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Platform Karst of Georgia

(Zemo Imereti Structural Plateau)

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The work covers the results of complex karst-speleological researches conducted by the authors over the years in the only platform karst region of Georgia - the structural plateau of Zemo Imereti. The conditions and factors of karst formation, the problems of karstogenesis and speleogenesis, the main signs of the origin and evolution of surface and underground karst forms are discussed. In connection with the complicated geoecological situation, the main centers and causes of pollution of karst springs involved in water supply system have been identified. The classical methods of karst research are widely used.

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F o r e w o r d

Zemo Imereti Structural Plateau is one of the most interesting parts of karst relief development and a constituent part of Georgian flatland karst belt. The mentioned karst region includes the easternmost part of the limestone line of western Georgia, which is characterized by peculiar natural conditions (relief, tectonics, climate, surface and underground waters) and is the sole region of the platform karst in Georgia. It should be noted that the evolution of the relief of Zemo Imereti structural plateau took place against the background of development of the complete composition of Zemo Imereti Plateau, as well as the development of the relief of the southern slope of the Caucasus and is significantly related with the neighboring massifs (of Racha, Kudaro-Valkhokhi), that is duly described in the work.

The work is based on existing literary and stock sources, as well as material obtained by the authors of the monograph by the researches carried out on the base of TSU Vakhushti Bagrationi Institute of Geography.

The work presents the results of complex karst-speleological studies carried out by the authors over the years on the Zemo Imereti structural plateau. Together with the use of numerous literary sources, the authors use the results of their own field, experimental and laboratory studies, thereby complementing and expanding the already known data and viewpoints on the Zemo Imereti structural plateau – platform karst. The book highlights the problems of water supply of the Chiatura zone and ways of its improvement, which attributes to it practical importance along with scientific one.

The work describes the main methods used by the authors, approved during the study of classical karst areas: there are given the results of field geomorphological and karst-speleological large-scale surveying; by means of structural decoding of aerial images a detailed scheme of fault dislocations is compiled and the regularities of distribution of karst forms are specified; the data of boreholes and analysis of cartographic material provided the basis for the general scheme of the hydrogeological situation made by authors that has been practically confirmed by indicator experiments; applying the method of tracing of dyed waters allowed us to study groundwater feeding basins, their traffic routes and discharge centers; for the first time the karst sources' regime, hydrochemical properties, chemical components of stalactites' concretions, and intensity of karst denudation are fully described; based on lithostratigraphic research, some peculiarities of sedimentation processes and evolution of karst caves are considered; electrometrical research methods are used to precise certain practical issues.

The work contains graphic material of various content (maps, block diagrams, schemes, plans, cross-sections, and tables) and photographs, most of which are compiled or taken by the authors.

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CHAPTER I.

LOCATION, BOUNDARIES, OROHYDROGRAPHIC PECULIARITIES

The only region of platform karst of Georgia is represented in the easternmost part of the continuous limestone strip of western Georgia and is known as the Zemo Imereti Structural Plateau. It comprises important northern, northwestern and southwestern parts of the Zemo Imereti Plateau built of limestone suites.

Administratively Zemo Imereti platform karst (structural plateau) is included mainly within the regions of Chiatura, Sachkhere and Kharagauli. A small part falls within the administrative regions of Terjola and Zestaphoni (Fig. 1).

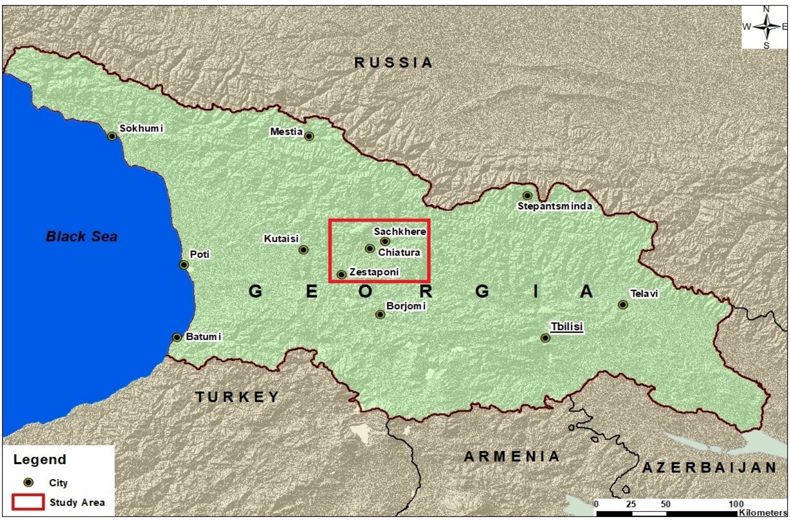

Figure 1. Location of Zemo Imereti Plateau and adjacent limestone massifs.

The Zemo Imereti platform karst (the same as the structural plateau) is a part of the integral plateau of Zemo Imereti and in some degree they went through the same path in the evolution of the relief. The Zemo Imereti platform karst relief was being developed against the background of geological development and in general development and formation of the Zemo Imereti Plateau relief. Therefore, the authors advise to consider certain moments of the origin and evolution of the Zemo Imereti Plateau (structural plateau) in the light of the evolution of the complete composition of the Zemo Imereti Plateau.

Zemo Imereti Plateau separates Kolkheti Lowland and Shida Kartli Plain, at the same time connecting the Greater Caucasus and the Lesser Caucasus in the foothill strip, i.e. it is a kind of orographic bridge. The foothill strip of the southern slope of the Racha Range forms the northern border of the Zemo Imereti Plateau. The eastern boundary runs along the eastern foothill strip of the Likhi Range. The western one coincides with the western end of the Zemo Imereti Plateau and conventionally goes along the Zestaphoni meridian. The southern border also conventionally goes along the northern foothill strip of the eastern part of the Achara-Imereti Range.

Zemo Imereti Plateau gradually ascends from the west to the east and reaches the maximal altitudes in the crest zones of the Likhi Range and Dzirula-Chkherimela watershed. Here, isolated peaks are erected at an altitude of 1200-1500 m above sea level. Most part of the plateau surface is at an absolute altitude of 500-900 m, and the minimal – is at the height of 190-m near the Zestaphoni-Shorapani translowland strip. The Zemo Imereti Plateau is the highest part of the Transcaucasian intermontane depression and is distinguished by its independence according to the geomorphological conditions. In A. Janelidze's opinion (1942), it is considered to be the Horstian uplifted massif of the Clod of Georgia, corresponding to a crystalline massif of Dzirula. Unlike the geosyncline karst zone of Georgia, the formation of this region was going on under platform conditions (Fig. 2).

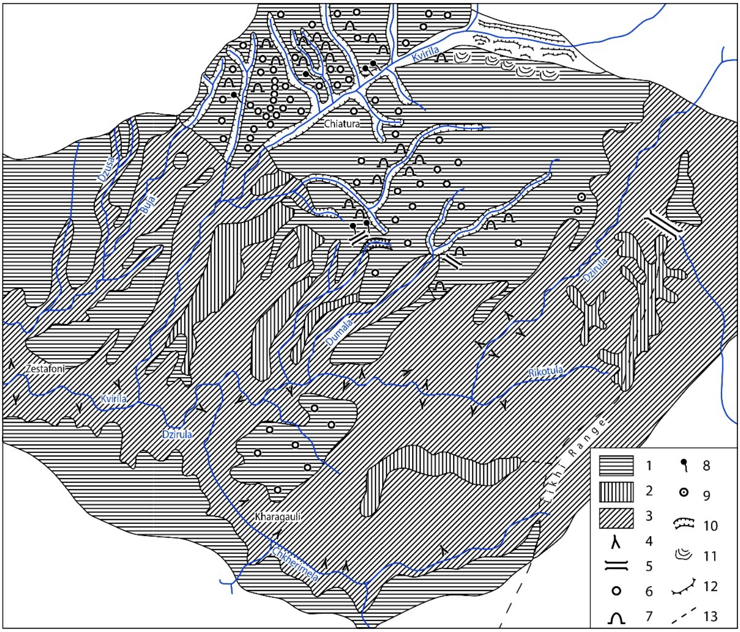

Figure 2. Geomorphological scheme of the Dzirula Massif. (Compiled according to L.I. Maruashvili and D.D. Tabidze). (Maruashvili, 1971).

LEGEND: 1– Structural plateau, created by Meso-Cenozoic sedimentary rocks, with karst forms and canyon-like gorges; 2 – Late Mesozoic peneplain on the crystalline substrate; 3 – Medium mountainous and hilly erosive relief on the crystalline substrate; 4 – Debris cones; 5 –

Ancient valleys; 6 – Karst sinkholes; 7 – Karst caves; 8 – Vaucluses; 9 – Young volcanoes (laccolithic-extrusive); 10 – Canyons in the limestones; 11 – Landslides; 12 – River terraces; 13 – Black Sea – Caspian watershed.

The Zemo Imereti Plateau has undergone a long and difficult rout of geological development (frequent change of continental and marine regimes), which is well reflected in modern terrain. It is possible to distinguish two groups of genetically different reliefs here. In the Upper Cretaceous and Oligocene-Miocene sediment distribution zone (denuded surface of the crystalline massif lies several hundred meters deep), a buried peneplain is represented (Maruashvili 1958). It extends on the both sides of the Kvirila valley from Sachkhere to the village of Jokoeti (approximately coinciding with the Chiatura Meso-Cenozoic sedimentation basin) and is a classically expressed structural plateau, and denuded part of the Dzirula massif, Likhi Range and the Dzirula-Chkherimela watershed are characterized by non-structural morphology and belongs to unearthed Peneplain type.

Difference in structure (coexistence of denuded and coated surfaces of the crystalline structure) among different parts of the Zemo Imereti Plateau leads to the existence of two very distinct terrain types genetically and morphologically within the plateau itself (Maruashvili, 1971). The denudation plateau, which occupies the southern and eastern parts, represents the remnants of the ancient (the end of the Mesozoic) peneplain, fragmented by a dense network of erosive valleys. These places generally give the impression of typical moderately mountainous relief. The second type of terrain, as mentioned above, includes the northern, northwestern and southwestern parts and is known as the Structural Plateau (Javakhishvili, 1947; Maruashvili, 1971). It is characterized by deep river gorges and peculiar gentle terrain of watersheds with ranges with plains and rounded peaks. The structural plateau, which represents the area of distribution of the platform karst (500-900 m absolute altitudes), is in turn partitioned by quite deep (100-300 m) canyon-like river gorges of the Kvirila River and its tributaries (Jrutchula, Nekrisa, Bogiristskali, Rganisghele, Katskhura, Buja, Sadzalekhevi, etc.). These river gorges separate from each other plateaus with steep slopes and plain surfaces, among which are noteworthy: Sareki, Darkveti-Zodi, Mghvimevi, Bunikauri, Tabagrebi, Rgani, Perevisa, Shukruti, Pasieti, Itkhvisi, Sveri, Merevi and others. On the plateaus' surface is developed a dense network of the waterabsorption of relief, and caves on the slopes are, represented in levels.

Zemo Imereti platform karst (structural plateau) boundary coincides with surface contact line of Cretaceous limestones with older formations (Bajocian porphyritic suite to the north and east, and middle Paleozoic granitoids to the south and west), which represents geological substrate of karst. Existence of solid Hercynian platform has conditioned the character of layout of Mesozoic and Cenozoic suites on it (subhorizontal or slightly inclined), which is represented mainly by Valanginian and Hotrivian limestones, Barremian and Turonian-Danian Tertiary clays and sandstones. Platform structure of the plateau has played important role in the genesis and development of surface and underground karst forms and underground karst streams.

I. 1. A brief overview of karst-speleological study

Georgia's karst caves have attracted researchers and travelers' attention from olden times. The first references on Zemo Imereti caves and karst phenomena are found in the work of Vakhushti Bagrationi - "Description of the Kingdom of Georgia" (1941). These references concern the caves of the River Kvirila Valley and the Buja Valley vaucluses.

The karst phenomena of Zemo Imereti has been described by foreign travelers, among them a German physician and naturalist J. Guldenstadt (80s of the 18th c.) and Swiss researcher Fr. DuBois de Montperreux (30s and 40s of the 19th c.) are worth to be noted.

The description of the caves and holes embedded in the horizontal layers of limestone in the middle part of the River Kvirila Gorge is given by Colonel Kraevich (1870), who compiled a military review of the region.

Since the beginning of the 20th century, researches of Zemo Imereti caves have been conducted mainly in the archaeological spectrum. Unique Paleolithic human dwellings have been also tracked in the caves developed on the slopes of the valleys of the rivers of Kvirila, Jrutchula, Rganisghele, Chkherimela, etc. Archaeological works also include geographical information about the caves. Interesting researches in this direction have been carried out by S. Krukovski (1916), G. Nioradze (1933), S. Zamyatin (1935, 1937), N. Kiladze (1944, 1953), Al. Kalandadze (1965), D. Tushabramishvili (1960, 1962, 1963, 1972), and M. Nioradze (1968). Archeological researches in Zemo Imereti are successfully being carried out today too. In this regard, it is worth noting the first specimen of spinning of wild flax of the Upper

Paleolithic Age, dated back to 32,000 years, found in 2009 by palynologist Eliso Kvavadze, (Academic adviser Tengiz Meshveliani). The first wall painting, the remains of ancient humans and volcanic ash, dated back to 35,000 years, found by Nika Tushabramishvili in Undosklde Cave, are also remarkable. The latter is particularly interesting and provides important information in terms of karst development.

The fauna of Chiatura caves is poorly studied. Only 10 of the more than 110 caves in the region are biospeleologically studied. Of the 54 species of invertebrates 32 belong to mites, 10 – to springtails, 5 – to spiders, 3 – to molluscs, and 2 – to multipeds; insects and roundworms are represented each by one species. Two species of new for science springtails - *Plutomurus eristoi sp.nov* and *P. Revazi* have been discovered and they were named after the famous biologist Eristo Kvavadze (Barjadze et al., 2015). Some interesting information about the wildlife (chiropteran – bats) of several karst caves of Zemo Imereti is presented in the monograph of Al. Bukhnikashvili, A. Kandaurov and in I. Natradze (2008).

D. Mshvenieradze in his book "Caved Constructions in Georgia", published in 1955, gives morphological characterization of Zemo Imereti caves.

We find some interesting conclusions and generalizations about the Zemo Imereti karst in the works of natural science (Praselov, 1931; Mikhailovskaya, 1936; Nutsubidze, 1949; Gvozdetsky, 1952; Tintilozov/Tatashidze, 1954, 1957; Vladimirov, 1958, 1975; Maruashvili, 1958, 1971; Astakhov, 1958; Sokhadze, 1958; Ukleba, 1962; Kavrishvili, 1959; Kikilashvili, 1959; Nemanishvili, 1959; Margvelani, 1969; and Chkheidze, 2003, 2004, 2008).

Interesting information on the Zemo Imereti karst is also found in a number of geological works; e.g., V. Bogachev (1929),

B. Meffert (1924), L. Konyushevski (1926), K. Markov (1931), P. Gamkrelidze (1933), I. Kuznetsov (1937), etc.

The contribution of alpinists to the study of inaccessible caves is also noteworthy, their findings are published in magazines and newspapers. Noteworthy are the researches by Aliosha Japaridze (1949) on the Katskhi Column, Givi Gaprindashvili and A. Nemsitsveridze's (1955) works on Chiatura's inaccessible caves, etc.

Special works were dedicated to the study of karst relief of Zemo Imereti by G. Dateshidze (1956), S. Nemanishvili (1957), D. Dvali (1957), and Sh. Gogatishvili (1957).

