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Research Article

The results of a complex study of the Turchu limestone hollow (polje). Western Georgia, Caucasus

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Keywords

Karst, Hollow, Corrosion, Sinkhole, Radarogram, Georgia.

Abstract

Based on the complex studies (geographical-geological, karst-speleological, and geophysical studies), conducted by the authors in the study area, karst forms such as sinkholes and ponors were identified, the width (2-17 m) of the Quaternary deposits located on the limestones were determined, the average and maximum discharges of the streams flowing on the bottom of the hollow were calculated. Studies have also shown that relatively heavy rains and snowmelt periodically flood the relatively low, western part of the hollow and create a temporary lake that soon dries up through the ponors at the bottom of the hollow, where the water stream are discharged. The closed shape of the Turchu hollow the limestone bottom covered with Quaternary deposits and the events described above indicate the corrosive origin of the hollow, which has been practically confirmed by our georadiological and electrometric studies. It is notable that the role of tectonic movements in the origin of the hollow along with the corrosive processes, which had a periodic character, and together with the uplifting of the area caused the lowering of the levels of underground waters and, consequently, the activation of karst processes.

Highlights:

-Geographical-geological, speleological and geophysical studies conducted in the study area

-Indicator experiment (dye tracing) was carried out in the western part of the Turchu hollow

-The unmanned aerial vehicle was used to study the surface karst forms of the Turchu hollow

-Karst forms such as sinkholes and ponors were identified, the with (2-17m) of Quaternary deposits

-It seems that the evolution of the Turchu hollow is still being actively carried out in the limestones

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1. INTRODUCTION

Georgia is a classical karst country with the development of diverse surface and underground karst landscapes (Asanidze et al., 2017a; Asanidze et al., 2019; Lezhava et al., 2019a; Lezhava et al., 2020). Karst processes are mainly developed in western Georgia, where it extends to the east as a continuous strip at 325 km from the Psou River to the vicinity of the Lake Ertso (Maruashvili, 1973; Kipiani, 1974; Tintilozov, 1976; Lezhava, 2015; Lezhava et al., 2019b). It includes the northernmost part of the Kolkheti Lowland and the peripheral strip of the southern slope of the neighbouring Caucasus. This strip is located on the border between the southern slope of the Caucasus folded system and the Block of Georgia. Important massifs of Askhi, Khvamrli, Zemo Imereti, Racha, Migaria, and others are represented exactly in the mentioned karst strip (Lezhava et al., 2015; 2019c; Asanidze et al., 2017b; Asanidze et al., 2017c).

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, including both hypogenic and epigenic caves (Gunn, 2004; Palmer, 2007; Ford and Williams, 2007). The vertical distribution of karst in Georgia starts from sea level and extends to the absolute elevation of 2757 m (the Speleologists Peak, Arabika Massif, western Georgia). The karst processes are relatively less intensely developed in other regions of Georgia, because of the lack of carbonate rocks and less favorable climatic conditions (Maruashvili, 1971; Lezhava et al., 2019d).

Karst in the Greater Caucasus Range is characterized by numerous rivers that cross the massifs dividing them into tens of isolated areas separated by erosive gorges (Tintilozov, 1961; Kipiani, 1974). Fragmentation into larger and smaller size karst massifs is a characteristic of the karst landscape of Georgia (Tintilozov, 1976). Karst landscapes in Georgia are characterized by very frequent and deep erosion that dissects the karst areas. This has a significant impact on the morphological and hydrogeological characteristics of the entire karst belt. Such intense dissection of the karst belt is caused by its location in the peripheral part of the continuing uplift zone, where substantial erosion processes have taken place and are still intensely underway (Lezhava et al., 2021). The total area of karstified rocks on the southern slope of the Caucasus (within western Georgia) reaches 12,454 km^2, which is 17,9% of the entire territory of Georgia (Asanidze et al., 2021).

Quite dense and deep erosive fragmentation, along with other geographical features characteristic of western Georgia's karst, has a significant impact on a number of essential moments in the morphology, speleology, and hydrogeology of the entire karst region.The division of this area into individual karst massifs is stipulated by its location in the peripheral zone of the sustainable ascending movements, where erosive processes were taking place and are going on quite intensively.

In the morphology of the limestone massifs of western Georgia, the primary tectonic relief is well preserved, represented by the alternation of sharply expressed synclinal and anticlinal folds with a general Caucasian distribution. Between the ranges we have hollows - depressions.

