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Development History of the Migaria Massif Karst Terrain

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Abstract

On the basis of many years of field, experimental and laboratory (dye tracing, laboratory study of bedrocks, data analysis of geological sections, etc.) studies and analysis of available literary sources, the history of karst terrain development was restored on the Migaria limestone massif. Based on the mentioned materials, it can be said that the karstification on the Migaria limestone massif took place throughout the Pliocene and partially in the Upper Miocene, and therefore, the beginning of the formation of the karst terrain can be considered the entire Pliocene and possibly the Upper Miocene as well. The Rhodanian orogeny phase (after the Middle Pliocene, during the Cuialnic era), which was continued into the Wallachian orophase, led to a new uplift of the Caucasus, followed by the activation of karst processes on the surface and underground. New orogenic movements of the Early Pleistocene enhanced the splitting of limestone suites and the activity of karst formation processes. The same period should be related to the formation of caves (Shurubumu, Koko, Khuru, etc.) developed in the gorges of the rivers of Khobistskali, Ochkhomuri and their tributaries, namely, the transition from the phreatic to the vadose period and their further development. Thus, it can be said that the formation of the karst cavities of the Migaria massif occurred mainly before the Pleistocene or in the Lower Pleistocene. In the post-glacial period, along with karst processes, rockfalls, landslides, and mudflows played an important role in the change of the terrain of the study area, as indicated by the displaced boulders of volcanic origin of the Bajocian age (tuff sandstone) distributed in the gorges of the Khobistskali River and its tributaries, as well as on the terrace steps and verified by our laboratory tests. The bedrocks are found in the upper reaches of the Khobistskali River and thay are brought as a result of powerful landslide-mudflow processes. In the last stage of the modern geomorphological cycle, surface and underground karst forms are actively modified by the flows of melted snow and rain water.

Keywords: Karst, Cave, Limestone massif, Georgia

Introduction

Georgia is a mountainous country located in the Caucasus region, between Russia, Turkey, Armenia, and Azerbaijan. As found in many countries in the world, Georgia is home to multiple, widespread karst massifs with well-developed karst areas and their associated landforms (Asanidze et al., 2017a; Asanidze et al., 2019; Lezhava et al., 2020; Lezhava et al., 2021). Different types of karst and pseudokarst features exist in abundance, due to the tectonic influences, nature of the bedrock, geologic structure, and hydrological complexity of the area (Tintilozov, 1976; Maruashvili, 1971).

The Migaria limestone massif is part of the medium and high mountain karst in western Georgia (Tintilozov, 1976; Lezhava et al., 2022). It is on the southern slope of the Samegrelo (Egrisi) range, between the Khobistskali and Tekhuri river gorges (Maruashvili, 1964; Gergedava, 1968; Gergedava, 1989; Tatashidze et al., 2009; Bolashvili et al., 2017; Asanidze et al., 2019; Lezhava et al., 2022). Administratively, the massif is located within the limits of Chkhorotsku and Martvili municipalities (Fig. 1).

Figure 1. Location of the Migaria massif on the general map of Georgia

The massif is separated from other areas by deep gorges: in the north and west it is represented by the gorge of the Khobistskali River, and to the east by the gorge of the Tekhuri River; to the south it borders the wide depression of the Ochkhomuri River, the left tributary of the Khobisskali River. The maximum stretch of territory within the mentioned borders is 17 km from west to east, and it reaches 6-7 km from north to south. The massif covers a surface area of approximately 100 km^2, with karst phenomena developing on an area of about 62 km^2.

The crest of the massif reaches its maximum height in the east (2025 m. - Peak Migaria; 1980 m. - Peak Jvari) and gradually lowers to the west, in the direction of Otsindale village, up to 650 m. These peaks are separated by deep saddle-like recesses. The northern slope of the massif, which descends into the valleys of Khobistskali and its left tributary, is characterized by steep cliffs.

To the west of Peak Jvari, the massif's tectonic zone is made up of two anticlinal hills that are parallel to each other. These hills surround a system of unfilled hollows that have formed in a synclinal structure that is 8 km long and 3 km wide (Maruashvili, 1964).

As a result, a big part of the Migaria massif is made up of a synclinal structure. In the middle of this structure is a closed basin made mostly of Barremian rocks. Their lowest points are located at a height of 900-1000 m above sea level and are represented by sinkholes, ponors, and underground forms (mainly, wells and shafts). The hollow divides into several secondary hollows, each with its own karst genesis. Among them, the Tsipuria hollow is notable for its size (length 5.5-6 km, width 2.5 km) and it occupies the western part of the unified hollow. We refer to the system of single hollows mentioned above as the Tsipuria hollow. It is much smaller than the Tsipuria hollow and is located northwest of the Tsipuria basin. It is made up of Barremian (Urgonian facies) limestones and is closed off from the Tsipuria basin (Fig. 2).