Zurab Tintilozov's/Tatashidze's (1959, 1963, 1969, 1973), Shalva Kipiani's (1959), Levan Maruashvili's (1958, 1961) karst character works, carried out on the Zemo Imereti Plateau are noteworthy. These authors provide very interesting data about the history of studies of the caves, their developmental conditions, age, karst waters, etc.

Zurab Tintilozov's monograph (1976) is worth to be noted, which includes the important information about the karst of Zemo Imereti and surrounding areas. Givi Gigineishvili and Demur Tabidze (1975) express interesting ideas about the existence of a uniform level of undeground waters in the interior of Chiatura Structural Plateau, based on indicator tests. The works of Kiazo Rakviashvili (1981, 1985) is also noteworthy that describe geological and tectonic conditions of karst development in Zemo Imereti and its adjacent regions.

Karst-speleological study of Zemo Imereti Structural Plateau became extremely relevant in complicated geoecological conditions. In this regard, numerous expeditions were conducted to investigate the causes of turbidity-pollution of the karst sources involved in the water supply of the Chiatura zone (Chiatura and adjacent settlements are mainly supplied with karst water) and to provide practical recommendations. Interesting papers have been published on individual topical theoretical and practical issues of the karst of Zemo Imereti and surrounding regions (Lezhava, 1989, 1990, 1991, 1992, 2014, 2015, 2016, 2017a; 2017b, 2019a, 2019b, 2019c, 2019d, Tintilozov, et al. 1991; Supatashvili, et al., 1990; Jashi, et al., 1997; Dvalashvili, et al., 2014; Dvalashvili and Lezhava, 2014; Lezhava, et al., 2015; Asanidze, et al., 2017a; Asanidze et al., 2019).

CHAPTER II.

CONDITIONS AND FACTORS OF KARST FORMATION

II. 1. Stratigraphy, lithology, distribution of carbonate rocks and their role in karst formation

One of the main conditions for karst formation is the existence of karstified (soluble) rocks. The oldest geological formation of the Zemo Imereti Plateau consists of Pre-Cambrian - Lower Paleozoic crystalline shales and granites (Fig. 3), the outcrops of which are found in the gorges of the rivers of Lopanistskali, Shuaghele and near the village of Bzhinevi. The Upper Paleozoic quartz porphyrites and their tuffs, tuff-breccias, tuff-sandstones, sandstones and conglomerates continue the ascending cross-section. Significant outcrops of the above-mentioned sediments are in the gorges of the rivers of Kvirila (Chiatura-Salieti section), Ghurghumela, Sadzalekhevi, and in the strip of the villages of Shrosha-Martotubani-Dilikauri. On the aforementioned suites the Liassic sediments are transgressively deposited, which unevenly transfer into the Bajocian porphyritic suites, and in the surroundings of the village of Beretisa - into the Upper Cretaceous sediments.

There are outcrops of the Liassic sediments in the surroundings of the village of Salieti and in the Katskhura River valley, where they transgressively lie on granites. Here Lias is represented by the red limestone facies. In the southeastern part of the region, between the rivers of Lopanistskali and Dzirula midstream the red limestones are facially replaced by marls and clay shales (Dzotsenidze et al., 1953). The total area of the Liassic limestones is 14 km [2] with an average thickness of 60-70 m. Its individual as well as small outcrops are weakly karstified. Of the karst forms here can be found the small caves (environs of the village of Shrosha) and the sinkholes (environs of the village of Salieti). Limestones are mainly used as the best covering material.

Bajocian porphyritic sediments are most widely represented. These sediments are outcropped in the northernmost, northeastern and southern parts. The suite width in the Mukura-Khreiti strip is 800 meters, and on the northeast periphery of the Dzirula massif it reaches 500 meters (Fig. 3).

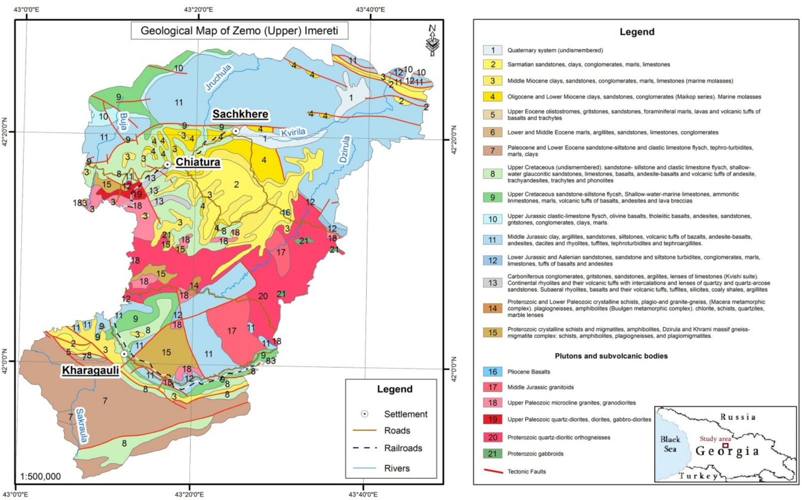

Figure 3. Geological map of the Zemo Imereti Plateau and adjacent regions (Gudjabidze, 2003).

Bathian clay-shales, suites of Callovian and Lower Oxfordian sandstones, clays, marls and gravelites are sequentially sat on the Bajocian sediments. The suits of this series, along with the Paleozoic sediments, play the role of the main water retaining foundation of the study area - the lower basis of karstification.

The ascending cross-section of the Lower Cretaceous begins with the Valanginian-Hotrivian Stage. These sediments build the southern gully cliffs of the Racha Range, contiguous to the Zemo Imereti Plateau, and are distinguished by considerable thickness (150-250 m). In the northwestern peripheral part of the Zemo Imereti Structural Plateau, the thickness of these suites declines rapidly (5–25 m).

Within the study area, Barremian sediments are represented by massive limestones of Urgonian facies and cover small areas. These sediments are distributed between the villages of Chalovani and Bajiti, as well as in the upper reaches of the rivers of Ghvitori, Tabagrebi, Bogiristskali and Rganisghele. Their thickness does not exceed 50-60 m. In the southernmost and south-eastern peripheral zone of the study area, the Barremian Stage sediments are outcropped in the gorge of the Chkherimela River; in the vicinity of the villages of Ghoresha, Moliti, Lashe and Kharagauli, their thickness exceeds 20-30 m.

Aptian marls are represented in the ascending section of the Barremian sediments. Marls transfer upwards into glauconitic sandstones and then into limestones. Limestones are well developed in the surroundings of the village of Ghoresha and especially in the Chkherimela River gorge, between the villages of Lashe and Kharagauli, as well as between Moliti and Tsipa, where their thickness is 8-10 m. The total thickness of the Aptian sediments varies within the range of 5–35 m in the study area. The Aptian is consistently continued by the Albian Stage, represented by sandstones, clayey marls and aleurolites. Albian sediments are poorly developed and in most cases are washed away like Aptians.

Therefore, in the study area the Lower Cretaceous rocks are characterized by mainly intermittent spreading and low thiknesses, and at the same time, with uneven facial and chemical compositions (Table 1). That's why, there are less favorable conditions for the development of karst phenomena and it has a limited character to some extent.

Upper Cretaceous (Cenomanian, Turonian, Coniacian, Campanian, Maastrichtian and Danian) sediments continue the ascending cross-section. They are transgressively deposited partly directly on the massif (granites), and partly on Jurassic formations, in particular, on the Bajocian porphyrites (rarely Mid Liassic colored limestones or on the Vallanginian-Hothrivian, Barremian and Aptian formations), but also are part of the structure of Zemo Imereti Structural Plateau and mainly lie slightly inclined or horizontally. The total area of the outcrops of Upper Cretaceous limestones exceeds 250 km^2.

The Upper Cretaceous cross-section begins with a Cenomanian Stage, mainly represented by carbonate and terrigenous sediments. The sediments of the above-mentioned stage in the southernmost and southeastern peripheral parts of the study area participate in the Kharagauli-Ghoresha and Moliti-Marelisi syncline structure. Their total thickness here is 50-115 m. In the northwestern part of the study area, small outcrops of Cenomanian sediments are found in the section between the rivers of Buja and Dzusa, as well as in the headwaters of the rivers of Katskhura and Bogiristskali, and are mainly represented by low-thickness (5–20 m) quartz-glauconitic sandstones and limestone sandstones (Mamulia & Gambashidze, 1964).

The Turonian-Coniacian sediments, located above the Cenomanian Stage, are relatively well outcropped in the Chkherimela River Valley and cover important sites. Everywhere, Turonian-Coniacian Stage is represented by whitish or pinkish layered limestones and chalk-like limestones with reddish insertions of flint. In the synclinal strip of Kharagauli-Ghoresha and in the surroundings of the village of Tsipa, Turonian-Coniacian limestones' thickness reaches 60-120 m. Within the Zemo Imereti (Chiatura) structural plateau, the Turonian-Coniacian sediments are relatively less distributed. Here, the outcrops of these sediments are mainly related to tectonic disturbances. The thickness of this suite does not exceed 50 m.

Isolated outcrops of Santonian-Campanian sediments are found in the Kharagauli-Ghoresha synclinal fold, where it is represented by thick-layered marly limestones. Significant outcrops of sediment from this stage are also found in the north-western peripheral part of the region, in particular, in the section of the rivers of Katskhura-Dzusa and Chiatura-Salieti. Here, the total thickness of Santonian-Campanian sediments exceeds 70 m (Tsagareli, 1954; Edilashvili & Lekvinadze, 1951).

Maastrichtian sediments in the southern peripheral part of the region are outcropped in the form of two narrow strips in the Partskhana-Khidari section and are represented by massive and thick-layered gray marly limestones, thickness of which equals to 20 m. In the northern part of the study area, the sediments of the Maastrichtian Stage are outcropped in the valleys of the Kvirila River and its tributaries. Here the Maastrichtian Stage is represented by massive and thick-layered crystalline gray limestones, dolomitized limestones, sandy-clay limestones, and middle layers of marls. According to the borehole data

(Kuchukhidze et al., 1986), the enrichment of the Maastrichtian limestones with clayey-sandy material takes place in the southern and eastern directions within the Chiatura structural plateau. According to the same data, the thickness of Maastrichtian limestones in the study area varies between 50-170 m.

The sediments of the Danian Stage within the structural plateau are most widely represented. Here the Danish sediments are characterized by a horizontal or sub-horizontal bedding everywhere and considtently are deposed on the Maastrichtian sediments. The Danian Stage is represented by massive and thick-layered breccia-like limestones, dolomitized limestones, limestony marls, and weakly sandy limestones. At the same time, the sand content in limestones increases in the south-eastern and eastern directions (Sachkhere). The role of the marly limestones in the same direction also increases, which affects the intensity of karstification. The thickness of Danian limestones in the vicinity of the Chiatura structural plateau varies between 50-170 m, while in the southernmost and eastern peripheral parts of the plateau it decreases to 15-20 m, and directly (sometimes with Maastricht) lies upon the Paleozoic and Jurassic formations.

In the study area, the widespread Tertiary sediments lie inconsistently (transgressively) on the Upper Cretaceous limestones, and this inconsistency is not an angular but stratigraphic. At the same time, the Tertiary sediments within the structural plateau, as well as the Upper Cretaceous sediments, are characterized by horizontal bedding. The total thickness of the Tertiary suites is variable and reaches maximum (260 m) in the north-eastern part of the Chiatura structural plateau (in Merjevi-Modzvi surroundings).

The Tertiary sediments' cross-section begins with Oligocene-Lower Miocene sediments and is mainly represented by noncarbonate clays and quartzitic sandstones. In the south-western part of the region the mentioned sediments are developed in the strip of the villages of Kvaliti and Khidari, and in the vicinity of the village of Vardzia. Oligocene-Lower Miocene sediments are relatively widespread on the Chiatura structural plateau (Chiatura town surroundings), where the Chiatura manganese deposits are associated with these sediments. In the vicinity of these deposits, lithologically the suite is divided into three parts: the lower part – the so-called sub-ore horizon is represented by gravelites and quartzitic sandstones, thickness of which decreases from east to west. For example, on the Sareki and Pasieti Plateaus, their thickness is 25-30 meters, on the Itkhtvisi and Shukruti – it decreases to 5-10 meters, and further in the west it decreases to zero, and on Perevisa and Rgani Plateaus, in some places, on the irregular denuded (sometimes karstified) surface of the Upper Cretaceous limestones already directly lie the manganese producing layers (Markov, 1931; Gavasheli, 1950; Kuchukhidze, 1986). The sub-ore horizon in the ascending section is consistently replaced by the so-called productive suites represented by alternating thin layers of manganese-containing and waste rocks (sands and clays). The thickness of productive suite varies from few meters to 12-15 m and wedges to the peripheries. The productive suite in the strip of Chiatura deposits is consistently covered with spongolite sandstones and thin-layered clayey sandstones, which from the top are followed by gray thin-layered limestones. The thickness of this suite in the deposits zone varies within the 10-90 m and decreases from east to west. In the surroundings of the villages of Perevisa and Rgani, it is completely out of the cross-section and the Chokrak sandstones are directly located on the productive suite.

The Mid-Miocene (Chokrakian, Karaganian, Konkian, Sarmatian) sediments, which transgressively cover the older formations, have a relatively important distribution.

In the vicinity of the Chiatura manganese deposits, the Chokrakian Stage is represented by sharply different lithological suites. The cross-section begins with conglomerates and gradually transfers to sandstones and sands. The thickness of the mentioned suite varies from 15-20 m (Zeda Rgani) to 75 m (Shukruti). Above, it is replaced by 3-7 m thick oolite and sandy limestones, which are continued by 15-35 m thick clays and sandstones. The total thickness of the Chokrakian Stage in the vicinity of the Chiatura manganese deposits varies within 60-100 m. In the southernmost and western peripheral part of the study area, the Chokrakian Stage is represented by clayey sandstones, sandy marls and oolitic, weakly sandy limestones, the total thickness of which reaches 80 m.

Upwards, the Chokrakian sediments gradually transfer into the Karaganian. The latter is mainly represented by the alternation of oolitic limestones, sandy clays, and limestone sandstones. In the vicinities of the Chiatura manganese deposits, Karaganian is represented only by oolitic limestones, where the clay middle layers are also rarely found. The limestone thickness reaches 25-30 m here.

Upwards, the Karaganian sediments are consistently replaced by Konkian sandy-clay sediments. In the southern part of the study area, small fragments of them have been preserved in the mould of synclines. Konkian sediments are relatively widespread on the Chiatura Structural Plateau, where the significant outcrops are presented in the vicinities of the villages of Nigozeti, Merevi, Modzvi, etc.

Significant outcrops of the Lower Sarmatian are found in the upper parts of the rivers of Kvirila, Dzirula, Sadzalekhevi and Dumala, and they are mainly represented by quartzitic-aleurolitic sandstones, the thickness of which in the vicinities of Chiatura ranges within 50-90 m. In the areas of the Zemo Imereti Structural Plateau, were these Tertiary sediments cover the top of the Upper Cretaceous limestones, hinder the infiltration of waters and accordingly – the karst processes. But where they are characterized by low thickness, there are relatively better conditions for the circulation of karst waters and the development of suction-type sinkholes. Sometimes in Karaganian and Chokrakian limestones, small caves and karst sinkholes are developed.