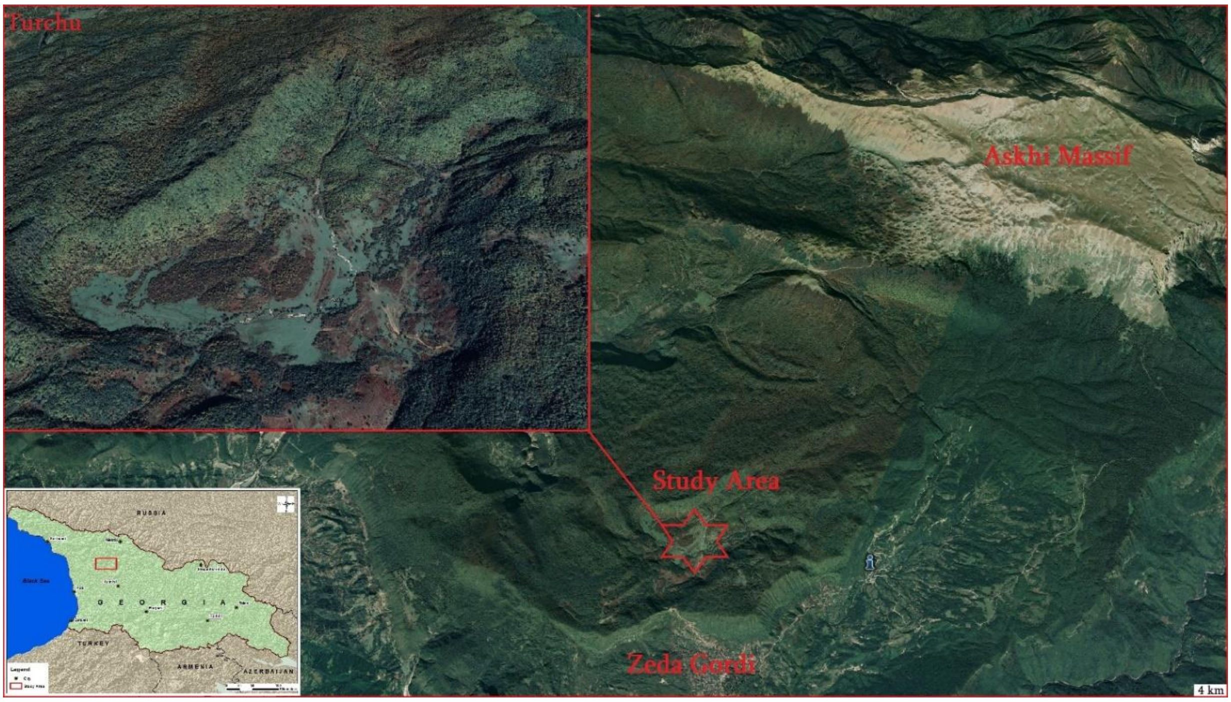
The study area, known as the Turchu Hollow (Depression), is located in the southern part of the Askhi limestone massif.

Based on complex studies conducted by the authors in the study area, it was found that corrosion occupies a leading place in the origination of the Turchu hollow, which is closely related to the periodic tectonic upliftings of the land. The deep canyons of the rivers developed near the Turchu hollow are clear indication of the latter. As studies show, the evolution of the Turchu hollow is currently actively underway in the limestones located beneath the Qaternary sediments.

2. STUDY AREA

Turchu hollow is located in the southern part of the Askhi limestone massif, at the bottom of which the Cretaceous limestones are covered with Quaternary sediments, which is why the underground karst processes are poorly studied. The hollow is surrounded on all sides and is closed by1000-1100 m height mountains built of limestones structurally presenting a syncline karst hollow/polje (Maruashvili, 1973). The lowest point of its bottom is located at 845 meters above sea level and rises to the north-east. The average depth of the hollow between the bordering mountain crests and the bottom is 120-150 meters. The length of the hollow is 5.3 km from the north-east to the south-west, the width is 3.2 km. The area of the bottom is 14 km^2. The flat bottom is 2.2 km long and 1.9 km wide, and the area exceeds 4 km^2 (Fig. 1).

Figure 1. Location of the study area (Turchu hollow) (*Google Earth image, 2020*)



The Upper Cretaceous (Turonian-Senonian) limestones that build the Turchu hollow and the surrounding mountains, like the Askhi Mountain massif, are affected by the solid and stable block of Georgia, due to which the tectonic structure is characterized by surface (sheet) folds, and the Cretaceous limestone layers are weakly dislocated (Gamkrelidze,1957, 1964). A. Janelidze (1941) explains the horizontal or weakly sloping layout of the Cretaceous limestone layers that build the mentioned hollow and the surrounding mountains by the influence of a local stable (solid) block.

The bottom of the hollow built of limestones is completely covered with Quarternary sediments, which are represented by riverbed and floodplain pebbles, sandstones and clays. The most part of the Quaternary sediments is a result of the ongoing chemical process in the constituent limestones of the hollow. Deluvial clays and limestone debris are widely represented at the foot and in the transition zone to the bottom of the surrounding mountains of the hollow. The width of the deluvial cover varies between 2-17 m as identified by of our geophysical surveys.

The bottom of the Turchu hollow is rich in surface karst forms, especially with ponors and sinkholes. Sunken and suction type sinkholes are found. Both old and new (sometimes placed one into another, two-story) sinkholes are presented. A kind of regularity is often observed in their layout. Sinkholes often follow a single line, which is a dry river valley characteristic of the old karst areas. There are also solely located sinkholes. The mentioned forms are concentrated in particular intensity in the western part of the hollow, which indicates the significant activity of karst processes in the mentioned area and the existence of a wide network of cracks (Fig. 2).

Figure 2. Intensive distribution of karst sinkholes in the Turchu hollow (*UAV-Phantom 4 image*)

From a geographical point of view the hollow is very interesting, because in the bottom of the Turchu hollow the Turchu River is flowing, which originates at the north-eastern edge of the hollow from the vaucluse of the same name (average debit: 60-80 l/sec., maximum – 400 l/sec.) and is the main artery of the water flowing through the hollow. In the middle of the river, on both sides, there are two terraced steps (relative height 20-22 and 4-5 meters), built of sandy clays, with weakly processed small limestone insertions. In the same strip, the tributary of the most important debit (0.05 m^3 sec) inflows the Turchu River from the left that originates from a deep lake formed by springs at the southern edge of the hollow. The lake stands in a karst sinkhole with a diameter of 8-10 meters.

From the modern geomorphological processes erosion and accumulation action of the Turchu River and its small tributaries in the bottom of the hollow are of leading importance, and physical weathering and karst processes - on the limestone slopes surrounding the hollow; rock falls and even rock avalanches are developed on the cliffs.

The forest cover in the Turchu hollow has been massively cut down, which greatly intensifies the erosion processes.