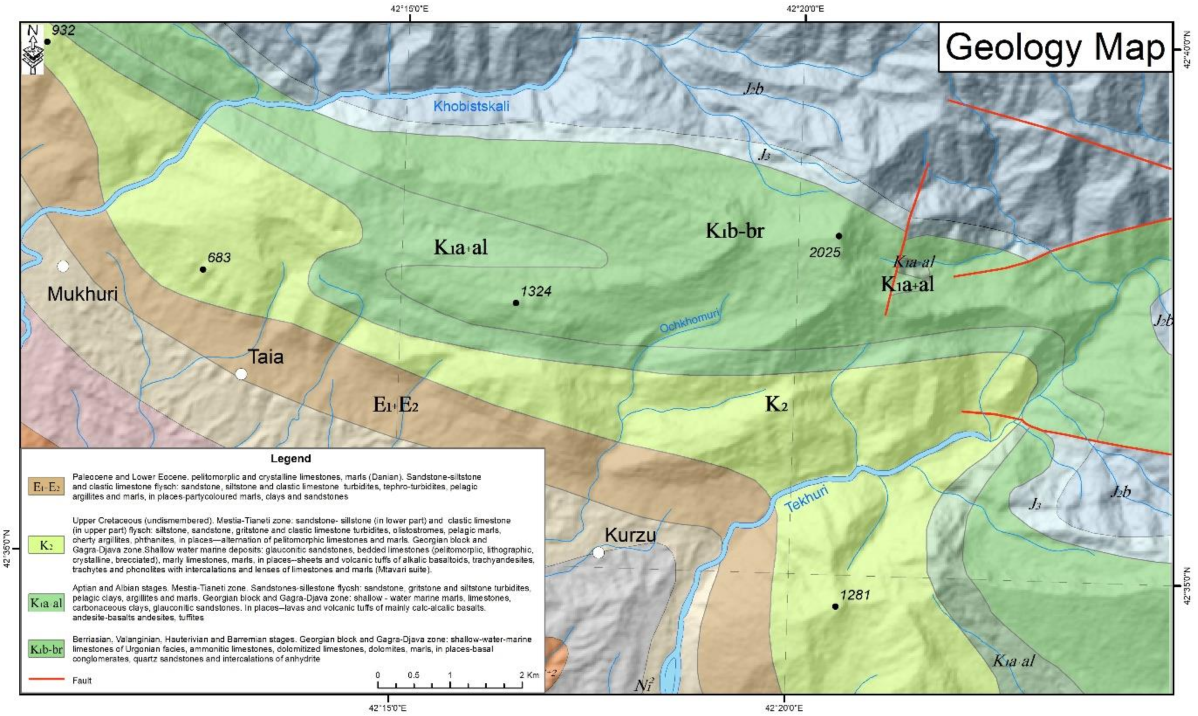

Figure 2. Geology of the Migaria limestone massif (Gudjabidze, 2003)

The hill of the monoclinic structure is on the southern slope of the Migaria massif. It is connected to and sticks to the Tsipuria synclinal core, which is made of Urgonian facies (Barremian) rocks from the Migaria massif (Maruashvili, 1963; Maruashvili, 1973; Gorzohon et al., 2004; Lezhava et al., 2015; Lezhava et al., 2022). It is built with Upper Cretaceous and Paleocene-Eocene limestones, and from west to east, its height increases from 1000 m to 1200-1300 m. The mentioned hill is separated from the high syncline massif by dry ravines and uvalas and is fragmented by the gorges of the Ochkhomuri River and its tributaries (Atamana, Vau, Khuru, etc.) (Fig. 3).