From the general overview of the geological structure of the study area, it is clear that Liassic, Lower Cretaceous, Upper Cretaceous and Chokrakian-Karaganian Stage carbonate sediments belong to the karstified rocks; the total area of their outcrops reaches 400 km^2. Among them, the Upper Cretaceous carbonate sediments are characterized by relatively wide distribution and significant thickness, which creates good conditions for karstification. For example, according to the borehole data, thickness of the Upper Cretaceous limestones in the territory of the village of Zodi is 260 meters. From here, the thickness of limestones in the western, eastern and southern directions gradually decreases and in the eastern edge of the village of Darkveti (on the right bank of the River Jruchula valley) it equals to 240 m; it reaches 220 m in the vicinity of the village of Tsasri, and in the surroundings of the villages of Tskalshava and Chorvila it decreases to 170 m. This regularity is somewhat violated in the vicinity of the village of Korbouli and town of Sachkhere, where the thickness of the Upper Cretaceous limestones increases to 320 and 310 m, respectively, while in the western part of Sachkhere it decreases to 50-70 m.

The mentioned fact must be conditioned by the structural peculiarities of the site. Therefore, the thickness of the Upper Cretaceous limestones within the Chiatura Structural Plateau varies between 50-320 m and in average equals to 230-240 m.

The formations of karstified rocks of different ages create a certain lithological-facial, structural and textural diversity, which affects the intensity of the karstification of this or that horizon, the morphogenesis of the underground or surface forms.

In the structure of the study area, as it was mentioned above, the Upper Cretaceous thick-layered and massive limestones have a wide distribution, which determines the morphological peculiarity of the surface and underground forms embedded in these suites. The massiveness or layering of karstified rocks has a significant impact on the morphology of karst corries, sinkholes and caves, which we will discuss in due chapter.

The rate of solubility and, therefore, the intensity of karstification processes largely depend on the chemism of the rocks, the structural-textural properties and the character of the substance that cements the mineral particles.

The study of the chemical composition of carbonate sediments in the study area confirms the well-known fact that in the presence of other favorable conditions, formation of karst forms is most intense in the rocks, where the content of the insoluble residues is insignificant. Table 1 below provides a clear picture of this, showing the chemical composition of the main stratigraphic and lithological horizons of carbonate sediments in the study area.

Table 1. Chemical composition of limestones of the Zemo Imereti Plateau and the surrounding area.

Ń	Place of sampling	Geological age (stages)	CaO	MgO	SO_3	Fe_2O_3	Al_2O_3	SiO_2	Hygroscopic water	Insoluble residue	Mineral particles' cementing substance
1	2	3	4	5	6	7	8	9	10	11	12
1	Sveri Village surroundings	Karaga nian	33.2	0.64	0.15	1.34	3.52	30.2	1.0	37.1	Calcite
2	Kveda Beretisa Village surroundings	Danian	53.1	0.44	0.60	0.10	0.31	2.7	0.26	3.2	Calcite
3	Upper reaches of the Tabagrebists kali River	,,	54.0	0.31	-	0.24	0.27	1.2	0.12	1.94	-
4	Midstream of the Rganisghele River	,,	55.0	0.31	-	0.06	0.38	0.47	-	0.96	-
5	Rgani Village surroundings	,,	55.1	0.25	-	0.18	0.18	0.9	0.16	1.34	-
6	Bunikauri Village surroundings	,,	42.4	10.4	0.16	0.11	0.32	0.2	0.08	0.76	
7	Perevisa Plateau	,,	55.6	0.15	-	0.04	0.17	1.0	0.16	1.72	
8	Lower reaches of the Jrutchula River	,,	56.1	0.19	-	-	0.8	0.6	0.10	0.75	-
9	Salieti Village surroundings	Maastr ichtian	55.9	0.21	-	0.21	0.28	0.05	-	3.9	-
10	Nigozeti Village surroundings	,,	52.4	0.44	-	0.64	0.89	2.8	0.55	5.04	-

11	Sveri Village surroundings	,,	52.4	0.50	0.15	0.30	0.53	3.0	0.22	4.51	-
12	Darkveti Village surroundings	,,	50.8	0.57	0.14	0.40	0.63	8.1	0.35	9.7	-
13	Midstream of the Katskhura River	,,	52.9	0.50	-	0.40	0.50	2.9	0.26	4.68	-
14	Katskhi Village surroundings	Santonian-Campanian	49.5	0.34	-	0.34	0.68	10.8	0.23	12.69	-
15	Kvatsikhe Village surroundings	Turonian-Coniacian	49.7	0.42	-	0.32	0.65	9.8	0.37	11.2	-
16	Lashe Village surroundings	,,	53.3	0.32	-	0.7	1.36	3.7	0.54	8.9	-
17	Head of the Katskhura River	,,	52.7	2.14	0.15	0.36	0.35	0.6	-	3.2	-
18	Leghvani Village surroundings	,,	51.1	0.24	-	0.5	1.36	8.4	0.9	9.68	Clay
19	Ghoresha Village surroundings	Cenomanian	29.6	3.2	-	1.34	3.6	33.4	0.7	39.8	Flint
20	Khoriti Village surroundings	Aptian	31.4	0.75	-	2.96	8.0	26.4	3.24	35.76	-
21	Khoriti Village surroundings	Barremian	45.6	7.38	-	0.19	0.62	2.0	0.38	3.26	-

As can be seen from the Table 1, the Upper Cretaceous limestones are distinguished by the high content of $CaCO_3$ and low amount of insoluble residue. Therefore, in the presence of other favorable conditions for karst formation, the Upper

Cretaceous limestones are intensively karstified. Most of the caves developed in the study area are related with the rocks of the same age. The insoluble residue content in the Upper Cretaceous limestones varies both stratigraphically and territorially. For example, by the highest percentage (53.1-56.1) of $CaCO_3$ and low amount (0.75-3.2) of insoluble residue first of all are distinguished Danian Stage limestones (Samples №-2-8). However, the content of $CaCO_3$ in it is reduced in some places due to limestone dolomitization (Sample № 6). Also, by high content (50.8-55.9) of $CaCO_3$ and low amount (3.9-9.7) of insoluble residue are characterized Maastrichtian limestones (Sample №9-13). The content of insoluble residue/constituent in Santonian-Campanian pelitomorphic limestones (Sample № 14) does not exceed 13, while in Turonian-Coniacian limestones their amount ranges from 8.9 to 11.2. Cenomanian quartz-glauconite limestones (Sample №-19), Aptian marly limestones (Sample №20) and Karaganian oolithic and clay limestones (Sample № 1) are characterized by relatively low $CaCO_3$ content and high amount of insoluble residue, because of that karstification processes are relatively weakly expressed in the mentioned rocks.

As it is known, the destruction of coarse-grained rocks occurs more rapidly than that of fine-grained rocks, and solubility - vice versa. Also, calcite cement is relatively easily soluble than clayey or flinty cement. In the study area the limestones of the Santonian-Campanian, Maastrichtian, and Danian Stages are characterized by a micro-grain structure, where in the role of cement calcite is mainly represented.

II. 2. Tectonic conditions of karst formation. The role of fissures and faults in karst formation

According to the scheme of geotectonic division of P. Gamkrelidze (1969, 1975), Zemo Imereti Plateau covers the Dzirula uplifting zone (crystalline massif of Dzirula) – the central zone of the Block of Georgia.

The Dzirula massif, which coincides with the Zemo Imereti Plateau, is a relatively uplifted part of the inter-mountainous strip of the Greater Caucasus and the Lesser Caucasus. It transfers into the Khreiti Tectonic Block in the north, and in the south, it joins the Achara-Trialeti folded system, and from the latter it is separated by a large frontal fault between Kharagauli and Surami. The development of the karst relief of the Zemo Imereti Structural Plateau (platform karst) took place against the background of geotectonic evolution of the entire composition of the Zemo Imereti Plateau, the adjacent areas (Racha and Kudaro-Valkhokhi massifs) and the southern slope of the Caucasus in general. The conception and evolution of the tectonic structures of the Zemo Imereti Plateau (plicative, disjunctive) is related to the Early Orogenic (Pre-Sarmatian), and much more - to the Late Orogenic (following Miocene) substages. The relief, created by the Early Orogenic phases (especially Bathian) undergoes a strong transformation in the Late Orogenic or Neotectonic (Upper Sarmatian) substages. The boundary of platform karst of the Zemo Imereti Structural Plateau coincides with the surface contact line of the Cretaceous limestones with more older formations (in the north and east - the Bajocian porphyritic suite, and in the south and west - the Middle Paleozoic granitoids), which is the geological substrate of karst. Geotechnically, as a part of the Block of Georgia, the Zemo Imereti Plateau is represented by two structural levels (Fig. 4).

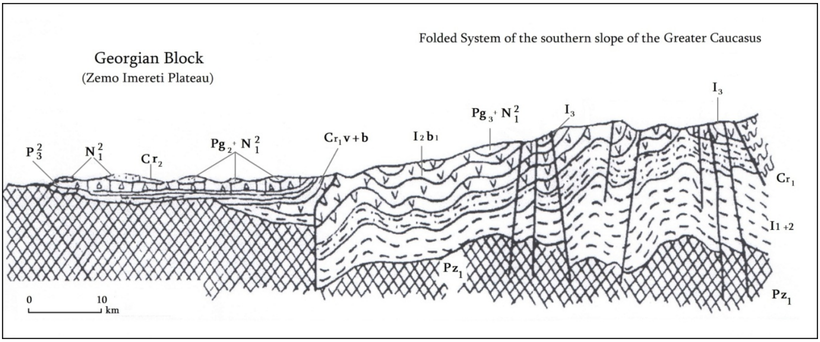

Figure 4. Geological cross-section of the southern slope of the Caucasus folded system and the Block of Georgia (Gamkrelidze, 1969).

The lower level is built of Pre-Cretaceous foundation (Pre-Mesozoic rocks) and it was formed in the Paleozoic - Orogenic phases, while in the Upper Jurasic and partly Lower Cretaceous periods it was denudated, resulting in creation of the Likhi Peneplain (Gamkrelidze, 1964; Maruashvili, 1971). The upper structural level, which occupies more than a half of the entire surface area of the lower level, is irregularly placed on this crystalline substrate and is represented by a weakly dislocated Meso-Cainozoic platform cover. Paleogeographically the latter is divided into two subhorizontal sublevels - Cretaceous carbonatic and Paleogene-Neogene terrigenous. Deposition of the above-mentioned sediments (upper level) took place in the platform conditions and therefore their total thickness on the structural plateau of Zemo Imereti did not exceed 500-550 m. From the point of view of karst development, we are especially interested in the upper structural level of the Zemo Imereti Plateau, with which are connected the karst processes. In the tectonics of the latter, an important role was played by the circumstances that its base is a washed and consolidated part of the Block of Georgia (Hercynian platform), which greatly resisted to the orogenic processes that took place in the Tertiary period. Namely these circumstances conditioned the simple tectonic structure of the plateau, specifically the calm, almost horizontal, or slightly sloping layout of the Cretaceous and Tertiary layers. Nevertheless, the Meso-Cenozoic suites, building the substrate seem to have undergone plicative and especially disjunctive dislocations. Intense tangential movements in neighboring geosynclinal zones on the Zemo Imereti platform have caused geodynamic tension. These movements were reflected on the Mesozoic-Cenozoic sedimentary cover located on a solid foundation by appearing of faults, overthrusts, cracks, wavy folds, etc.

Among the plicative dislocations, a number of researchers (Markov, 1931; Gabunia, 1936; Chikhelidze, 1948; Gavasheli, 1950.) distinguish Chiatura-Sachkhere weakly expressed synclinal depression with sloped limbs, which extends latitudinally from the north-east to the south-west along the Kvirila River. Its limbs are poorly complicated with secondary folds that cause wave-like layout of sedimentary rocks, especially tat of Tertiary layers. Under the currently washed away Miocene sediments, the Upper Cretaceous limestones are outcropped with the common north-northeastern sloping of the layers on the southern limb of the syncline and south-southeastern - on the northern limb. At the same time, the northern limb of the syncline along the northern edge of the manganese deposits is sloped very inclined, but to the north it quickly transfers into quite steep one, and already to the north of the village of Bunikauri the sloping rapidly changes from 8-10 degrees to 28-30 degrees, and in some places (e.g., in the vicinities of the village of Tsirkvali) it reaches 60^0. These circumstances should have contributed to the outflow of underground karst waters formed on the limbs of the syncline (especially on the northern limb) towards the Kvirila River, where they discharge. This assumption has been substantially confirmed by our indicator experiments (Lezhava et al. 1989; Lezhava et al. 1990 Lezhava, 2015).

Within the Zemo Imereti Plateau, among the plicative dislocations two syncline structures of the Cretaceous sediments are comparatively well expressed in the Chkherimela River valley. Of these, the Kharagauli-Ghoresha syncline is an asymmetrical fold, the north-western limb of which is characterized by a mild sloping, while the south-eastern one is erected vertically. Cretaceous-carbonate sediments occupy an area of 100 km^2 within the Kharagauli syncline (Rakviashvili, 1985). Within the frames of this structure, karst is not characterized by intense development that should be first of all explained by the heterogeneous facial composition of the layers. Here, mainly are developed suction type sinkholes, dry ravines, karst springs and small horizontal caves. To the east of Kharagauli-Ghoresha syncline, in the vicinity of the villages of Marelisi and Moliti, there is another syncline of well-defined Cretaceous rocks, the heart of which is built of Miocene rocks, the northern limb – of Cretaceous limestones and the southern limb is broken by the overthrust line of Upper Cretaceous sediments and is displaced towards the crystalline massif. Within the Marelisi-Moliti syncline frames, karst forms are relatively outstanding by their diversity. Here are developed packed sinkholes, corrie surfaces, wells and caves.

Disjunctive dislocations play an important role in karst formation. As it seems, it is widespread within the Zemo Imereti

Structural Plateau (platform). The faults separate Zemo Imereti Plateau from the Khreiti block in the north, and the latter from the Shaori block. Zemo Imereti Plateau is also separated from the south by a number of faults from the Achara-Trialeti folded system.

Among the disjunctive dislocations within the Zemo Imereti Plateau, first of all, should be noted the so-called South-Okriba-Mukhuri extreme overthrust (Janelidze, 1940; Mamulia, 1963), developed on the border of the Cretaceous and Jurassic rocks, which appears in the vicinity of Sachkhere, at the bottom of the northern cliff of the Modinakhe hill, and extends westward to Khreiti, and then moves into the Mukhuri cave. Along the mentioned edge overthrust the inclined or horizontal layout of the Turonian-Danian limestone layers is significantly disturbed and their inclination angles reach $40\text{-}45^0$.

It is also expressed in the relief by replacing the sloping surface with the steep one (e.g., the southern slope of the Modinakhe hill, etc.). In the northern part of the Zemo Imereti Plateau, this edge overtrust should make a kind of barrier and should obviously make it difficult for underground waters, formed in the Bajocian porphyritic suite, to enter the Turonian-Danian limestones, although it should be noted that the intensity and displacement amplitude of the overthrust at different sites are different, causing appearance of crosswise thrust-faults, alongside which water exchange is not excluded.

It is worth to note Patara Satsalike thrust-fault, developed in the north of the site of Patara Satsalike on the southern slope of the Racha Range adjacently to the study area. Along the aforementioned thrust-fault, the Aptian sediments of the south-eastern lowered limb are in contact with Barremian massive limestones of the uplifted limb (Fig. 5).