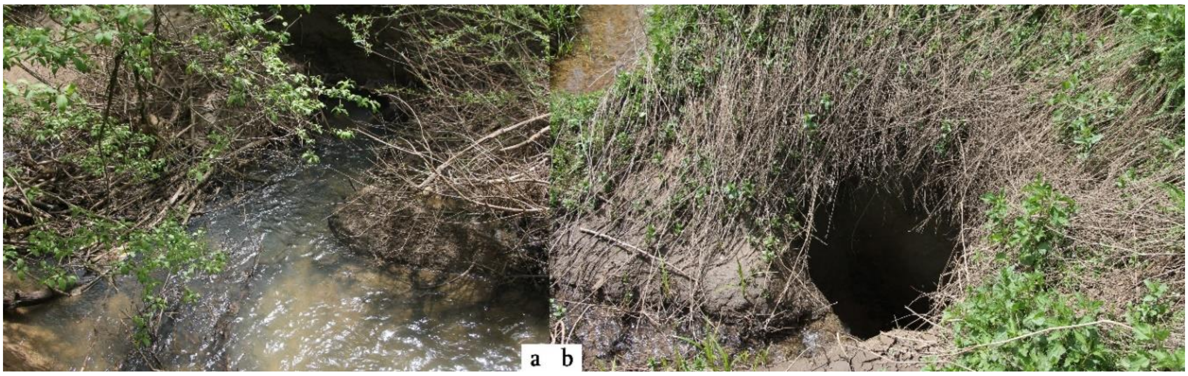
Consequently, the lands, that were arable years ago, were washed away in such a way that they have lost their function, which is a very sad fact.

The Turchu River crosses the hollow from east to west, collects the the springs flowing out from the deluvium in the junction of hollow bottom and slopes or at the contact line with the limestones, and finally noisily disappears under the ground in the western edge of the hollow through several ponors (Fig. 3).

The Turchu River, leaked in the mentioned ponors, flows out through the stream flowing from the Toba Cave, which is located at a distance of 3-4 km to the west of the Turchu hollow that has been identified by the indicator experiments (Jishkariani and Kaldani, 1977;

Jishkariani, 1981), which is also confirmed by the indicator experiments conducted by us. Thus, the Toba River is an underground extension of the Turchu River flowing at the bottom of the Turchu hollow (polje).

Figure 3. a) Water loss spot of the Turchu River. b) A small stream flowing into the ponor



In May the Turchu River discharge calculated by us in the fieldwork period was 0.40 m^3/sec. - 0.45 m^3/sec. (May 7 and 9 of 2019, respectively). Taking into account the morphological-morphometric characteristics of the riverbed and the surrounding area, the maximum river discharge was also calculated, which was 1.96 m^3/sec. (Fig. 4).

Figure 4. Measuring the Turchu River discharge

Due to the small distance (3.5 km) the water level of the Turchu River does not undergo intensive changes. The noticeable variability of the level occurs during rain and snowmelt. In this case, the water does not penetrate timely into the air tubes developed within the polje and accumulates at the bottom of the polje, resulting in the occurrence of temporary small lakes, after drying of which the wetlands are remained for a long time in some areas (Fig. 5).

G. Devdariani (1948) considers the last period of Pliocene or the early period of Quaternary as a beginning of the origin of the Turchu hollow. At the initial stage, there should have been karst sinkholes of small depth within the Turchu hollow. The long and intense course of karst processes connected and deepened the sinkholes, resulting in the development of extensive karst depression. It should be also noted that the process of hollow formation took place unevenly, against the background of periodic tectonic uplifting of the land.

Figure 5. A small lake formed in a swampy area

The cyclical nature of the hollow should be explained by the several times of repetition of the vertical (epirogenetic) movement of the land, which is generally considered to be a confirmed phenomenon for the Caucasus and caused significant changes in the morphological structure of the Caucasus. These movements caused the reduction of the level of underground karst waters and thus – activation of karst processes. The morphological character of the river valleys neighboring the hollow to the west and east that have experienced intense deepening of the bottom and are represented by deep canyon valleys (respectively the rivers of Abasha and Okatse) can be named as confirmation of the epirogenetic movements.

3. MATERIALS AND METHODS

Large-scale geomorphological and karst-speleological survey of the area was carried out during the research process. The unmanned aerial vehicle (drone) - Phantom 4 was used to study the relief of the hollow and to reveal the surface karst forms.

An experiment of dyed water tracing (indicator experiment) was carried out in the western part of the hollow to identify the movement paths and discharge centers of the underground streams flowing into the water loss hotspots.

In the selected sections of the river Turchu, the stream velocities were measured with a small dimensional hydrometric device ГГ-55 and the discharge was calculated, and the maximum discharge was calculated using the formula Q = FV, where F -is the area of the live cross-section (m^2), and V - is the average velocity (m3/sec.) of the stream.

The area of live cross-section was identified by the morphometric characteristics of the river bed and the traces left by the floods on the Turchu River, and the average velocity of the river flow was determined by Chezy's formula:

$$V = C\sqrt{Ri},$$

where R -is a hydraulic radius, which is equal to the ratio of the cross-sectional area to the wet perimeter (P), and i -is a hydraulic sloping, for calculation of which a longitudinal profile of the river bed was surveyed (Fig. 2). The report used the sloping of a bed in the red lines in the Figure 2, where the calculating cross-section of the maximum discharges is located. C -is a Chezy's coefficient. It is calculated by the formula:

$$C=R^{1/6}/n,$$

where n -is the coefficient of roughness of the bed, and is taken from a special table.

Fissured structures, disintegrated areas, significant cavities, humidified and waterlogged areas, waterpermeables and sinkholes were detected in the limestones beneath the Quaternary sediments at the bottom of the Turchu hollow using georadiolocation and electrometric methods.

4. RESULTS AND DISCUSSIONS

Field researches have shown that the bottom of the Turchu hollow is completely covered by the Quaternary sediments, where ponors and sinkholes are intensively developed. It is a closed hollow with the only river flowing through the bottom that gets into the ponor and disappears under the ground. The lake, which periodically occurs in the bottom of the hollow during the intense rains and snowmeltings, quickly empties through the ponors and disappears. The above-mentioned facts established and studied by us during the field research period clearly indicated the intensity of the karst processes taking place in the limestones beneath the Quaternary sediments in the depth of the hollow and the existence of significant karst cavities. Geophysical surveys have been conducted by us to determine the current processes in karst rocks at certain depths beneath the Quaternary sediments.

