazi, P., 1990. Physical Geography of Albania (in Albanian). Shtypshkronja e Re, Tirana.

Liko, V., 1962. Tectonics and characteristics of the development of Mali me Gropa Region (in Albanian). Bulletin of Tirana University, Natural Sciences, **3**: 37–47.

Meço, S., Aliaj, Sh., 2000. Geology of Albania. Gebrüder Borntraeger, Berlin-Stuttgart.

Pali, N., 1973. About the possibility of increase the discharge of Selita and Shenmeria springs (in Albanian). Ndertuesi, **2**: 25–30.

Parise, M., Qiriazi, P., Skender, S., 2004. Natural and anthropogenic hazards in karst areas of Albania. Natural Hazards and Earth System Sciences, **4**: 560–581.

Parise, M., Qiriazi, P., Skender, S., 2008. Evaporite karst of Albania: main features and cases of environmental degradation. Environmental Geology, **53**: 967–974.

Qiriazi, P., 2001. Physical Geography of Albania (in Albanian). Aferdita, Tirana.

Speleo Nederland, 1993. Special Albanian Expedition, July 1992.

Williams, P., 1971. Illustrating morphometric analysis of karst with examples from New Guinea. Zeitschrift für Geomorphologie, **15**: 40–61.

Williams, P., 1972. Morphometric analysis of polygonal karst in New Guinea. GSA Bulletin, **83**: 761–796.

Williams P., 2008. The role of the epikarst in karst and cave hydrogeology: a review. International Journal of Speleology, **37**: 1–10.

Xhomo, A., Kodra, A., Xhafa, Z., Shallo, M., 2002. Geology of Albania, Notes of Geological Map of Albania, sc. 1:200,000 (in Albanian). Tirana.

Sources of maps:

Digital Terrain Model (DTM) (2015–2017), pixel 0.1 m [https://geoportal.asig.gov.al/service/wmts], https://geoportal.asig.gov.al/map/?fc_name=Hillshade_2015_group&auto=true, (http://asig.gov.al/index.php/2014-11-06-22-34-05/ligji).

Digital Sufrace Model (DSM), pixel 0.1–0,2 m, Modeli Dixhital i Sipërfaqes (DSM 2015- 2017) 3D, [https://geoportal.asig.gov.al/service/wmts2], https://geoportal.asig.gov.al/map/?fc_name=Dsm_Hill_Group&auto=true, (http://asig.gov.al/index.php/2014-11-06-22-34-05/ligji).

Geological Map 100K, (Harta Gjeologjike 1:100,000), [https://geoportal.asig.gov.al/service/wms], https://geoportal.asig.gov.al/map/?fc_name=harta_gjeologjik_100k, EPSG:28404 Pulkovo 1942 / Gauss-Kruger zone 4, data 1990,publication 2001. Shërbimi Gjeologjik Shqiptar.

Geological Map 200K, (Harta Gjeologjike 1:200,000), [https://geoportal.asig.gov.al/service/wms], https://geoportal.asig.gov.al/map/?fc_name=gjeologjia_200k, EPSG:28404 Pulkovo 1942 / Gauss-Kruger zone 4, data 1990, publication 2001. Shërbimi Gjeologjik Shqiptar.

Hydrogeological Map of Mali me Gropa Karst Massif, scale 1:50,000, Hydrografia [https://geoportal.asig.gov.al/service/wms].

Land Cover – Corine 2018, 100m, CORINE Land Cover (CLC), Corine/CLC2012_WM, https://land.copernicus.eu/pan-european/corine-land-cover, [https://geoportal.asig.gov.al/service/wms].

LandSat8: GeoTIFF, UTM Projection (Output: WGS 84) [http://ldcm.usgs.gov, http://ldcm.nasa.gov/].

Orthophoto 2015–2016, 20 cm pixel [https://geoportal.asig.gov.al/service/wmts] https://geoportal.asig.gov.al/map/?fc_name=OrthoImagery_20cm, Autoriteti Shtetëror për Informacionin Gjeohapësinor (ASIG), Behaudin Dobi (GIS Specialist).

Orthoimage mosaics, Copernicus, https://land.copernicus.eu/imagery-in-situ/european-image-mosaics/very-high-resolution/vhr-2012?tab=mapview

Topographic Map 25K 1:25,000, 1959–1985 [https://geoportal.asig.gov.al/service/wmts], https://geoportal.asig.gov.al/map/?fc_name=25k_krgjsh, EPSG:28404 Pulkovo 1942/Gauss-Kruger zone 4. Instituti Gjeografik dhe Infrastrukturës Ushtarake (ish ITU).

Topographic Map 50K 1:50,000, 1960–1991 [https://geoportal.asig.gov.al/service/wmts], https://geoportal.asig.gov.al/map/?fc_name=50k_krgjsh, EPSG:28404 Pulkovo 1942/Gauss-Kruger zone 4. Instituti Gjeografik dhe Infrastrukturës Ushtarake (ish ITU).

Topographic Map 100K 1:100,000, 1978–1988 [https://geoportal.asig.gov.al/service/wmts], https://geoportal.asig.gov.al/map/?fc_name=100k_krgjsh, EPSG:28404 Pulkovo 1942.