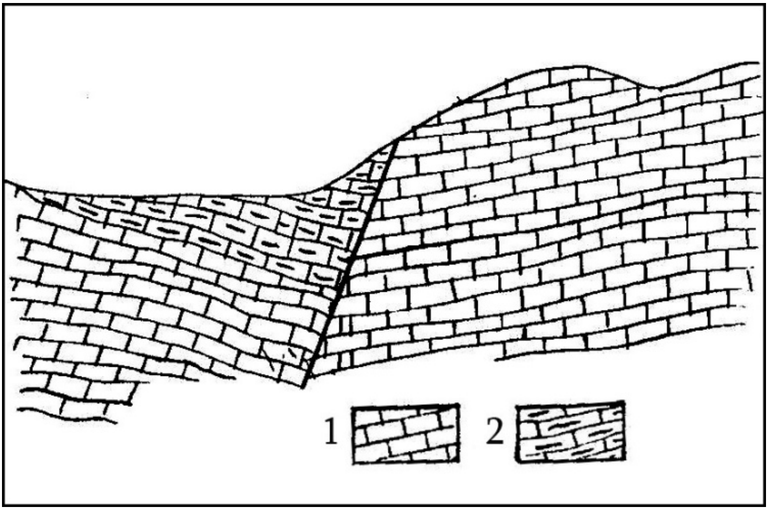

Figure 5. Patara Satsalike thrust-fault (Geguchadze, 1973).
1. Thick-layered and massive limestones (Barremian).
2. Marly limestones and marls (Aptian).

The amplitude of the thrust-fault is 100-120 m (inclination 70°) and it gradually disappears to the east. Smallness of disturbance amplitude (100-120 m) in comparison with the limestone thickness (300-400 m) allows maintaining the underground connections of karst waters between the northern and southern limbs of the fault, because of what the underground waters on the Satsalike Range have bilateral discharge –to the north and a relatively small amount – to the south too. It is not excluded that underground waters from Satsalike environments have the connection with the structural plateau of Zemo Imereti, which is allowed by the narrow (1.5-2 km) neck, built with Hotrivian limestones.

The Pre-Miocene and Post-Miocene times thrust-faults are also developed directly within the Zemo Imereti Plateau. Among them the thrust-fault along the River Chkherimela is noteworthy, which had caused the rupture of the layers of the Middle Liassic limestones (Gamkrelidze, 1933; Chikhelidze, 1948). The thrust-fault, developed on the left side of the Dzirula River, between Shrosha and Ghoresha, first sinks under the young sediments and then re-emerges on the surface in the Bzhinevi Village district. Similar thrust-faults have been developed also further south. They are complicated by sectional thrust-faults on the Shrosha-Bzhinevi line. Within the structural plateau a large Pre-Miocene tectonic dislocation of the so-called "Main thrust-fault" should be noted, which begins in the northwestern part of the Rgani Plateau and passes to the Perevisa Plateau. The inclination angle of the thrust-fault is 70^0, and its amplitude reaches several tens of meters. On the left side of the Kvirila River, the magnitude of the fault decreases and it passes to the flexure (Geguchadze, 1973).

In the Katskhi-Tvalueti line, the Pre-Middle Miocene age Tvalueti fault has been recorded, by which the Paleozoic, as well as Jurassic and Upper Cretaceous sediments of the old crystalline massif are disrupted. To the north-west of this fault, almost parallel to it, the Katskhura thrust-fault is found, which disrupts the same formations as the Tvalueti thrust-fault does. In the areas of distribution of these thrust-faults, the limestones are highly crushed and cracked, creating favorable conditions for the development of karst.

In addition to the above-mentioned dislocations, a number of minor faults of the sublateral and submeridional directions (amplitude 3-18 m) have been developed on the Zemo Imereti Plateau, especially within the Chiatura Structural Plateau, identified during the excavations of mines or study of the underground karst forms (Fig. 6).

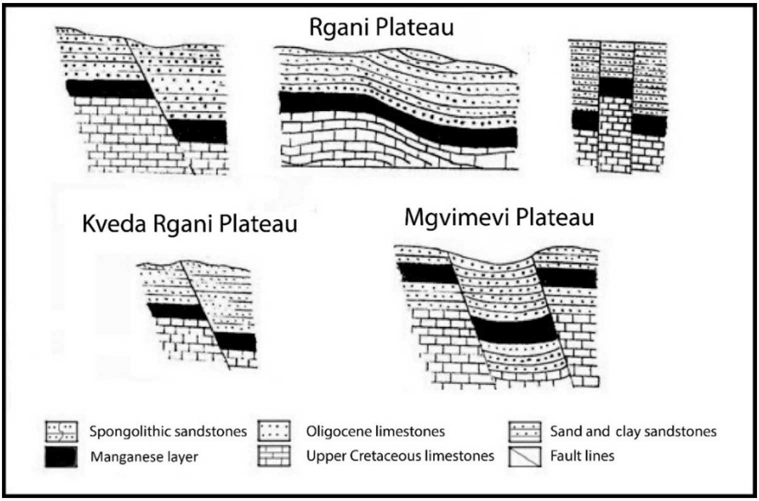

Figure 6. Fault dislocations on the Chiatura Structural Plateau (Gavasheli, 1950).

Based on field geomorphological surveying, indicator experiments and geophysical studies, some faults (Lezhava et al., 1989, 1990; Lezhava, 2015; Jashi et al., 1997) were first identified. In particular, the fault line observed in the southernmost part of the Mghvimevi Plateau, as it became known, continues westward via the Rgani River bed to the so-called Phirana Abyss (Rgani Plateau). The existence of a fault in the area of Sachkhere (on the territory of the cotton flooring factory) and its connection with the underground basin of Ghrudo through the Kvirila River bed was confirmed experimentally. As a result of electro-reconnaissance works, karstified cracks and karst cavities were observed at different depths from the surface. On the Sareki Plateau alone, 60 such karstified areas were registered, and in the tectonic fault zone traced in the Kvirila riverbed – strongly crushed limestone suite with a thickness of up to 40 m, where the influence of the waters in the depths is enhanced and they are connected with the Ghrudo and other springs. Karstified cracks and water content horizons at different depths have also been observed in boreholes (Table 2).

Table 2. Karstification of limestones in the individual boreholes.

Absolute height of a borehole	Borehole Location	Limestone thickness according to borehole, m	Water containing horizon's interval, m	Water containing horizon's thickness, m
450.6	Town of Sackhere	310	362-382	20
538.1	Village of Merjevi	240	385-415	30
701.3	Village of Zodi	260	262-285	27
1002.0	Village of Tskhami	170	120-170	40
659.0	Village of Chorvila	180	220-245	25
750.0	Tsasri Village of Tsasri	225	60-90	30
860.0	Goradziri Village of Goradziri	160	160-180	20
823.0	Modzvi Village of Modzvi	240	400-440	40
716	Korbouli Village of Korbouli	32	70 90	20

With the purpose of deeper study of the tectonic situation on the Chiatura Structural Plateau, we structurally decoded the aerial imagery of the area, which allowed us to draw up a detailed scheme of the fault dislocations and to precise the regularities of distribution of karst forms. Based on the decoding, a dense network of tectonic faults and cracks in various directions unknown so far has been identified.

The picture clearly shows the linear oriented systems of karst forms-sinkholes, cavities and ravines, which appear in the role of indicators of fault disorders. Fault dislocations within the Chiatura Sstructural Plateau control the absorption of underground streams and their movement routes. Particularly noteworthy are the places of intersections of submeridional and sublateral faults, to which the outlets of underground waters are related and generally the intensification of karst formation as well. Most of the caves in Zemo Imereti are also related to such areas. It seems that tectonic faults played an important role in the formation of the canyon-like gorges and determination of direction of the rivers.

Block tectonics seems to play a leading role in shaping of the karst relief of Zemo Imereti. The block tectonics of this plateau can be clearly seen by the structural decoding of the aerial imagery (see Fig. 10). This is also indicated by a topography of bedding rock of the upper tectonic level (Meso-Cenozoic) of the plateau (Fig. 7), which was restored based on the analysis of boreholes and geological cross-sectons' data (Fig. 8).

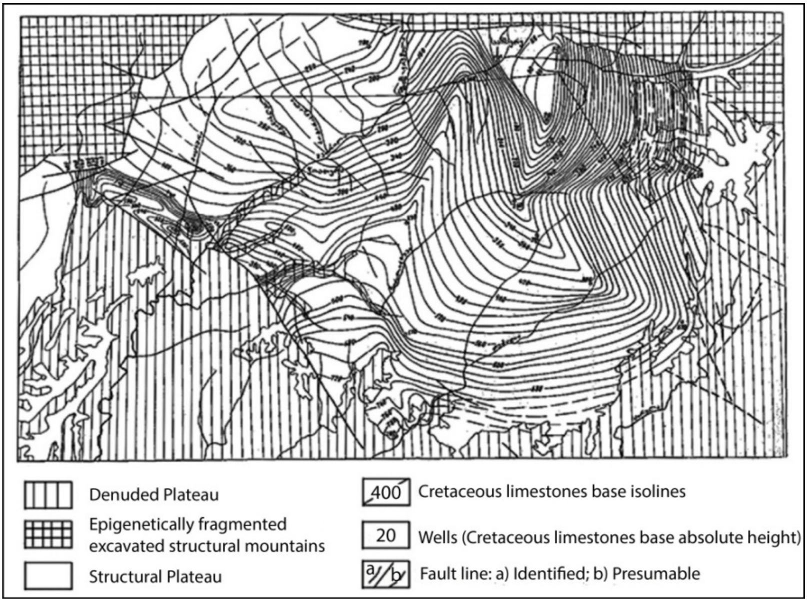

Figure 7. The topography of the bedding rock of the upper tectonic (Meso-Cenozoic) level of the Chiatura Structural Plateau.

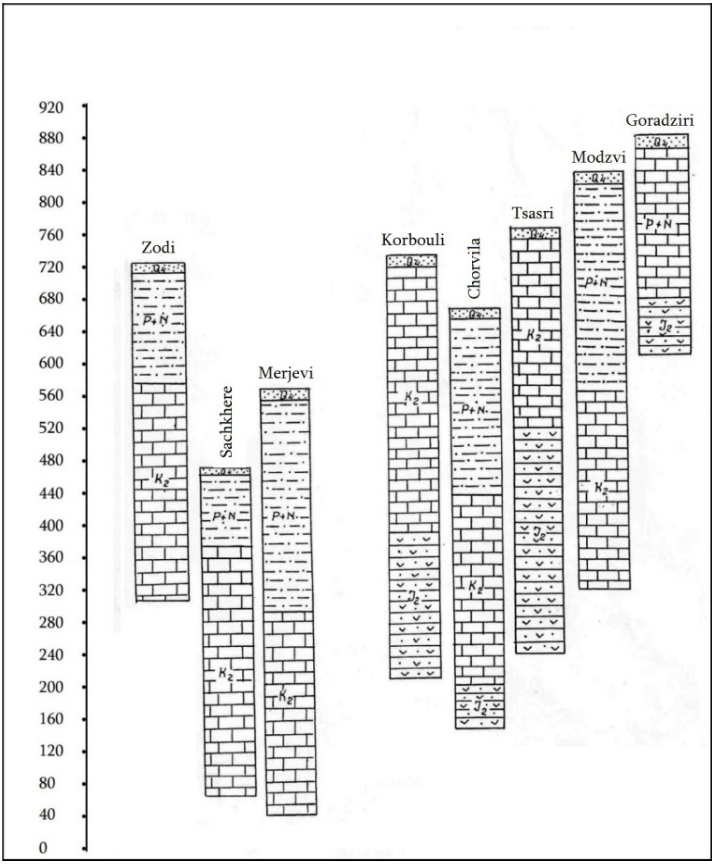

Figure 8. Geological cross-section of the boreholes in the Zemo Imereti (Chiatura) Structural Plateau.

Based on the above mentioned materials, we performed a palaeomorphologic structural zoning of the Chiatura Structural Plateau and distinguished two hydrogeological basins (Fig. 9).

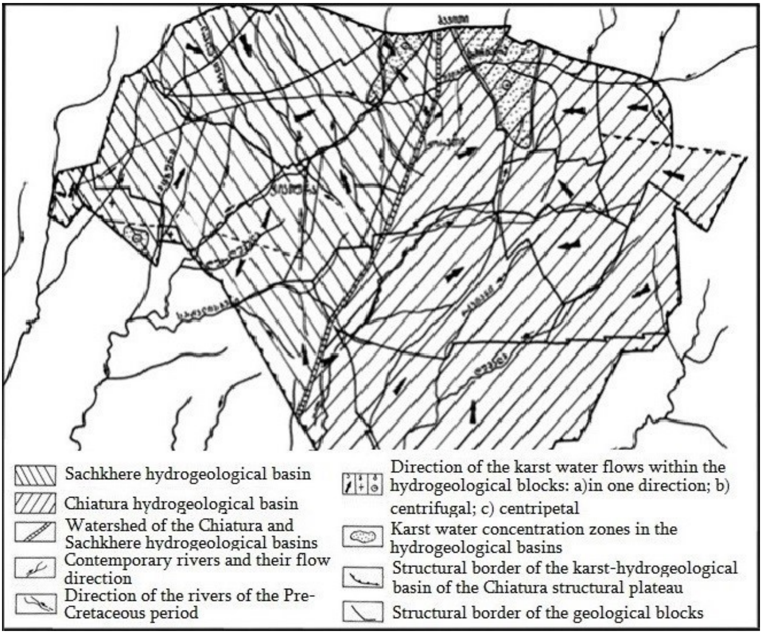

Figure 9. Paleomorphostructural zoning of the submerged block of the Chiatura Structural Plateau
(according to the general scheme of the hydrogeological situation).

While separation of individual blocks by fault lines, the situation was taken into account that the crystal foundation is raised to different heights within the Chiatura Structural Plateau, and the cross-section and thickness of the sedimentary cover are also different. The directions of movement od underground waters within the individual blocks separated by the faults seem to be different, although the water exchange between the blocks is not excluded either. The directions of movement underground waters within the individual blocks and hydrogeological basins in general have been practically confirmed on the basis of the indicator experiments, carried out by us. However, if we take into account the geological structure of the neighboring areas, we can admit the entry of "foreign" waters into the unified underground basin of the Zemo Imereti Structural Plateau from the southern slope of the Racha limestone range (for clarification of this we need to conduct indicator experiments in the future).

Thus, the morphostructures of the Chiatura Structural Plateau are presented as mosaics of ascending or descending blocks of various sizes, which originated in the process of evolution of regional and local submeridional and sublateral faults. Most of the old faults undergo transformation and rejuvenation along with tectonic movements, which is facilitated by intensively ongoing karst processes.

The great role that fissure water permeability plays in the karstification process is well known. (Gvozdetsky, 1954; Sokolov, 1962; Maksimovich, 1963; Kiknadze, 1972; Dublyanski, 1971; Tintilozov, 1976.). Exactly the trust-fault line dislocations create the best base for fissure water permeability, which is so characteristic for the Zemo Imereti Plateau karst region. The genetic type and intensity of fissures in the area vary and depend on the nature of the tectonic structures, rock density, layering, lithological composition, geomorphological features, etc.

Of the types of fissures developed within the Zemo Imereti Plateau, the horizontal layered fissures are most widespread, the favorable conditions for the formation of which are formed by the smooth layout of Upper Cretaceous or Middle Miocene limestones on the solid basement of the Dzirula massif. Opening of these fissures is related to the discharge of the internal tension in the rocks, which is caused by the washing of the above-mentioned suites and the deep erosive fragmentation of the massif.

In addition to the mentioned fissures, lateral pressure, erosion and technogenic fissures are widespread within the Zemo Imereti platform karst.