Among the multidisciplinary scientific geophysical research methods, the georadiolocation and electrometric methods of research used to detect karst cavities, fissures, fault lines, underground streams, and others, have been widely used to detect and pursue the covered structural units.

The aim of the research was to: identify the capacity of the horizons located above the limestones in the geological cross section; revelation of underground karst cavities, fissure structures; identification of filtration streams; and precise some of the opinions we have suggested.

Georadiolocation and electrometric studies have been conducted in the western part of the Turchu hollow that is a relatively active part in terms of the manifestation of karst processes. It is noteworthy that the studies conducted with these methods complement each other that make the results of the interpretation unambiguous (Odilavadze et al., 2015).

Georadiolocation profiling was carried out in the designated sectors of the study area using Georadar "Zond-12" with its 75 MHz staff dipole antenna, and data obtaining-processing was implemented using software – Prism-2.6. In total, 33 profiles were done (Fig. 6).

Presentation of large volume of material obtained as a result of geophysical studies was not possible in this article. Therefore, we will discuss only 6 profiles below, which more or less reflect the overall picture of the 33 profiles mentioned above (Fig. 6).

The radarograms below show the georadiolocation cross sections of the drawn profiles according to the depths and displacement distances (in meters). The average length of the profiles presented in the radarograms is 100 m, and the depth is up to 30 m.

The georadiolocation profiles and their locations are presented in the form of diagrams below (Fig: 7, 8, 9, 10, 11, and 12).

Figure 6. The scheme of a layout of georadiolocation profiles and observation points

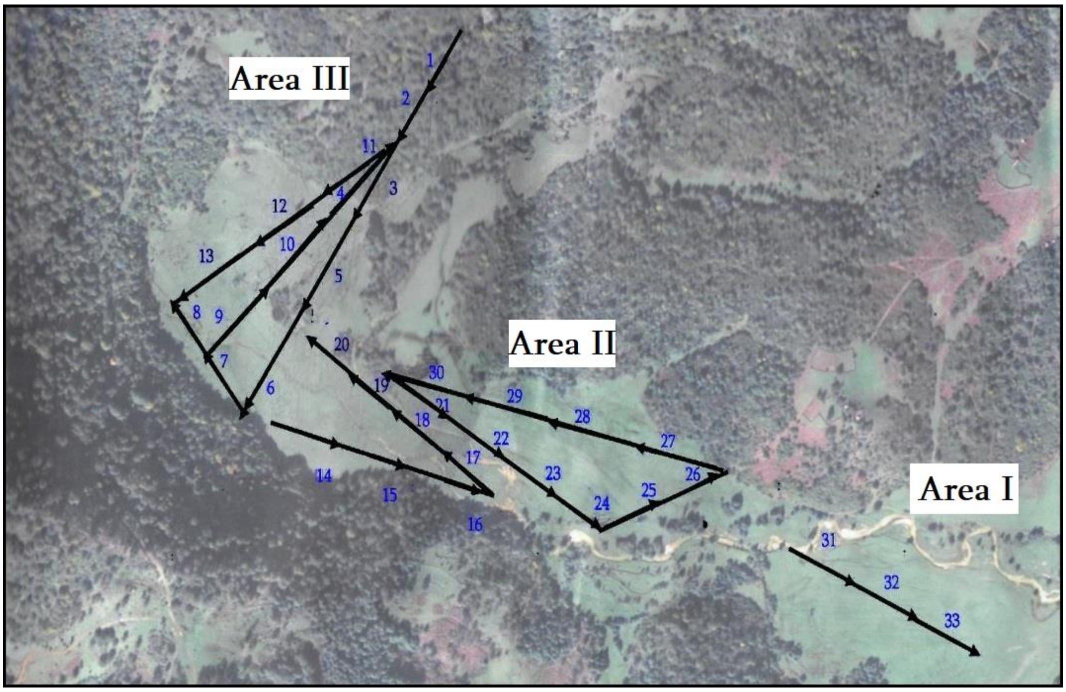
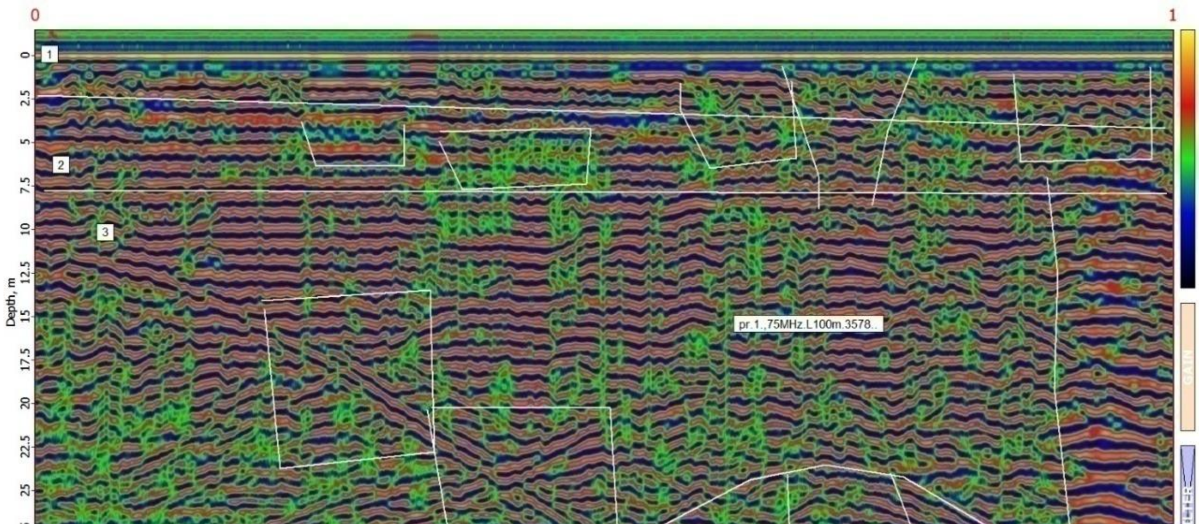