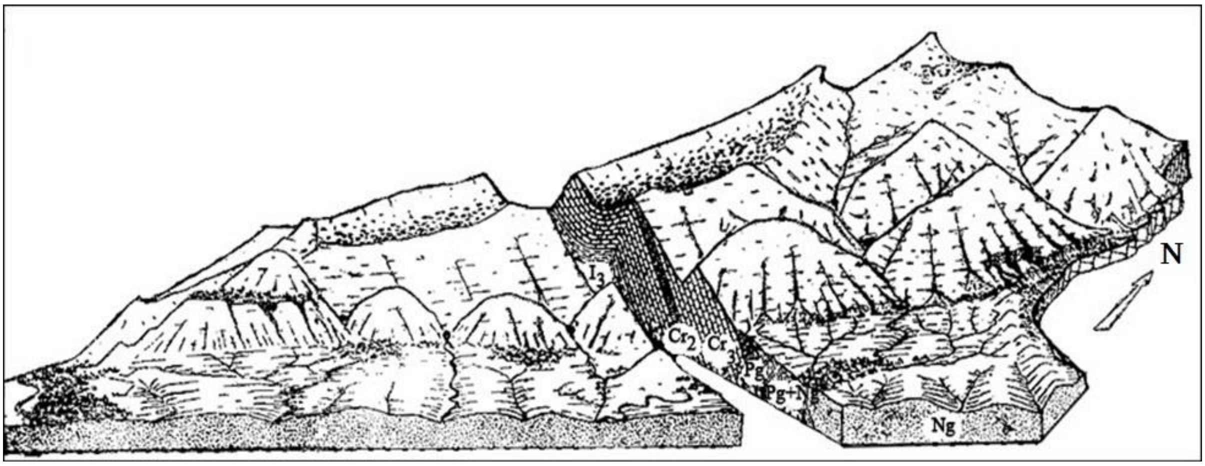

Figure 3. Block diagram of the Migaria limestone massif (Tabidze, 1966)

There are many karst sinkholes in the Tsipuria synclinal hollow, on the anticlinal hills that surround it, and on the tops of Migaria and Jvari peaks. There are also Corrie surfaces to be found. With its high energy level (2000 m) and other helpful factors, the terrain supports the active flow of karst processes. This creates caves, wells, shafts, and abysses underground in the core of the massif. The theoretical depth of massif karstification and penetration here is 1500-1600 m.

Methods and Materials

The work employs field, experimental, and laboratory research methods. In the research process, the study of existing cartographic and geological material was carried out as well as the field geomorphological and karst-speleological large-scale survey of the territory. In order to study the terrain and identify the karst features, an unmanned aerial vehicle (Phantom 4) was used. We identified the composition of the displaced boulder by laboratory examination of its fragment sample, which allowed us to identifie the place of the boulder's break off and, accordingly, the distance of its displacement. We identified the movement routes of underground karst waters and discharge areas using the dye tracing (indicator test) method. It was found that there is a shared karst-hydrological system called the Deidzakhi hydrogeological system and separate flows of fissure-karst water.

Results and discussions

It is difficult to argue about the formation of karst cavities in ancient times, especially when the region has been uplifted several thousand meters from its original location and has also been exposed to exodynamic agents for a long time. The development of the karst terrain took place against the background of the geological development of the study area and the formation of the terrain in general (Maruashvili, 1963; Tintilozov, 1976; Lezhava et al., 2019a). It can be said that on the Migaria limestone massif, as well as on the massifs of the karst sone of western Georgia (Lezhava et al., 2019b; Lezhava et al., 2019c; Asanidze et al., 2021), karst formation and the formation of karst terrain begin in the Upper Miocene-Lower Pliocene, when the Attic phase of the orogenesis caused a significant uplift of the study area and, accordingly, intensive washing of the surface (Edilashvili & Gudjabidze, 1954; Tsagareli & Astakhov, 1971).

This process was further influenced and activated in the Late Sarmatian period, in particular, in the Meotian and Pontic centuries, which is confirmed by the faunistically dated (Meotian-Pontic) Samegrelo (Odishi) foothill sediments washed off from the southern slope of the Caucasus, represented mainly by limestone conglomerates. In the Cimmerian (Middle Pliocene), as a result of the sea abrasive action on the southern slope of the Migaria massif (also the Gaucha massif), the Cimmerian Sea abrasion flatland is developed, known as the Tarzen-Otsindale flat surface (level) and currently presented at 700-750 m a.s.l. So, the Migaria massif went up 700 meters after the Cimmerian transgression. This means that by the end of the Tertiary period (Upper Sarmatian age), the massif was at least 1300 meters a.s.l. (Maruashvili, 1964). But if we take into account the denudation processes (Lezhava et al., 2019d; Lezhava et al., 2021), which followed the differentiated uplift and which should have caused its lowering, then it would be much higher. Therefore, it can be said that the uplift of the Migaria massif and the phase of continental development should have been started at a rather distant moment in the Tertiary period, and it is logical that already in the Upper Sarmatian age, when large-grained molasses (in particular, limestone conglomerates) began to accumulate in the Transcaucasian highlands, Migaria was hypsometrically on the border of hilly and medium-mountainous terrain (Maruashvili, 1964). Based on the above, karstification on the Migaria massif took place throughout the Pliocene and possibly in the upper Miocene as well, and therefore, the mentioned period can be considered as the beginning of the formation of the karst terrain.