Lateral pressure fissures are well expressed in the limestone cliff outcrops on the Zemo Imereti Plateau. Their development is caused by discharging of internal tension of the rocks. In this regard, the valleys of the rivers of Katskhura, Rganisghele, Jruchula, Sadzalekhevi and Kvirila are outstanding. The dense network of lateral pressure fissures, especially in the areas, where they are intersected by vertical cracks, contributes to the development of exotectonic phenomena. Some rock avalanches and landslides are related to these fissures in the valleys of the rivers of Sadzalekhevi and Kvirila.

The weathering fissures are widely represented on the Zemo Imereti Plateau. In this regard, the outcropped surfaces and cliffy areas of the southern exposure are particularly distinguished. The weathering fissures in limestone outcrop areas quickly absorb atmospheric precipitations and cause complete dehydration of limestone surfaces. These fissures are characterized by variable direction, embranchment and sinuosity. The depth of their distribution varies from a few centimeters to 1-1.5 m, and their number (density) decreases rapidly depthward. Surface karst forms – corries are mainly associated with weathering fussures.

We finish discussing the categories of fissures by technogenic fissures that are particularly widespread on the Chiatura Structural Plateau. They significantly change the hydrodynamic situation of the region and contribute to the activation of karst processes.

II. 3. On the genesis of karst caldera - the denudation-tectonic morphostructure

As a result of the structural decoding of the aerial imagery carried out by us on the structural plateau of Zemo Imereti, in the watershed strip of the Kvirila River and its left tributary-Sadzalekhevi (Prone), unknown so far landforms of chain-like layout have been observed. Separate similar forms have been outlined in other areas too (Fig. 10).

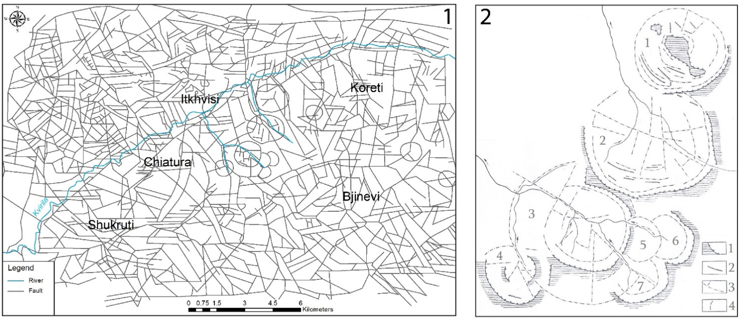

Figure 10. Scheme of fault dislocations of the Chiatura Structural Plateau (compiled by decoding of aerial imagery).

1) Scheme of fault dislocations of the structural plateau of Zemo Imereti (compiled by decoding of aerial imagery). 2) Radially concentrated structures of karst calderas and a scheme of their layout. The numbers in the figure indicate the calderas: 1-Koreti; 2-Kveda Itkhvisi; 3-Zeda Itkhvisi; 4-Shukruti. 5-7 - Small caldera-satellites without names. Legend: 1-Denudation-tectonic cliffs on the upper cover of the carbonate rocks; 2-Denudative-tectonic remnants on the bottom of the karst caldera; 3-Radial and concentrated fissures (faults, lineaments) revealed by structural decoding; 4-Identified external contours of the karst caldera.

The diameter of the mentioned landforms, identified during decoding, ranges from 0.6 to 2.2 km and they morphologically are represented as depressions. These forms are developed in the terrigene sediments of the Neogene age, which in their turn cover the Upper Cretaceous limestones. The depressions are linearly circular, with slopes of 40-60 m in height, almost having not undergone erosion and have a well-defined eyebrow and back side (Lezhava, 2015). These slopes border a flat subhorizontal bottom of saucer-like depressions (Fig. 11).

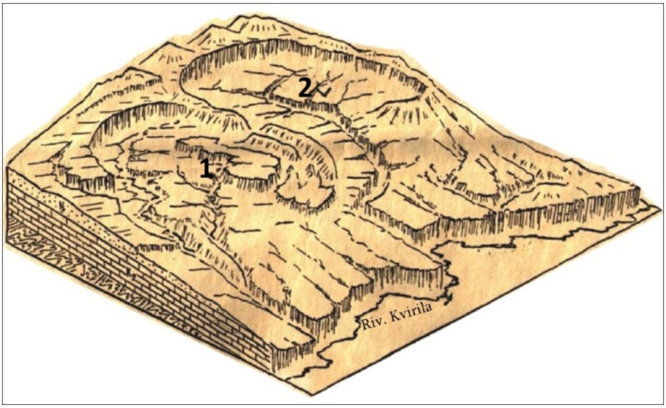

Figure 11. Block diagram of Koreti (1) and Itkhvisi (2) karst calderas.

The described particularities distinguish these depressions from the usual water collecting depressions of exogenous origin. In our opinion, endogenous processes play an active role in the origin of these depressions, which must be stipulated by the following circumstances and facts. It is well known that the hydrodynamics of river flows in the process of their development, if they are not controlled by tectonic disturbances, do not produce strict geometric forms - neither linear nor circular (Edilashvili, 2006; Borisova and Glukha, 1982).

The endogenous nature of the occurrence of these depressions, which prepared the tectonic conditions for the realization of further denudative processes, also indicates: the radially concentrated denudative remnants, built with Tertiary rocks, which greatly complicate the flat bottom relief of these depressions; as well as radially and concentrically oriented lineaments (cracky zones) that were observed in consequence of decoding within depressions. It should be noted that the lineaments are connected with cracks and fault lines.

These circular landforms are also well represented in the schemes we made using GIS systems. These schemes clearly show the circular shape structures on the Pre-Cretaceous substrate, which coincide with the structures obtained by our decoding (Fig. 12).

It is noteworthy that the occurrence of similar circular depressions is characteristic of certain stages of the development of volcanic apparatus (Astakhov, 1973). Given that in the study region in the Pre-Cretaceous foundation cross-section volcanites are represented, and in the Quarternary Period volcanism occurrences took place resulting in the formation Goradziri (Fig. 13) and other laccolith-extrusives, the mentioned depressions along the faults can be considered the depressions of magmatic genesis, formed above them. Concidering these circumstances, we for the first time introduced the term "caldera" to denote a previously unknown morphostructural formation. However, taking into consideration the intense development of karst in limestone rocks in the study area, we finally called it karst caldera, genesis of which is endogenous-exogenous. Thus, the mechanism of origin of karst caldera is similar to that of volcanic, or, more broadly, inversive depressions of magmatic origin (Lezhava et al., 2019b).

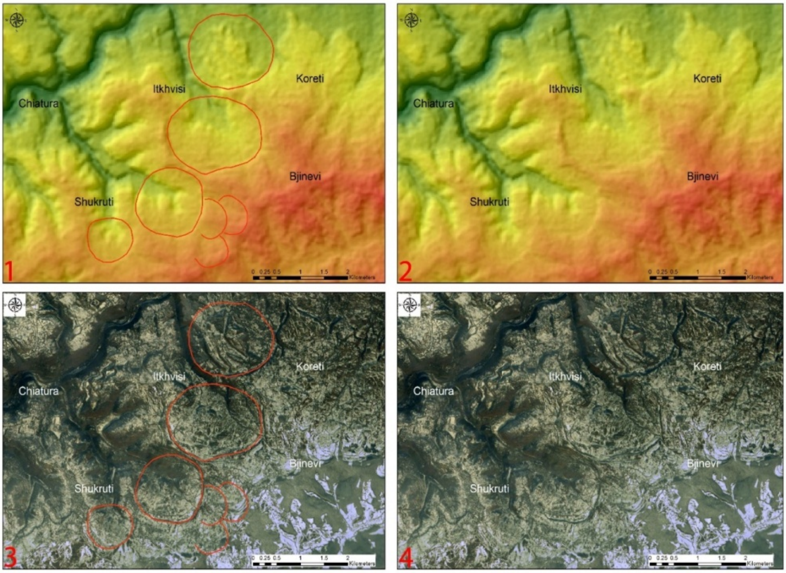

Figure 12. 1) The red circular lines show the distribution areas of karst calderas in the Zemo Imereti Structural Plateau (the 30-meter resolution digital 3D model); 2) The distribution areas of karst calderas are seen without the red circular lines in the 30-meter resolution digital 3D model; 3) The red circular lines show the distribution areas of karst calderas in the Google Earth's image; 4) The distribution areas of karst calderas are seen without the red circular lines in the Google Earth's image.

Figure 13. Goradziri hill of volcanic origin.

The chain layout out of these karst calderas is similar to the chain layout out of circular volcanic-tectonic morpho-structures on Kamchatka and other volcanic regions (Kozlov, 1982). All of these make us think about the formation of karst calderas along the fault on their top. Their strict circular shape indicates a focal mechanical tension that may be the central-type structures (volcanic apparatus, isometric-shaped intrusives) on the Pre-Cretaceous substrate. These structures control faults and act as tectonic stamps. The latter, in its turn, leads to the disintegration of the uniform cover of the platform and creates favorable conditions for the activation of selective denudation. Naturally, the relatively weakly consolidated Neogene-Terrigenous deposits are primarily denuded, resulting in the excavation of Cretaceous rocks.

The denudative-tectonic genesis of the karst calderas discussed by us can be extended to the Akhalsopeli (Tkibuli) hollow (West Georgia), which is part of the karst strip of Georgia, where erosive-denudative processes have gone deep and reach the base rocks. The Tkibuli hollow tectonically coincides with the wide and sloping dome structure of the Okriba arch. The dome of the arch is washed away and in the middle part, on the important area washed away in the Bathian orophase Jurassic rocks are exposed, in particular, the volcanogenic porphyritic suite of Bajocian stage. In the geological past, these sediments were completely covered with Cretaceous limestones stretched brachyanticlinally or dome-likely, which experienced intense denudation with active participation of karst processes, and which are currently preserved only on the peripheries of the arch (Konuchevski, 1925; Meffert, 1930; Janelidze, 1940).

The Akhalsopeli hollow can also be attributed to the karst caldera-the morphostructural type described by us, only with the difference that it is at a much more mature stage of development than the described by us karst caldera, developed in the Kvirila River basin.

II. 4. Morphographic-morphometric conditions

Important effects on karstification processes are the inclination of the relief surface, the depth and density of fragmentation. Vertical-erosive fragmentation contributes to the intensity of frissure-karst water movement and the essential moments of the origin and development of karst forms. The inclination of the surface conditions particularities of infiltration of atmospheric precipitations (rain, and snow), the duration of the impact of water on karstified rocks (Tintilozov, 1976; Lezhava, 2015).

The main morphological particularity of the Zemo Imereti Plateau is determined by geological structure. It is the highest elevated part of the Block of Georgia, although the modern plasticity of the relief is substantially modified by exodynamic processes and tectonic impact. The relief of the plateau bears many signs of individuality: all over Georgia only here can be found elevated at significant heights denudative-structural plateau-like surfaces with a quiet, tectonically almost smooth layout of constructing layers.

Morphologically, the distribution areal of Zemo Imereti platform karst coincides with the structural plateau of Zemo Imereti. Its relief with gentle topography is divided by deep (100-300 m) canyon-like gorges of the rivers of Kvirila, Dzirula, Sadzalekhevi and their tributaries. Among the canyon gorges, produced in limestones, the most important are the last sections of the Kviriala River and its tributaries (Jruchula, Rganisghele, Nekrisa, Katskhura, Bogiristskali, etc.) between Salieti and Sachkhere. Here, the rivers cross the thick-layered limestones of the Turonian-Danian horizontal suites. Kvirila canyon starts a couple of kilometers away from Sachkhere and gradually becomes deeper in the direction of Salieti. If the height of the steep (45-90^0) slopes of the valley is insignificant (several tens of meters) at the initial section, it reaches 200-300 m near Chiatura. The slopes towards Salieti are somewhat spread out, and the canyon loses its typical severe appearance.

These canyon-like gorges cause the fragmentation ofthea integral structural plateau into separate small plateaus. Such table-uplands/elevations (plateaus) are morphologically well expressed on both sides of the River Kvirila. These are Koreti, Darkveti-Zodi, caves - Tabagrebi, Rgani, Sareki, Itkhvisi, Shukruti, Perevi, Pasieti, Sveri, and Merevi. These plateaus bear the names of the villages located on them and are bordered on three sides by erosive valleys. They are characterized by a common inclination towards west and towards Kvirila Valley. Their main axes stretch from northwest to southeast.

Most of the plateau surfaces on the right side of Kvirila have elongated shape, at the same time, they are more strongly washed away and are distinguished by high rates of vertical partition. The valleys separating the plateaus on the left side are characterized by less length and a significant falling. Also, their surfaces are covered with relatively thick Tertiary clays and sandstones. The relative heights of these plateaus range within 100 to 300 m, and the absolute height is 500-800 m above sea level. The surface of the plateaus is somewhat complicated in some areas as a result of washing away of the Tertiary rocks and takes on the appearance of a gentle hilly relief. However, in some areas (where limestones are outcropped directly) there are typical table surfaces (Fig. 14).

Figure 14. Fragment of structural plateu.

Therefore, the structural plateau of Zemo Imereti (Chiatura) with its deeply cut canyon gorges is a classic region of deep relief fragmentation. These conditions obviously influence on the intensity of karst processes and the formation of morphographic features of speleo objects, as the evolution of hydrodynamic zones of fissure-karst waters and caves of the region was passing along against the background of the vertical cutting of the plateau surface and consequently the gradual descent of the erosion base (against the background of the intensive depth circulation of waters at the same time).

Clear evidence of this is the fact that most of the caves open on the slopes of river valleys and are often located at different heights from the river valley thalweg. Also, the activation of karst processes is connected with the fragmented areas of the relief - ravines, depressions, dead valleys, the dense network of which is presented within the plateau. Dead valleys must have been formed as a result of intense depth fragmentation and the movement of karst waters into the depths.

As it is known, the density of relief fragmentation affects the intensive revalation of karst processes. Chiatura plateaus are relatively weakly fragmented by erosive networks; they somewhat lack for permanent streams; therefore, the density of relatively weak (0.5-1.0 km/km^2) fragmentation in the intensive karstification areas should be considered a common phenomenon in the study area.

The surface inclination of the relief significantly influences the course of karst processes, conditioning the infiltration and influence peculiarities of atmospheric precipitations, as well as the duration of the impact of water on karstified rocks. Experiments conducted by S. Fyodorov (1950) have shown that total sum of the amount of the infiltration is the largest (and in this connection these are the most favorable conditions for karst development) on the slightly sloped (5-10^0) surface and decreases with increase of the relief inclination, and in the conditions of inclination of 15^0, except of very seldom cases, creation of surface karst forms is already suspended. The best proof of this is the weakly sloped surfaces of the structural plateaus of Zemo Imereti. Analysis of the maps of inclination of the surfaces and the distribution of karst objects that we had made based on the large-scale topographic map, allowed us to determine the direct relationship between the distribution of karst forms and the inclination of the surfaces (Table 3). Namely, most of the surface and underground karst forms, common in the study area, are associated with weakly sloped (6^0-12^0) surfaces.

Table 3. Inclination of surfaces of the Zemo Imereti Plateau and adjacent regions.

Inclination angle	Areal area, km^2	Areal area compared to total area,%
$0^0 0^I$ - $1^0 3^I$	114.6	3.9
1^0 3 - 3^0	99.8	3.3
3^0 - 6^0	183.4	6.3
6^0 - 12^0	559.4	19.2
12^0 - 20^0	838.9	28.8
20^0 - 30^0	746.0	25.6
30^0 - 40^0	308.7	10.6
More than 40^0	59.2	2.3

Surfaces with an inclination of 6^0-12^0 occupy a significant area (Table 4) in the study area and the largest part of the karst landforms are associated with them. Indeed, here the plains and slightly sloped surfaces are characterized by a significant distribution of corrie fields, karst sinkholes, wells, and shafts, which are the result of long-time influence of atmospheric precipitations on slightly sloped surfaces, along with other conditions. There are favorable conditions on such surfaces for areal infiltration and influence of precipitation, which also conditions the intensity of depth karstification.