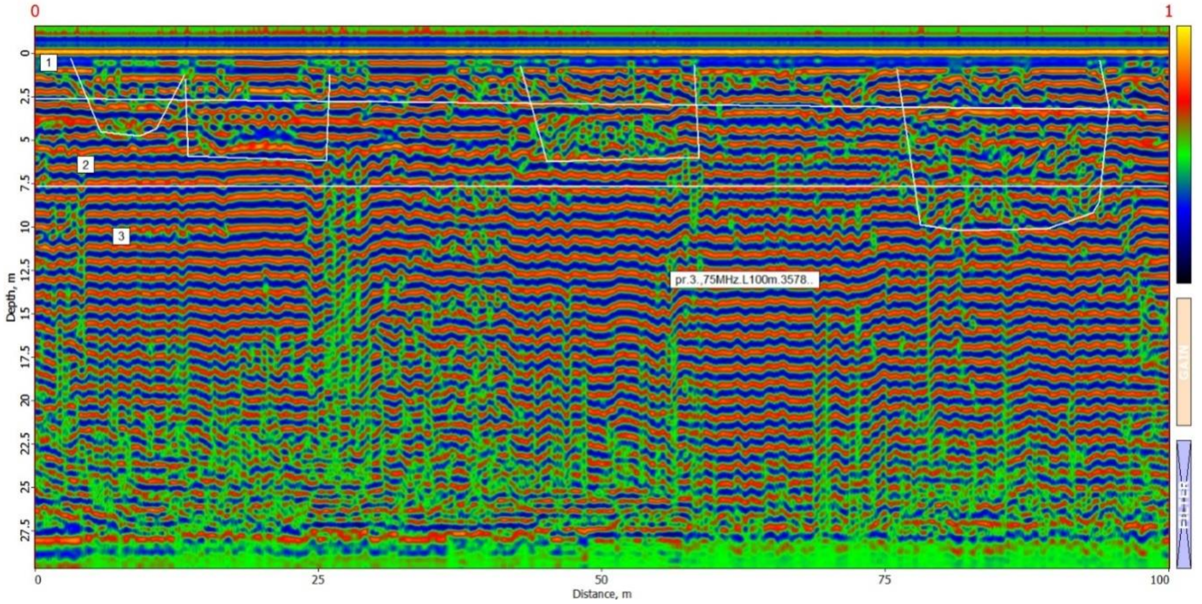
Figure 7. The radarogram of the Profile № 1
(*It is performed using 75 mHz receiver-transmitter dipole antenna of georadar; the profile length -100 m*)



According to the texture of the synphasing axes, three georadiolocation layers were distinguished on the Profile № 1 (Fig. 7): the first layer-with a capacity of about 2.5 m, the second layer – from 2.5 m to 7.5 m and the third layer extends below 7.5 m. Radioimages of a number of geological formations, the location of which are marked with white lines, were highlighted in the radarogram. Clearly are highlighted the radioimages corresponding to cavities transition from the first to the second layer at distances of 50-75 m with a depth of 7.5-8 m. There was also marked a cavity at the end of the profile at about 100 m distance. In the second layer, at depths of 2.5 -7.7 m, the forms of disintegrated (destructed, fragmented) environment were marked at distances of 25-50 m. In the third layer, at distances of 25 and

50 m, a peculiarity of the "Bow-tie" type is observed that should correspond to the cavities of the appropriate size with centers at depths of 17 and 25 m. At a depth of 25 m, at a distance of 75 m, a cavity separated by overlap was observed. At a distance of 100 m, environment containing cavities was distinguished and marked by texture. The area presented in the radarogram is characterized by the presence of waterlogging.

Figure 8. The radarogram of the Profile №3
(*It is performed using 75 mHz receiver-transmitter dipole antenna of georadar; the profile length -100 m*)



According to the texture of the synphasing axes, three georadiolocation layers were distinguished on the Profile № 3 (Fig.8): the first layer - with a capacity of about 2.5 m, the second layer – from 2.5 m to 7.5 m and the third layer extends below 7.5 m. Radioimages of a number of geological formations, the location of which are marked with white lines, were highlighted in the radarogram. Clearly are highlighted the radioimages corresponding to cavities transition from the first to the second layer at distances of 0-25 m and 75-100 m found in the roofs of the first, second and third layers with a depth of about 5-7-10 m. In the first layer, at a distance of 50 m, relatively uniform rock synphasing axes were limited up to about 0-2.5 m with the features of cavity, below which there is a significantly disintegrated (washed out) environment, which extends up to 7.5 m. Hydration is concentrated in relation to the marked cavities.

According to the texture of the synphasing axes, four georadiolocation layers were distinguished on the Profile № 6 (Fig. 9). The fourth layer enters at distances of 0-50 and 75-100 m from a depth of 12.5-15 m. The first layer with a capacity of 2.5 m, the second layer with a capacity of 2.5-6 meters. The third layer extends below 6 m. The fourth layer was marked in the lower left and right corners of the radarogram. Radioimages of a number of geological formations, the location of which are marked with white lines, were highlighted in the radarogram. The deformed (asymmetrical) radioimages corresponding to cavity transition from the first to the second layer at distances of 50-75-100 m with the depth less than 7.5-8 m are distinguished. In the third layer, a "Bow-tie" type of radioimages were marked at depths of 15-25 m. The second layer shows the hydration and disintegration of the synphasing axes.