The Rhodanian orophase (after the Middle Pliocene, during the Cuialnic era) caused a new uplift of the Caucasus (along with the Migaria massif), which was followed by the activation of karst processes both on the surface and in the underground (Tintilozov, 1976). It was during this phase that the modern structures of Georgia's folded mountain system were fully formed. This process continued during the Wallachian orophase, which happened at the start of the Quaternary period, between the Cuialnic and Chaudian eras (Tsagareli & Astakhov, 1971).

By our assumption, these phases should be connected with the formation of the Migaria deep fault, other fault dislocations, and block tectonics of the entire Migaria massif, as a result of which karstified rocks acquire collector properties. Among the disjunctive dislocations identified for today, the Migaria fault, which passes between the Jvari and Migaria mountains and extends from the northeast to the southwest, is noteworthy surface (Edilashvili & Gudjabidze, 1954). As a result of faulting, the Barremian, Aptian, and Albian-Cenomanian suites are shorn, and they reach the porphyritic suite. The mentioned fault should create a kind of barrier and make it difficult for the underground karst waters formed in the eastern half of the massif to move westward (representing the watershed of the Deidzakhi hydrogeological basin), which is also confirmed by the indicator tests we have conducted.

In the mentioned period, along with an important uplift of the study area, destructive processes were revived-weathering and denudation intensified, as well as deep erosion of rivers. As a result of the latter, the area was intensively fragmented. Karst processes have intensified. They formed both surface and underground karst features. Based on the mutual comparison of the levels developed in the Khuru and Ochkhomuri river gorges, L. Maruashvili (1964) indicates the 3-4 intermittent uplifts of the Migaria massif in the recent geological past (in the Middle and Upper Quaternary). The area's periodic upward movement also led to the formation of caves at various hypsometric levels.

It seems that the evolution of karst cavities, like other limestone massifs of Georgia (Asanidze et al., 2017b; Asanidze et al., 2017c; Asanidze et al., 2017d), was closely related to the action of pressurized waters in the early stage of their development. In the karst cavities of the Migaria massif, clear traces of the mechanical and chemical impact of these waters have been preserved so far (smoothed, levelled and perforated surfaces, ceiling corries, rounded arches, deaf pockets and niches). Even today, pressurized water plays an active role in the formation of karst cavities (Shurubumu, Ko, Khuru, and other caves) and their systems.

Early Pleistocene (Pasadena phase) new orogenic movements enhanced the fissuring of limestone suites and, therefore, the activity of karst formation processes. Further evolution of the river network and karst cavities along with it takes place. Before the Middle Pleistocene, L. Maruashvili (1964, 1971) indicated different directions of the rivers of the Migaria massif. In particular, the Ochkhomuri River joined the Tekhura River and the Skurcha River joined the Khobistskali River, and the Khobistskali River flowed through the bed of the current Shiksha River. In the middle Pleistocene (Old Euxine-Uzunlan-Karangat time) the uplift of the southern slope of the Caucasus continues, which naturally affected the activity of groundwater movement and the development of caves. Based on the correlation of the terrace levels, L. Maruashvili (1964) indicates the uplift at the height of 130-140 meters of the Migaria massif after the Riss era, which should be connected with the formation of the modern gorges of the Ochkhomuri, Skurcha, Tekhuri, and Khobistskali rivers. The formation of caves (Shurubumu, Koko, Khuru, etc.) developed in the gorges of the Khobisskali and Ochkhomuri rivers and their tributaries should be related to the same period; in particular, the transition from the phreatic to the vadose period and exposure to daylight. Thus, it can be said that the formation of the karst cavities of the Migaria massif occurred mainly before the Pleistocene or in the Lower Pleistocene.

On the southern monoclinal slope of the Migaria massif, the widespread depressions devoid of constant flow - "dead gorges" - seem to have been developed before the last uplift of the massif, which caused the lowering of the karst drainage level. After the deep shifting of the hydro-network, many caves remained completely without water, and in some areas, where there was a significant mass of water moving in depth along the crack, groundwater has produced caves at lower levels and in some cases reached the level of the main river. Based on the results of the indicator tests we did on the Migaria massif, we can say that the different conditions that led to the formation of caves in the study area showed that separate water streams were formed. In addition, in the modern stage, individual karst caves, shafts, wells and channels of vaucluse springs, formed in the early stages, were united into a single karst aquifer system of "Deidzakhi", which is still impenetrable to humans and within which the development of karst cavities is yet underway (Fig. 4).