The regular distribution of karst relief is also observed in the vertical cross-section. The karst relief is best developed within the 400-600 m and especially within the 600-800 m altitudes (Table 4).

Table 4. Distribution of karst caves according to hypsometric level.

Hypsometric levels, m	Number of caves	The total length of caves, m
Less than 400	9	781
400-600	37	4598
600-800	41	5414
800-1000	3	1190
1000-1600	6	773
1600-2000	4	124
2000-2500	4	111
More than 2500	-	-

The reason for this (along with other factors) is that it is this stage that the plateau surfaces of the region comply with, where ideal conditions are created for the development of karst phenomena. Apart from this, in this hypsometric interval, snow cover appears and melts several times during the winter, and mostly falls liquid atmospheric precipitation. To this contributes the average positive temperature in January, which drops below zero only above 800-900 m. Therefore, at this altitude, favorable climatic conditions are being created for the formation of aggressive waters with low temperatures. Based on the study of the height distribution of caves on the southern slope of the Caucasus (Tintilozov, 1976), it has been established that a significant part (28%) of the studied caves are located at an interval of 500-900 m. As a result of our study of the height distribution of caves on the Zemo Imereti Plateau and the surrounding karst regions, it was found that most of the studied caves (81%) are presented within the interval of 400-800 m and these altitudinal levels include the structural plateau (platform karst).

Thus, the mentioned morphographic-morphometric peculiarities of the structural plateau of Zemo Imereti, in particular, sparce, but deep fragmentation, sharp separation of the plateaus, their altitudinal distribution and the plain surface, the Turonian-Danian layers that construct the substrate, as well as the common inclination of the Tertiary layers and topographic surface, etc., create favorable conditions for the development of karst.

II. 5. Climate and karst formation

The intensity of karst processes largely depends on the climatic conditions. Particularly important are the amount of atmospheric precipitations, their distribution and mode, the diurnal, and partly annual motion of air temperatures.

Existing literary sources (Napetvaridze, 1948; Gogishvili, 1958; Kordzakhia, 1961, 1962, 1963; Chirakadze, 1964; Javakhishvili, 1977, 1982), as well as data from meteorological stations and field observations, have been used to characterize certain climate elements of the Zemo Imereti Plateau.

The study area is located on the eastern periphery of the humid subtropical Kolkheti region. Therefore, the typical features of western Georgia's Black Sea coastal humid subtropical climate are weakened. It is relatively continental, precipitation amount is reduced, annual and diurnal amplitudes of temperatures are increased.

In the hilly area of the foothills (500 m above sea level) the average annual air temperature varies between 11.7^0-14^0 C (Table 5). At the height of 500-1000 m it is 8-10.5° C, and in the higher parts 5-6 ° C. As the height increases, the winter becomes harsher. The coldest month is January. The average January temperature is positive in most parts of Zemo Imereti (600-700 m above sea level) and ranges from 6^0 to 0^0 C. At the height of 1200 m it is - 4^0 C and at 1500 m it is - 6^0 C.

In the warmest month (July) the average temperature in most parts of the area (up to 600 m above sea level) is 20-24^0 C. The maximum temperature (42^0C) is observed in the Chiatura area due to the overheat of the hollow, surrounded by the rocky slopes.

The average monthly and annual temperature values in Zemo Imereti are quite high, with annual temperature amplitudes gradually increasing from west to east. The sum of autumn months' temperatures is always greater than the sum of spring months, but the difference between them is gradually reduced from west to east at the expense of autumn temperatures.

In the study area, in soil-vegetation-free areas, large daily fluctuations of air temperature and temperatures of ground surfaces (denuded limestone surfaces during the warm season can be overheated to 47^0C during the day, and cooled to 10-11^0 C at night due to strong radiation. On certain days the temperature of soil is 15-20^0C higher than that of air) cause extensive development of physical (temperature, frost) weathering, which is accompanied by the emergence of initial cracks of weathering. In some areas, temperature and frost weathering is essential reason for disintegration of karstified rocks. For example, laboratory tests of Upper Cretaceous limestones (Aroshidze et al.,1984) have shown that their hardness can be reduced 15 times or more by the effects of physical weathering processes. The water absorption capacity of limestones also increases by 3-4 times. On cracked and weathered cliffy slopes, rock-avalanches and stone falls develop quite often. Canyon like gorges of the Kvirila River and its tributaries attract particular attention by the intensity of gravitational processes.

According to the inter-annual distribution of atmospheric precipitation, a heterogeneous picture is created, which is caused primarily by the strongly seasonal nature of the atmospheric circulation processes and by the vertical fragmentation of the surface. In the low-mountain zone, maximum of precipitations fall in autumn and winter. The main peak is mostly in October and November, and the relatively weak secondary peak is in January-February. In the average mountainous zone, the main maximum of precipitations is in April and summer months with the main minimum in winter. Even more complex is the territorial distribution of atmospheric precipitations, where relief plays a key role.

The effect of precipitations depends on slopes' exposition. Precipitation on the Zemo Imereti Structural Plateau gradually decreases from west to east. This is due to the fact that the elevation from west to east in the axial zone of the Zemo Imereti Plateau is very insignificant, so that upward currents do not develop and condensation conditions are not created. Particularly small amount of precipitations falls on the Chiatura-Skhvitori section of the Kvirila River gorge (900-1000 mm). On the eastern periphery of the Zemo Imereti Plateau, the Likhi Range forms a steep uplift, on the western slope of which rising currents of air masses are developed and the amount of precipitations markedly increases (1000–1400 mm).

Table 5. Meteorological elements of Zemo Imereti (Javakhishvili, 1977).

Stations	Height above sea level, m	Air temperature, ^{0}C			Relative Humidity, %		Annual cloudiness by total cloudiness, %	Precipitations, mm			Number of days with precipitation	Coefficient of moisture
		Of the coldest Month	Of the warmest Month	Average Annual	The driest month	Average Annual		Summer	Winter	Annual		
Kharagauli	280	3.2	23.0	13.2	69	73	61	308	391	1366	161	1.9
Chiatura	348	1.8	23.2	13.0				224	345	1237	152	2.0
Sachkhere	415	1.3	22.6	11.7	69	76	65	172	284	904	140	1.9
Korbouli	793	-0.3	20.2	10.0	72	76	65	253	528	1477	161	2.1
M. Sabueti	1245	-3.9	16.2	6.3	79	83	70	226	327	1101	181	1.7

The sum of precipitations of the winter months is higher than that of the summer months. Long-lasting rains are not uncommon for the summer season, which K. Gogishvili (1958) links with the influence of the less moving waves on the south polar front. Torrents, mudflows and floods are associated with this process, which is sometimes very harmful to agriculture and other branches of economy.

Downpours and long-lasting rains play a major role in the formation of karst relief. At this time, most of the caves, which are connected to the surface by karst sinkholes, are filled with water. A good example of this is the Buja River water loss, Shekiladzeebi (Guburebi), Cheruli, Ormoebi, and other caves. Periodic watering of dry caves, which is indicated by the thick deposits of mud left on their bottom, is associated with prolonged rains. The floods that occur at this time accelerate the course of karst phenomena. Periodic contamination and pollution of vaucluse springs is mainly associated with rains and torrents, which produce them.

Precipitation in the study area in the form of snow is expected everywhere, but the thickness and duration of snow cover varies according to altitudinal zones. With less durability and thickness, snow cover is typical in Chiatura. The first snowfall here is expected in the first decade of November, but sustainable snow cover only occurs from the first decade of January and can last until the end of February. In Corbouli (793 m above sea level), the first snow may fall in the first decade of October, and the stable snow cover is formed in the first decade of December. The maximum thickness of snow cover reaches 191 cm.

The efficiency of the impact of atmospheric precipitations on limestone surfaces and karst processes in general depends not so much on the absolute values of the falling precipitations as on the amount that remains after its evaporation. On the Zemo Imereti Structural Plateau, precipitations fall more than evaporate almost everywhere during the year. Summer months are exception; in this period the humidity is negative (Table 6) in some areas. Here the evaporation annual rates fluctuate between 400-800 mm according to territories.

Table 6. Balance of atmospheric humidity in mm (Kordzakhia, Javakhishvili, 1962).

Stations	Months												Annual
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Sachkhere	76	72	34	- 3	-26	-25	-46	-51	-11	34	60	64	179
Korbouli	89	93	89	21	5	-9	-13	-24	7	75	69	77	429
Kharagauli	104	99	68	28	42	39	18	-17	8	49	65	81	574
Sakara	113	112	69	10	-17	-10	-40	-53	6	57	91	111	448
Mt. Sabueti	67	71	59	-4	22	18	-12	-35	7	68	60	56	367

The annual internal distribution of evaporation is greatly influenced by the average air temperature course. Its minimum values correspond to winter minimum temperatures and maximum – with maximum summer temperatures. As the temperature rises, the average monthly and annual evaporation rates decrease. The lowest zone of the study area (the middlestream of the Kvirila River and the downstream of the Dzirula River) is characterized by the maximum annual evaporation rate (800 mm).

The coefficient of humidity on the Zemo Imereti Structural Plateau is 1-1.5. In the Kvirila River basin, over 1000 m above sea level, moderately excess (1.5-2.0) and excess (2.0-2.5) humidity zones are distinguished (Kordzakhia, Javakhishvili, 1962; Javakhishvili, 1977, 1982).

Based on the comparison of amount of atmospheric precipitations and evaporation data, it can be noted that the annual runoff balance is positive everywhere within the karst zone of the study area, leading to an active course of karst processes throughout the year, and especially during the cold period of the year.

II. 6. Underground waters and karst formation

II. 6. a. Important karst sources

Regime observations on karst springs in the study area have not yet been performed. Therefore, when we characterize them, we mainly rely on the materials obtained by us based on field researches. During this period, 120 karst springs and underground streams were studied, of which about 70 springs were sampled and chemically analyzed. Seasonal regime observations have been made on some springs, and so on (Table 7). The sources of the Zemo Imereti Structural Plateau differ in the structure and lithological composition of the exits (derived from the Upper Cretaceous as well as Tertiary limestones, deluvial deposits, boulder deposits), altitude distribution (from 300 m to 900 m above sea level), debit (from very insignificant up to 300-400 l/sec.) and regime.

According to the conditions of coming out to the surface, most of the springs belong to the descending type. There are also ascending pressure springs that outfkow mainly at riverbeds levels. The formation of the latter is related to local lithological or tectonic conditions. Springs related to the aeration zone outflow at different altitudes above river levels. Their debit ranges mainly from 0.1 to 10 l/sec., and sometimes exceeds 20-30 l/sec. Springs of significant sizes are related with levels' seasonal fluctuation and full saturation zones.

Table 7. Average monthly discharges and temperatures of karst springs.

Name	May		June		July		August		October		February	
	Debit, l/sec.	Water, t°C	Debit, l/sec.	Water, t°C	Debit, l/sec.	Water, t°C	Debit, l/sec.	Water, t°C	Debit, l/sec.	Water, t°C	Debit, l/sec.	Water, t°C
Ghrudo	360	10.2	300	13.4	290	15.5	210	16.0	260	14.0	180	9.2
Monasteri	240	11.3	200	12.5	185	13.8	150	12.6	185	12.4	145	11.2
Lezhubani	130	11.3	180	12.0	66.5	12.0	62.5	12.8	88	12.2	72.5	11.4
Sakurdghlia	0.8	11.3	0.5	12.2	0.4	12.6	0.4	12.4	-	-	-	-
Tavistkivili	-	-	1.2	7.5	0.8	7.0	-	-	0.5	7.2	0.3	7.0
Tiri	-	-	130	12.0	100	12.4	85	12.6	128.5	12.2	95	11.0
Kldistskaro	-	-	-	-	2.0	11.0	-	-	1.7	11.0	1.2	7.0
Shvilobisa	-	-	7	11.2	6.5	11.0	5.4	11.2	6.7	11.4	3.4	10.6
Katskhura I	-	-	5.5	11.5	-	-	-	-	5	11.6	-	-
Katskhura II	-	-	28.5	11.5	-	-	-	-	23.5	11.4	-	-
Katskhura III	-	-	45	12.0	-	-	-	-	36.8	12.5	-	-
Khvedelidzeebi	-	-	0.8	13.0	0.3	13.6	0.1	13.8	-	-	0.5	6.8
Ormoebi	-	-	-	-	0.5	14.0	0.1	15.2	-	-	0.3	5.0
Tskhrapira	-	-	95	12.0	72.5	12.0	-	-	87.5	12.2	75	11.4

On the Zemo Imereti Structural Plateau, temperatures of karst springs vary between 5-16^{0}C during the year. In the coldest months (January-February) temperatures mainly fluctuate between 5-11.5^{0}C, and in the warm months (July-August) – in the range of 11-13^{0}C. The exception is the source of Tavistkivili, which is characterized by almost equal temperatures (7-7.5^{0}C) and debit (1-1.2 l/sec) throughout the year. Noteworthy are the high temperatures of the Ghrudo Spring in July-August (15-16^{0}C). On some days of these months, the water temperature here sometimes reaches even 17^{0}C. High temperatures of the Ghrudo Spring are the result of intense mixing of the periodically leaking water from the

Kvirila and Jruchula rivers with the Ghrudo groundwater basin, this was confirmed by field studies and indicator experiments.

For example, on July 4, 1991, just a few hours after one of the repeated earthquakes (4 magnitude) in the Chiatura-Sachkhere region, the water temperature rose rapidly from 14^0 to 17^0C (at that time, the water temperatures on the Kvirila and Jruchula rivers were respectively 19^0 and 18.4^0C), and the debit increased from 150 l/sec. to 500 l/sec., and became very turbid (it was flowing almost the same as the Kvirila River and was carrying mazut spots), which lasted for almost a month. Tsiskvilistskali is also distinguished by high temperature (16.4^0C), flowing out in the Dzusa River basin on its left side. As the residents of the Village of Vardigora point out, often in the water of this spring they see fish, which they catch by means of the so called "patseri" (lattice).

On this fact, in his unpublished work, Givi Gigineishvili (1971) expresses his opinion that there should be a widely developed network of underground streams in the mentioned area, where there are conditions for living of fish, which get from the Dzusa riverbed. We fully share this viewpoint and definitely consider conducting indicator experiments here in the future.

In the study area decrease of temperature with an increase of the absolute heights of source outlets is observed (Fig. 15).

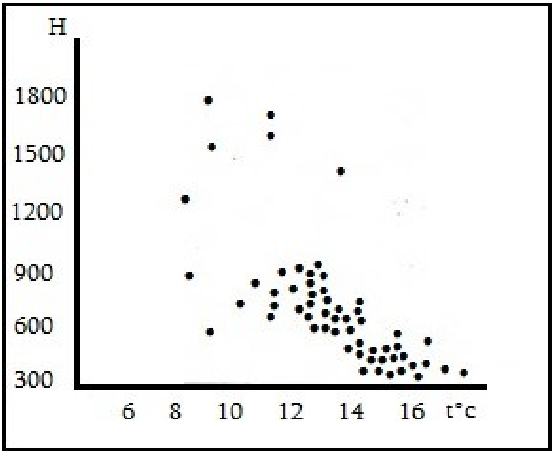

Figure 15. Dependence of the temperature of karst waters on height.