According to the texture of the synphasing axes, four georadiolocation layers were distinguished on the Profile № 13 (Fig.10): the first layer –with a capacity of about 3 m, the second layer – with a capacity of 8 m, the third layer – from 8 m to 25 m and the fourth layer extends below 25 m. Radioimages of a number of geological formations, the location of which are marked with white lines, were highlighted in the radarogram. In the first and second layers, the corresponding deformed (asymmetrical) radioimages corresponding to the cavity at distances of 25-50 m at a depth of not more than 8 meters are distinguished; both layers are hydrated and significantly disintegrated. In the fourth layer, at a depth of 17-25 m, cavities are identified and hydration is observed.

Figure 9. The radarogram of the Profile №6
(*It is performed using 75 mHz receiver-transmitter dipole antenna of georadar; the profile length -100 m*)

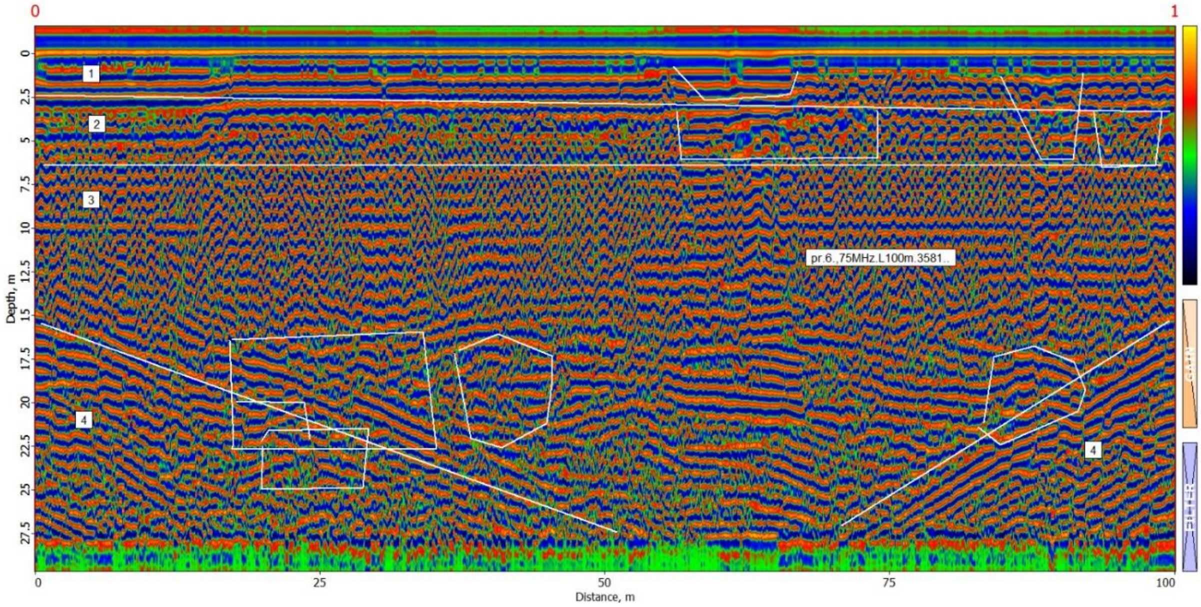
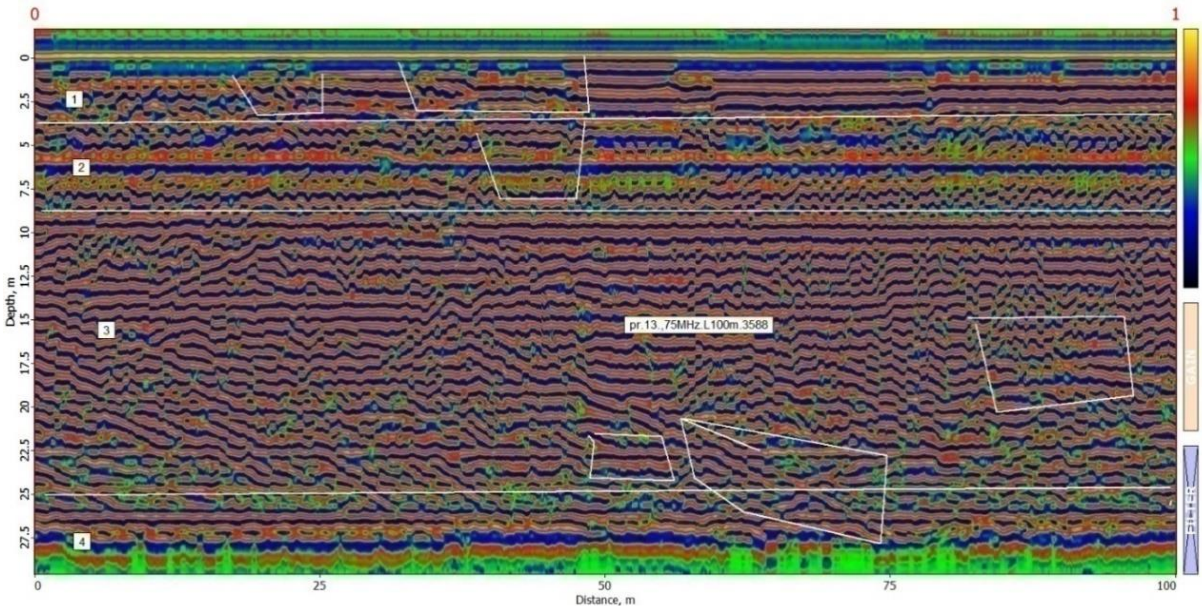
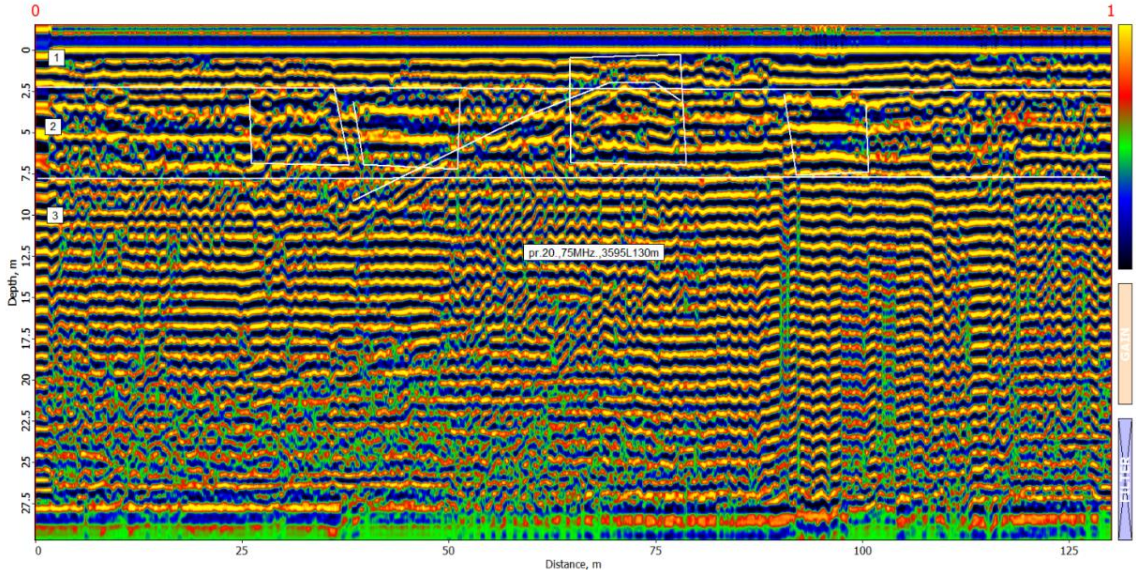