Figure 4. Deidzakhi vaucluses. a) Deidzakhi karst streams during the flooding period. b) The junction of the Deidzakhi karst streams with the Khobistskali River (UAV-Phantom 4 images)

In the post-glacial period, rockslides, landslides, and mudflows played an important role in the change of the terrain of the study area, together with karst processes. This period (in the Upper Quarternary) should be related to a landslide of grandiose size (more than 1 km wide) that developed on the southern slope of the Migaria massif in the vicinity of the village of Doberazen. Individual areas of the mentioned landslide continue to periodically activate. In general, landslides, rock avalanches, and rockfalls are common events in other parts of the southern slope of the Migaria massif as well. Here, together with the landslide events in Tertiary clays and marls, the limestones are also destroyed and lead to the occurrence of rock avalanches and rockfalls. To the mentioned period should be related developed in the Khobistskali river gorge the landslides, rock avalanches and mudslides and huge displaced boulders brought by the latter to the gorges of the Khobistskali River and its tributaries. One of these displaced boulders (its mass reaches 150-160 tons) was observed by us on the first terrace level above the left floodplain of the Khobistrskali River, at a height of 2-3 m above the river level (298 m a.s.l.), in the distribution zone of the Lower Cretaceous carbonate rocks (limestones), (Fig. 5).

Figure 5. Deidzakhi displaced boulder in the Khobistskali river gorge

As a result of the laboratory examination of the sample fragment from the boulder, it was identified that it is a volcanic, fine-grained tuff sandstone of Bajocian age, the bedrocks of which are found in the upper reaches of the Khobistskali River, 4-5 km from the current location of the boulder (it extends for two tens of km in the upper reaches of the Khobistskali River). So, the Deidzakhi boulder was brought to the direction of the Khobistskali riverbed in the limestone distribution zone, at least from 4-5 km. Based on the mentioned fact, we can assume that in the upper reaches of the Khobistskali River, as a result of a landslide, rock avalanche, or their combination, caused by a strong earthquake, the river bed was completely blocked and a lake appeared; after the accumulation of water mass, its sudden breakthrough took place, and a strong stone-muddy mudflow caused the distribution of boulders and mudflow material on the bed and slopes of the Khobistskali River and its tributaries. In this regard, it is particularly noteworthy the lower part of the Gvalashara river gorge (the right tributary of the Khobistskali River, Lugela vicinities) flowing through the Middle Jurassic-Bajocian porphyritic rocks, where the mass of individual smoothed boulders scattered over the flattened right level of the gorge reaches several tens of tons. We observed boulders of similar size in the gorges of other tributaries of the upper stream of the Khobistskali River. In the same period, the lower level of the Shurubumu cave system should have been filled up with rock avalanches and mudflow materials. It seems that during the mentioned period, some of the karst cavities developed in the Migaria massif collapsed and were partially or completely filled with boulders and debris material, or were blocked as a result of the tectonic activity of the region. Based on the study of the karst cavities detected so far on the Migaria massif, it can be said that the conditions of their conception and evolution in relation to the peculiarities and the hydrological regime of the terrain considerably differ from the contemporary conditions. Namely, the evolution of cavities seems to have been more intense in the past, as indicated by the morphological-morphometric indicators of karst cavities, as well as corridors, halls, etc. Currently, surface and underground karst features are actively modeled by melting snow and rain water flows.

Conclusion

It is worth noting that according to the scientists (Edilashvili & Gudjabidze, 1954; Maruashvili, 1971; Tintilozov, 1976), the leveled surface (Tarzen-Otsindale step) with the height of 700-750 m a.s.l. belongs to the step formed as a result of the abrasive action of the Cimmerian Sea at the end of the Tertiary period. Therefore, it seems that after the Cimmerian transgression, the Migaria massif experienced an uplift of 700 meters. From this, we can conclude that at the end of the Tertiary period, the massif reached at least 1300 m a.s.l. Based on the above mentioned, the uplift of the Migaria massif and the phase of continental development should have started at a distant moment of the Tertiary period (Attic phase), and already in the Upper Sarmatian age, when large-grained molasses (in particular, limestone conglomerates in the mountainous area of Odishi) began to accumulate in the Transcaucasian intermountains, the hypsometric evolution of Migaria should have crossed the edge of the hilly and medium mountainous terrain. Thus, we can conclude that the erosion on the Migaria massif took place throughout the Pliocene and possibly in the Upper Miocene as well.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

L.Z. wrote the manuscript. T.K. B.N. T.T. A.I. G.G. K.R. N.A. A.L. helped to assist general review of the manuscript. C.N. did text and language editing. All authors provided critical feedback and helped shape the research, analysis, and manuscript.

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