At the same time, water mineralization changes within the range of 160-2290 mg/l, it is mainly equal to 200 - 600 mg/l and remains unchanged according to the height (Fig. 16).

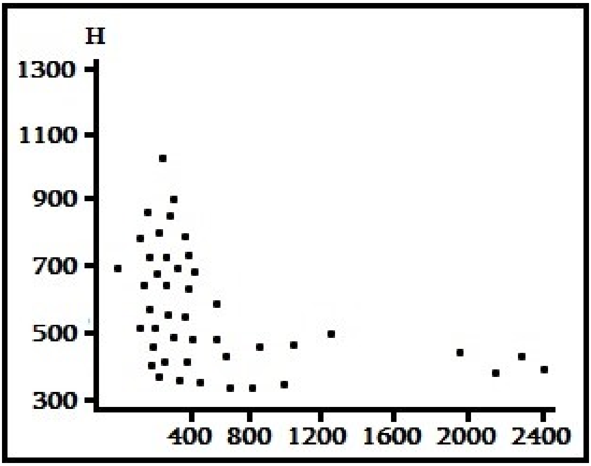

Figure 16. Dependence of mineralization of karst waters on height.

A significant part of the karst springs of the study area is used for water supply of the city of Chiatura and the surrounding villages. In this regard the vaucluse spring of Ghrudo is of particular interest that outflows at an altitude of 370 m above sea level (6 m above the level of the Kvirila River) at the foot of the steep southern cliff of the Darkveti Plateau. Currently, due to pollution, our recommendation is to use Ghrudo's vaucluse spring only as technical water. The outlet of the powerful stream (average multi-year discharge of 300 l/sec.) coincides with the intersection of the cracks in the Upper Cretaceous thick layered limestones. It is a typical karst vaucluse spring that is fed mainly from the surface sreams, falling into negative surface forms (sinkholes, ponors, cracks, etc.), as well as with the waters, leaked from the riverbeds. Visual observations in the field have shown that the change in atmospheric precipitations is reflected somewhat delayed (3-10 days) on the Ghrudo water discharge. This regularity is generally characteristic of the karst springs on the border of seasonal fluctuations and full saturation zones. For the Ghrudo Spring, as well as for some of the vaucluse springs of the structural plateau (Monasteri, Tiri, Lezhubani, and Kldekari), is characteristic periodic strong turbidity during the rains, which is mainly caused by anthropogenic factors.

As indicator experiments have confirmed, Ghrudo has a fairly large underground basin. Its maximum water discharge falls on April and coincides with flooding of rivers. Then the discharge decreases slowly and reaches the minimum in August-September. For the most of the karst springs in the study area, the maximum discharge is also characteristic in April, and for some of them - in May (the May discharge is slightly higher than that of April). The minimum discharge on the most of springs is clearly expressed in August-September, after which, especially from November, there is a sharp increase in discharge. In December, there is a weakly expressed secondary maximum, and then also a secondary minimum is in February.

II. 6. b. Hydrochemical peculiarities of karst waters

The hydrochemical peculiarities of the karst waters of the Georgian limestone strip are very poorly studied. Some regions, including the Zemo Imereti Platform Karst; and it can be said that in this regard they are unexplored at all.

Detailed hydrochemical studied were carried out by our expedition group on the structural plateau of Zemo Imereti (platform karst). In addition, in order to solve a number of issues of karstogenesis (migration of substances, formation of underground karst waters' composition, etc.) by the stationary observations and laboratory studies, chemical (in particular, macro and micro elements of surface streams, karst springs and underground streams) composition and hydrochemical regime was identified. For this purpose, more than 200 samples were processed in the laboratory (chemical analysis of the samples was performed at the Department of Analytical Chemistry of the Ivane Javakhishvili Tbilisi State University under the guidance of Prof. Guram Supatashvili). We checked the chemical composition of vaucluse springs and underground streams periodically (in all seasons of the year). In total, we took eight series of samples. The results obtained by us and the materials previously accumulated at the Department of Analytical Chemistry of the Iv. Javakhishvili Tbilisi State University (Supatashvili et al., 1990) significantly fill the gaps in the hydrochemistry of karst waters of Georgia (Table 8).

Table 8. Chemical composition of karst waters of Georgia.

(SF-surface flow, KS-karst spring, US-underground stream;
There are the extreme data in the denominator, and the average – in the numerator).

District	Waters	Sample Number	pH	Mg. L $^{-1}$							
				Cl^{-1}	$SO4^{2-}$	$HCO^{-}3$	Na^{+}	Mg^{2+}	Ca^{2+}	Fe	Σi
Apkhazeti	SF	5	7.30-7.61 7.51	0.2-0.6 0.4	3.8-13.0 9.7	98-159 133	0.7-2.7 1.3	4.0-11.0 7.3	27.0-41.3 35.3	0.02-0.12 0.05	129-217 187
	KS	7	7.18-7.56 7.47	0.2-0.5 0.5	4.2-9.4 8.8	94-159 139	1.3-1.8 1.4	5.1-10.0 6.0	25.0-43.3 37.4	0.02-0.08 0.04	132-211 193
	SS	10	7.15-7.85 7.53	0.1-1.3 0.4	1.0-12.0 4.9	71-146 105	0.7-25.8 8.8	0.7-7.9 3.5	11.0-38.8 21.0	0.01-0.05 0.03	94-199 145
Lechkhumi	SF	6	7.36-7.66 7.53	0.8-1.5 1.2	4.2-7.5 5.5	59-165 134	1.4-5.1 2.9	1.4-9.5 6.7	15.2-43.1 33.7	0.02-0.07 0.05	85-225 184
	KS	15	7.06-7.90 7.37	0.4-8.4 1.8	2.2-10.4 6.2	60-354 207	1.4-6.0 3.4	2.7-21.0 10.2	17.6-108 51.8	0.01-0.03 0.02	94-476 288
	US	8	6.75-7.50 7.08	0.1-1.1 0.6	3.0-5.0 4.0	166-339 245	10.2-18.0 14.4	4.9-10.1 7.1	41.7-95.3 60.7	0.01-0.03 0.03	264-460 337
Khvamli	SF	3	7.19-8.02 7.74	1.1-1.7 1.5	5.2-19.2 11.0	181-203 194	2.6-6.4 4.4	1.6-7.3 5.4	56.2-58.0 57.1	0.02-0.03 0.03	249-291 270
	US	5	7.31-8.05 7.76	0.5-0.8 0.6	2.6-7.0 4.4	159-203 185	0.5-4.1 1.9	2.8-7.4 5.0	41.8-57.0 52.9	0.01-0.03 0.02	212-275 255
Nakerala	SF	6	–	2.8-8.2 4.8	17.4-61.8 31.1	86-151 115	5.7-17.9 9.8	3.1-10.8 5.3	30.1-40.8 37.4	–	157-238 202
	US	10	–	2.7-5.0 3.8	2.9-37.2 9.7	107-184 135	1.4-13.1 5.5	4.3-12.0 7.3	25.8-46.2 34.5	–	147-290 193
Zemo Imereti Plateau	SF	10	7.64-8.35 7.86	0.3-3.8 2.3	0.8-68.0 30.1	134-226 181	3.0-23.0 8.3	4.3-12.2 9.4	33.2-59.2 49.8	0.01-0.07 0.02	194-368 281
	KS	78	6.82-8.30 7.53	0.2-14.8 4.0	0.5-460 40.3	112-397 259	3.2-58.0 11.3	2.4-82.0 18.4	18.0-196 63.0	0.01-0.22 0.03	160-1090 395
	US	78	6.62-8.26 7.72	0.5-56.6 10.6	1.2-1302 257	71-368 261	2.2-65.0 18.3	3.4-360 45.1	21.4-493 112	0.01-0.35 0.05	106-2290 704

In addition to the Zemo Imereti Plateau, the chemical composition of karst waters of other regions is given according to Prof. G. Supatashvili, Head of the TSU Laboratory of Analytical Chemistry.

Mineralization of underground karst waters of the study area is 1.5-3 times higher than similar indicators of neighboring districts. The reason for this is not only the complex lithological-stratigraphic structure of the region, but also the widespreading of open pit mines of manganese ore. Intensive washing of substances from loose rocks takes place in open quarry areas (especially during heavy rains). For this reason, on the left side of the Kvirila River, where the open quarries are relatively less present, karst waters are about twice less mineralized than on the right side ($\sum$ ¡ 422 and 712 mg.l^{-1}, respectively).

On the example of the groundwaters of the structural plateau of Zemo Imereti, there can be noticed a close connection between the rocks of which the region is built and the chemical composition of karst waters (Table 9).

Table 9. Dependence between the chemical composition of underground karst waters and the rocks that construct the region.

Rocks	pH	Mg. L $^{-1}$						
		Cl^-	SO_4^{2-}	HCO_3^-	Na^+	Mg^{2+}	Ca^{2+}	$\sum$¡
Pure limestones	8.03	0.4	1.1	183	3.3	5.0	51.4	244
Sandy and marly limestones	7.83	1.2	6.6	242	4.9	9.4	64.1	328
Dolomitic limestones, gipsum	7.62	8.9	165	261	15.6	34.0	91.0	575

The least mineralized are the waters that wash away pure limestones. Except Ca^{2+} and HCO_3 ions, these waters are less different by their chemical composition from the atmospheric precipitations in Georgia (Supatashvili, 1973). Waters that wash dolomites, magnesites, gypsum and other rocks are distinguished by their maximum values of the main ions ($\sum_i$).

The high mineralization of sulfate-magnesium waters is due to the good solubility of gypsum and magnesite compared to limestones (Table 10).

Table 10. Relationship between class, type and chemical composition of karst waters (SF-surface flow, KS-karst spring, UF-underground flow).

Water index	Sample	Total anount of samples, %	pH	Mg. L $^{-1}$						
				Cl^-	SO_4^{2-}	HCO_3^-	Na^+	Mg^{2+}	Ca^{2+}	$\sum_i$
C-Ca	SF	100	7.86	2.3	30.1	181	8.3	9.4	49.8	181
C-Ca	KS	91.9	7.54	3.6	15.5	255	8.7	15.6	59.1	341
C-Mg	KS	1.7	7.92	2.1	39.0	287	23.0	36.0	33.6	421
S-Ca	KS	3.2	7.35	10.6	460	325	50.5	38.4	187	1072
S-Mg	KS	3.2	7.40	10.6	305	249	39.2	71.6	67.0	742
C-Ca	UF	39.7	7.83	3.8	17.5	256	8.9	14.8	59.8	361
C-Mg	UF	38.4	7.74	2.3	7.4	252	8.8	27.4	35.3	333
S-Ca	UF	21.9	7.48	38.3	1126	287	52.1	128	347	1978

According to the available reference book, the solubility of $CaCO_3$, $MgCO_3$ and $CaSO_4$ is equal to $1.2 \cdot 10^{-8}$, $2.1 \cdot 10^{-5}$, $2.5 \cdot 10^{-5}$, respectively. Magnesium-type water should usually be more mineralized, but in this case the limited distribution of dolomite and magnesite does not make it possible. Mineralization in the samples of water we have studied is normally being increased in the following order: surface flow-karst spring-cave stream (Table 11, 12). However, there are also deviations. In particular, abnormally high mineralization ($\sum_i$ - 960 mg.l^{-1}) is characteristic of the River Nekrisa, which is fed by also high-mineralized karst springs and cave streams ($\sum_i$ 1052–2290 mg.l[-1], respectively). In this case such high rates of mineralization are also mainly due to the wide distribution of manganese open quarries in the feeding basins of underground karst waters. Often the inflow of influential waters is one of the main reasons for the reduction in the mineralization of cave streams (Table 11).

Table 11. Change of $\sum_i$ value in the cave stream.

Caves	Number of samples	Mg. L $^{-1}$			
		Entrance	Exit	Confluent	From stalactite
Khvedelidzeebisklde	7	371	385	-	401
Shvilobisa	7	347	302	312	275
Ormoebi	8	1800	1959	1892 (Lake)	-

As regime observations have shown, the studied waters can be arranged in the following order according to the stability of the chemical composition during the year: surface flow - cave stream - karst spring. Separate deviations of mineralization ($\sum_i$) values from the annual average for karst springs and cave flows are ± 6 and 12%, respectively. Spring and autumn are distinguished by the minimum concentration of the main ions, summer and winter - by the maximum. The mineralization values of karst groundwaters have close feedback to the amount of atmospheric precipitations fell before taking samples.

Compared to the surface waters of the other regions of Georgia (Karsanidze & Supatashvili, 1979), the content of manganese and boron in the karst waters studied by us has been increased (Table 12).

Table 12. Content of microelements (mkg.l^{-1}) and acidity (mg.l^{-1}) in the underground karst waters of the Zemo Imereti Structural Plateau.

Element of acidity	Karst springs		Underground streams		Surface waters of Georgia	
	Min. Max.	Average	Min. Max.	Average	Min. Max.	Average
B	0.06-0.50	0.22	0.02-0.09	0.29	0.01-0.07	0.04
Sr	0.75-1.00	0.86	0.90-1.12	1.03	-	-
Al	0.03-0.08	0.06	0.03-0.10	0.04	0.01-0.08	0.03
Mn	0.05-0.14	0.09	0.08-0.15	0.12	0.00-0.19	0.02
Fe	0.01-0.22	0.03	0.01-0.35	0.05	0.00-0.37	0.06
Acidity	0.1-1.1	0.9	0.1-2.5	0.6	0.5-7.0	-

This fact should be explained by wide distribution of manganese ore in the study area and direct relation of boron content and mineralization values in the natural waters (correlation coefficient + 0.84).

Based on the predetermination of permanganate acidity, it can be said that the content of organic substance in cave streams and especially in vaucluse springs is negligible. Only in one case was the presence of hydrogen sulfide observed in the cave stream (Tuzi Cave). This fact and a whole range of polluted water absorption centers, we have tracked during our field research, in addition to the direct links of the latter with karst springs (Lezhava, 2015, Lezhava et al. 2015. Lezhava et al. 2017a, b), does not exclude the danger of organic and bacteriological contamination of drinking waters.

II. 6. c. Peculiarities of underground karst streams' movement

In connection with complicated geoecological situation in the study area and solution of a number of problems of Chiatura water supply (turbidity and pollution of karst springs, used for drinking), it bacame necessary to determine karst underground streams' feeding basins, movement ways and discharge centers). For this purpose, we have performed experiments (8 in total) of groundwater tracing on the Zemo Imereti (Chiatura) Structural Plateau (in the region of the platform karst).

The water marking method was used for the experiments. For this purpose, we chose pure fluorescein or its sodium salt - uranine, which can be found in the stream even in the case of a very large dilution. We poured the dye solution into the pre-tracked surface streams (which undergo the influence in the zone of tectonic faults), as well as into karst sinkholes and cavities (sometimes to a depth of 100 m from the surface). Activated charcoal pouches were attached to the the water absorbing centers to fix the paint released into the expected discharge centers. Such carbon has the ability to adsorb or retain fluorescein. It even retains a small amount of fluorescein in the water and keeps it for a long time. Fluorescein can be extracted from activated charcoal at any time using 5% alcohol solution of KOH. We detected the presence of a marked substance by means of fluoroscope in the filtered solution, which is equipped with two flashlamps of ultraviolet light and a violet light filter. The use of activated charcoal pouches allowed us to systematically control all sources. In this case, there is no need for day-night shifts at the checkpoints. In addition, at some stations it was arranged to determine the flow velocity by periodically changing the carbon pouches.