Figure 10. The radarogram of the Profile № 13
(*It is performed using 75 MHz receiver-transmitter dipole antenna of georadar; the profile length -100 m*)



According to the texture of the synphasing axes, three georadiolocation layers were distinguished on the Profile № 20 (Fig. 11): the first layer with a capacity of 2.5 m, the second layer – from 2.5 m to 7.5 m, and the third layer extends below 7.5 m. The first layer is uniform. At a distance of 75 m, the second layer is hydrated and contains a tube-type radioimage corresponding to heterogeneity. Cavities were also marked. The third layer contains a possible crack or boundary that begins in the first and second layers and continues in the third layer to a depth of 12.5 m.

Figure 11. The radarogram of the Profile № 20
(*It is performed using 75 MHz receiver-transmitter dipole antenna of georadar; the profile length -130 m*)



According to the texture of the synphasing axes, three georadiolocation layers were distinguished on the Profile № 33 (Fig.12): the first layer – with a capacity of about 2 m, the second layer – 7.5 m and the third layer extends below 7.5 m. The first layer is more or less uniform and partially disintegrated. The second layer contains the radioimages of hydrated water-permeable areas. The third layer does not contain significant cavities; the moistened area is marked below 20 meters.

Georadiolocation studies have shown that out of 33 profiles (Fig. 6) presented on radiograms, 1-30 profiles contain inhomogeneities, cavities, humidified and hydrated areas, water permeables and sinkholes. Cracks (fissures) were distinguished in the lower layers of the 17-20 profiles. 31-33 profiles are almost uniform; they do not contain significant cavities and are characterized by hydrated, water-permeable areas and are partially disintegrated.

The general picture is as follows – a number of radioimages of geological formations were identified in the radarograms, the location of which is marked with white lines.They are distinguished in the first, second, and third layers; also, in the transient capacities after the first-second, second-third and third layers, the radioimages, disintegrated (disintegrated, fragmented) forms of the environment corresponding to cavity are observed. There are peculiarities of the "Bow-tie" type, which should correspond to the appropriate size of the cavities.

The distinguished cavities correspond to the cavities prevalent in the limestone-karst environment and characteristic of this environment, such as the sinkhole-type cavities, including the embedded type, or one sinkhole-type cavity transferrs into the sinkhole-type cavity below it. Cavities created by more or less parallel walls or closed spaces with both irregular horizontal and well-formed arched roofs are observed. The studied area also includes enclosed areas that contain subcavities partially or completely filled with crumbling material, water, and partially - water and emptiness (air).

In the same segment of the Turchu hollow (in the western part), electrodetection studies also were carried out using the method of vertical electric sounding (VES) of constant current (Emilia et al., 2019), which is based on the use of artificially created electromagnetic fields on the daily surface, allowing implementation of lithological differentiation of rocks according to variation of self electroresistance (ρ ohm) according to depth. For sounding, Werner's four-electrode symmetrical device with spreading the feeding electrodes AB = 200-300 m was selected, allowing sounding of geoelectric section to a depth of 50-70 m. Sounding was conducted at 2 segments, at 14 points. According to the data obtained, four geoelectric cross sections were made (Fig. 13).

Figure 12. The radarogram of the Profile № 33
(*It is performed using 75 MHz receiver-transmitter dipole antenna of georada; the profile length -100 m*)

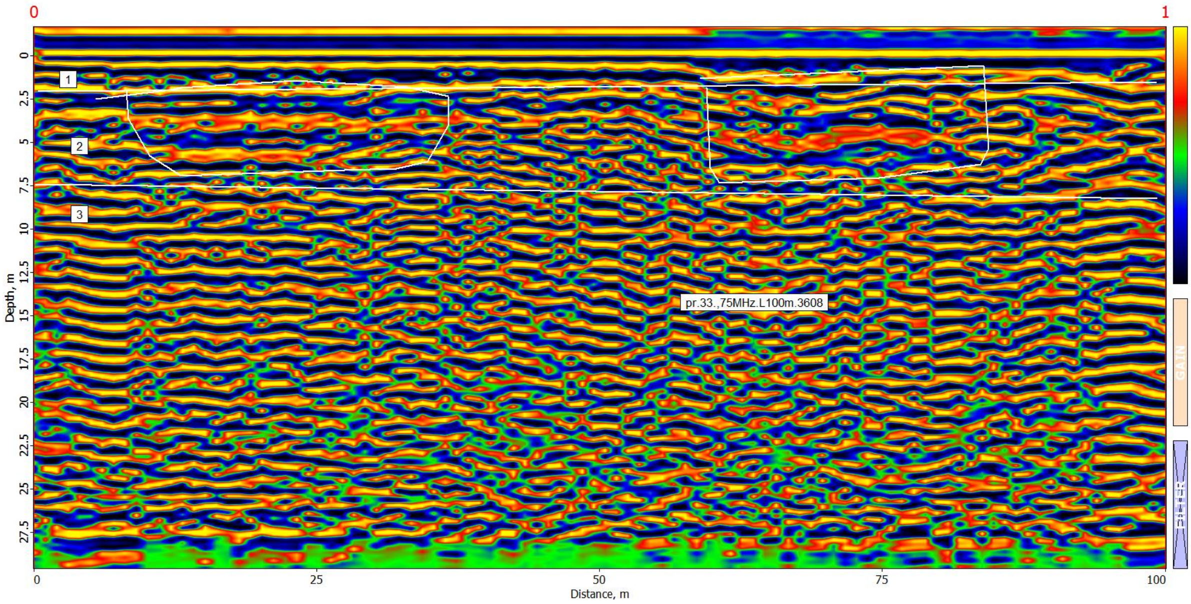
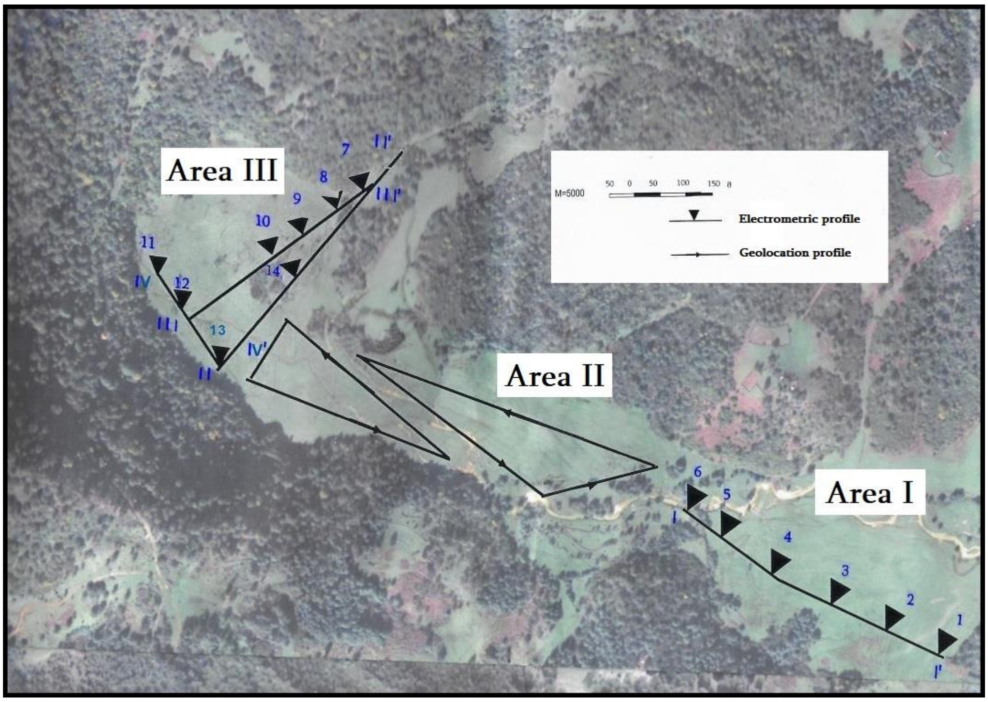


Figure 13. Scheme of location of the observation points of vertical electronic sensing



The cross sections made by vertical electronic sensing and radiolocation methods combine each other; the results obtained are in good harmony with each other and uniquely depict the real karst and geological environment.

Thus, based on geophysical studies, it has been practically identified that at the bottom of the Turchu hollow, in the limestones covered by Quaternary deposits, underground karst processes are actively underway, and removal of dissolved material takes place through underground karst canals, indicating the main role of corrosion in the origin (evolution) of the Turchu hollow.

4. CONCLUSIONS

Thus, it can be said that the closed shape of the Turchu hollow is due to the fact that the removal of dissolved material took place and is now taking place through underground karst ways (underground corrosion) – cracks and ponors.The origin of the hollow is genetically related to karst, and it is no different from the typical karst polje by hydrological conditions. These characters allow us to consider the Turchu hollow as a karst-erosive polje, in the origin of which corrosion (underground corrosion) occupies a leading place.

It should also be noted that the emergence of Turchu karst depression has been going on for a long time and in addition to karst processes it was associated with tectonic vertical movements, which had a periodic character, and which is considered a confirmed phenomenon for the Caucasus. A. Janelidze (1941) mentions tectonic uplifting in the geological past of the Askhi massif. This is confirmed by the deep canyon gorges of the rivers of Abasha and Okatse, located on the border of the Turchu hollow (in the west and east).

The ascending tectonic movements, which were periodic in nature, led to a decrease in undergroundwater levels together with the uplifting of the area and, consequently, to the activation of karst processes. It seems that the evolution of the Turchu hollow is still being actively carried out in the limestones located beneath the Quaternary sediments, as evidenced by our geophysical studies.

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