The first experiment aimed at identification of underground connection between the territory of the Sachkhere cotton spinning plant and the Ghrudo karst spring involved in the Chiatura water supply system. Sachkhere cotton spinning factory is built on the first left terrace above Kvirila floodplain (relative height of 2-4 m), and on a strongly karstified foundation, which was not taken into consideration in time (Fig. 17).

Figure 17. Former Sachkhere cotton spinning factory, located on the first left terrace above Kvirila River floodplain.

According to the available information, water loss facts were reported at various points in the factory area (water cooling building, intermediating pool, westernmost district). At the same time, it was suggested that the polluted water of the factory was also mixed with the Chiatura water supply system (currently the factory is no longer functioning). The distance between the water loss centers on the territory of the factory and the Ghrudo vaucluse sprting is 5 km, and the difference between their heights reaches 30 m. Our expedition team poured 4.8 kg fluorescein solution into the water absorbing hole at the bottom of the water cooling building.

Coal pouches were attached to the Ghrudo and some other springs, where the dyed water was expected to come out. The result of the experiment is as follows: after 16 hours, the Ghrudo Spring was clearly dyed. The speed of the underground stream was 312 m/h. In the other springs (Parduli, spring near Lezhubani, Gaghma Gryphon) the dyed flow was not visually observed, although laboratory tests of activated charcoal confirmed a weak but reliable sign of fluorescein passage in them (Table 13). Tests at the Monasteri and Lezhubani springs yield no results.

Table 13. Results of indicatot tests in the Kvirila riverbed.

Name of the checkpoint	Absolute height, m	Distance between the waterloss center and outlets, km	Time of dye passing, hr	Average velocity of groundwater stream, m/hr km/one day
Ghrudo	370	5	16	312 7.5
A spring near Ghrudo	368	5.2	17	306 7.3
Farduli	375	4.8	15.5	310 7.4
Gaghma Gryphon	363	4.5	15	300 7.2

The mentioned experiment allowed us to draw the following conclusions: 1) The polluted waters of the cotton spinning plant are connected to the underground basin of Ghrudo. 2) The marked water crossed the Kvirila River bed several times from below.

Therefore, Kvirila in a certain area is a "hanging" river. This very interesting fact clearly indicated the existence of a hitherto unknown tectonic fault in the area, which makes possible their hydrogeological connection. The existence of this tectonic fault was later confirmed by electrometric studies (see Chapter Geophysical Research). 3) The area of the factory is located on a weakly armored with river alluvium karstified foundation and we can expect the loss of polluted water from any point. 4) Exploitation of the Ghrudo vaucluse requires emergency measures in such conditions. Currently, based on our recommendation, Ghrudo water is used only for technical purposes.

The next experiment of water marking (tracing) had a purpose of determining if there is an underground connection between the water loss centers of the Rganisghele riverbed and the so called Monasteri spring, involved in the Chiatura water supply system. It became known that in connection with the operation of the limestone quarry in the bed of the Rganisghele River (1.5 km above the Lezhubani organized springs), began a periodic, strong turbidity of the Monasteri Spring. Based on the field observations, in the riverbed of the Rganisghele, at the “Samkherkhao” (sawing shed) district, a water absorption hearth was detected. On the mentioned section the water in the Rganisghele riverbed had been lost before too, but the powerful blasts in the quarry further widened the existing network of absorption cracks. The ruined boulders flooded the river and contributed to its total absorption underground. Under the boulder mass the riverbed was left without water.

The direct distance between the water absorption hearth and the Monasteri spring is 3 km, and the difference in height is 185 m. A 3 kg solution of fluorescein was released into the water absorbing hearth. Earlier, checkpoints with activated charcoal pouches were set up at all suspicious springs, where fluorescein-dyed water was expected to come out. 4 hours after dyeing, the marked water was observed by checking the charcoal pouch in the Monasteri spring, and after 5 hours the Monasteri spring was clearly dyed, and bringing out of the dye continued for 30 hours. The release of the painted stream was not observed in other springs, but laboratory tests of activated charcoal gave us a positive sign of the passage of fluorescein at the springs of Ghrudo, Chikauri, and the Bogiristskali River stream. Of these, the marked water on the first two was observed with some delay (Table 14).

Table 14. Results of indicator tests in the Rganisghele riverbed.

Name of the checkpoint	Absolute height, m	Distance between water absorbtion centers and outlets, km	Time of dye passing, hr	Average velocity of groundwater stream, m/hr km/one day
Monasteri Spring	355	3	4	750 18
Riv. Bogiristskali	375	2.5	3	833 20
Ghrudo	370	6	9	667 16
A spring near Ghrudo	368	5.8	8	725 17.4
Chikauri Spring	363	3.5	72	48 1.2

Thus, for the first time it was experimentally proved that the waters absorbed in the Rganisghele riverbed following the tectonic fault line, run below the Bogiristskali riverbed and appears in the river water. The main underground flow is discharged into the Monasteri spring (the speed of the underground river is 750 m/h), and a part of it reaches the Ghrudo Spring also.

During a large-scale field-geomorphological surveying, many underground and surface karst forms, as well as intense water absorption center were revealed. One of such centers is the so called Pirana Abyss (on Rgani Plateau, in Khvedelidze district), which was used by the locals as a garbage dump.

Garbage dumping in karst cavities is always very dangerous, especially since karst waters are widely used for water supply for the nearest settlements. In the nearly vertical 100 m deep abyss of Pirana, a powerful underground stream passes, a debit of which was 25 l/s and temperature 11^{0}C. Garbage dumped into the entrance sinkhole of the abyss during the rains and melting of snow was brought into the depths and contaminated the aforementioned karst stream.

In order to identify an underground connection between the flowing stream in the Pirana Abyss and karst springs in the study area, we put 2.8 kg of fluorescein (the third experiment) into the flowing stream in the abyss. Observations on karst springs have been ongoing for 15 consecutive days. A weak sign of fluorescein passage was observed on the 10th day in a charcoal pouch put into the Tiri spring (see. Fig. 19, Table 15).

Table 15. Results of indicator tests on the Rgani Plateau.

Name of the checkpoint	Absolute height, m	Distance between water absorbtion centers and outlets, km	Time of dye passing, hr	Average velocity of groundwater stream, m/hr km/one day
Monasteri	355	5.7	18	316 7.5
Tiri	420	5.5	240	23 0.5
Tskhrili	610	1.5	192	8 0.2

No outflow of dyed stream was observed at other checkpoints (although a suspicious sign of water coloring was observed at the Monasteri and Ghrudo springs). The direct distance between the Pirana Abyss and the Tiri spring is 5.5 km, and the difference in height (the absolute height of the flow in the Pirana Abyss at the site of dyeing is 649 m, and the absolute height of the Tiri Spring is 420 m) is 220 m. The speed of the underground river turned out to be 20 m/h (552 m/day). This in itself is a low speed, which suggests that there must be significant karst cavities in the bosom of the Rgani Plateau.

The above (third) indicator test, it can be said, was not fully successful. We no longer found the pouches attached to Katskhura's two springs on the spot: in addition, we learned about the existence of some springs (Chorta I and II, Sasaklao, and Grigola) in the mentioned zone later, and therefore, they were left beyond the study. Finally, 2.8 kg of fluorescein did not appear to be sufficient, and because of large dilutions was not observed in the springs. Because of all this, we considered to repeat the experiment using a higher dose of fluorescein (the fourth experiment). This time, 5.2 kg of fluorescein was released (almost twice as much as during the previous test). Also, it is noteworthy that during the previous experiment, the debit of karst springs was almost everywhere higher (Tiri - 200 l/sec., Monasteri - 160 l/sec., Ghrudo 220 l/sec., Tskhrili - 15 l/sec.), rather than during the repeated test (Tiri - 80 l/s, Monasteri - 130 l/s, Ghrudo 160 l/s, Tskhrili - 35 l/s). The only exception was the Tskhrili Spring.

20 hours after releasing the dye, the marked water at the Monasteri Spring was observed by checking the charcoal pouch, and after 24 hours it was clearly dyed. Coming out of painted streams at other checkpoints was not visually observed.

Laboratory testing of activated charcoal confirmed a weak sign of fluorescein passage only at the Tskhrili Spring.

Thus, during the repeated experiment, the paint dropped into the abyss of Pirana appeared in the Monasteri Spring. The direct distance between them is 5.7 km, and the difference in height (the absolute height of the flow in the abyss at the place of painting is 640 m, and the Monasteri Spring - 355 m) - 285 m. The speed of the underground river is 235 m/h (6840 m/day). As for the Tskhrili gryphon, its absolute height is 610 m, and the direct distance from the water absorption hearth to the mentioned spring is 1.5 km. The underground stream took more than 7 days and nights to cover this distance. Therefore, the velocity of the underground flow is 8 m/h (192 m/day), which is very low. This fact points at the presence of still unknown extensive water basin under the riverbed, with difficult water exchange. In this regard, we consider it advisable to continue the advanced karst-hydrogeological research on the Chiatura Structural Plateau using a wide range of geophysical and indicator experiments.

Based on the indicator experiments conducted on the Rgani Plateau (in the Pirana Abyss), the following conclusions can be drawn:

1) For the first time, the connection of the flow in the Pirana Abyss with the Monasteri Spring was experimentally confirmed. At the same time, a discontinuity was identified, controling flow movement, which was hitherto unknown in the literature.

2) The first experiment, conducted on the Rgani Plateau, confirmed the connection of the flow in Pirana Abyss with Tiri springs. During the repeated experiment, passage of fluorescein was observed only in the Monasteri and Tskhrili springs. This should be caused by the following: in the bosom of the Rgani Plateau, it seems, the isolated systems of karst streams are present, which are

connected to each other by tunnels, or narrow cracks. These fissure systems are located at different heights, and the water exchange between them must take place at high levels of karst waters.

Indicator experiments were conducted on the left side of the Kvirila River as well. For this purpose, many karst sinkholes have been studied on the Sveri Plateau, some of which are used by the local population to dump garbage. Most of them are ended with a ponore or pass into a well, in some of them a temporary lake is formed. The latter is often swamped and highly polluted. In our opinion, the waters in these sinkholes are connected with the Kldekari and some other karst springs, involved in the water supply of Chiatura and its environs, from which the latter should periodically become turbid.

For this purpose, the fifth indicator test was conducted on Sveri Plateau, in one of the karst sinkholes, which is located in the environs of the village of Sveri.

In the environs of Sveri Village, 3.8 kg fluorescein solution was released by us in the motorway area, near the karst lake. During the test, as long as there was no constant flow in the sinkhole (a narrow well is developed at the bottom), a fire truck was used to pump water from the lake to the dry sinkhole continuously for 1.5 hours (≈ 70 tons of water was discharged into the dry sinkhole).

60 hours after dyeing, the marked water at the Kldekari spring was observed by checking the charcoal pouches, and after 62 hours the Kldekari spring was visibly colored, and it took almost 48 hours for the paint to be brought out. The direct distance between the water absorption hearth and the Kldekari spring is 1.8 km, the difference in height (karst sinkhole- 660 m, Kldekari Spring - 560 m) is 100 m.

The appearance of the painted stream on other springs was not visible, but the laboratory inspection of activated charcoal gave us a weak, but reliable sign of the passage of fluorescein in the Tsereteli Spring, in the water of the Rekevisa River and the small debit springs on the left bank of the Sadzaliskhevi River. The marked water first of all was observed in the springs on the left bank of the Sadzaliskhevi River.

Thus, for the first time, it was experimentally identified that the polluted waters absorbed in the karst springs on the territory of the village of Sveri are directly connected to the Kldekari spring, where the main flow is discharged (underground river speed is 30 m/h), and part of it is connected to the spring of Tsereteli and those coming out on the left slope of the Sadzaliskhevi River and in the Rekevisa River bed (or directly to the river water). At the same time, the low velocities of the groundwater flow indicate the presence of significant cavities in the bosom of the Sveri Plateau (Table 16, see fig. 19).

Table 16. Results of indicator tests on the Sveri Plateau.

Name of the checkpoint	Absolute height, m	Distance between water absorbtion centers and outlets, km	Time of dye passing, hr	Average velocity of groundwater stream, m/hr / km/one day
Kldekari	560	1.8	60	30 / 0.7
Tsereteli	570	2.2	62	35.5 / 0.85
Spring on the left bank of the Sadzalekhevi River	580	1	24	41.6 / 1.0
Rekevisa River	550	3	64	47 / 1.1

In order to identify the ways of movement and discharge points of underground karst waters in the bosoms of the plateaus on the left side of the Kvirila River, another (sixth) indicator test was performed by our expeditionary team in the stream flowing into the karst cave (and disappearing in the depths of the cave) between the villages of Sveri and Mandaeti. In literature this cave is known as Kotiasklde. A 2.5 kg solution of fluorescein was released into the flow in the cave by us, and before that, at all of the suspicious springs, where the coming out of the water colored with fluorescein was expected, were fastened the pouches with activated charcoal to hold the paint.

Observation on karst springs took place periodically for two weeks. The passage of fluorescein was visually observed at the Kvabisi spring on the 6th day. The distance between the water loss center and the Kvabisi spring is 1.5 km, the difference between the heights (Kotiasklde Cave - 710 m. Kvabisistskaro - 640 m) - 70 m. The appearance of the painted stream on other springs was not visually observed, but laboratory testing of activated charcoal gave us a positive sign of the passage of fluorescein - in the springs of Ghrudo, Bondi, Kldekari, Tsereteli, and the Rekevisa River stream.

Thus, the results of the experiment allow us to conclude that the flow in the Kotiasklde Cave is directly related to the Kvabisi Spring, where its main part is discharged.

However, the fact that the velocity of this flow is very low (11.5 m/h) indicates the presence of significant volumes of karst cavities in the area.

It is also noteworthy that the part of the groundwater flow in the Kotiasklde Cave is found in other springs (Bondi, Tsereteli and Kldekari), and a part of it must reach Ghrudo and take part in feeding of the Ghrudo underground basin (Table 17).

Table 17. Results of indicator tests on the Sveri Plateau.

Name of the checkpoint	Absolute height, m	Distance between water absorbtion centers and outlets, km	Time of dye passing, hr	Average velocity of groundwater stream, m/hr / km/one day
Kvabisi	660	1,5	130	11.5 / 0.27
Ghrudo	370	11,5	240	48 / 1.1
Kldekari	560	4,5	172	23.3 / 0.55
Tsereteli	570	4,5	176	25.5 / 0.6

In order to strengthen this opinion, we consider it necessary to conduct a number of indicator experiments on the plateaus on the left side of the Kvirila River, and at the same time we will definitely consider repeating the experiment in the future in the Kotiasklde Cave using a higher dose of the indicator.

The 7th and 8th experiments were conducted in the streams flowing in the caves developed in the vicinities of the villages of Sveri (Data Cave) and Mandaeti (Zakariasklde Cave), the painted water of which was visually observed, respectively, in the first case - in the karst springs coming out in the Sadzalekhevi riverbed and in the second case – in the karst spring and in the lake, coming out on the slope of the karst sinkhole, located in the surroundings of the Mandaeti Village (fig. 18).

Figure 18. The result of the 7th and 8th experiments.

Thus, the results of our indicator experiments on the Chiatura Structural Plateau give us the basis for the following conclusions:

1) The directions of movement of underground karst streams within the structural plateau are mainly determined by the common submerge of karstifying rocks from the periphery to the center. At the same time, no less important is the role of fault dislocations, which often control the absorption of groundwater flows and their movement routs.

2) As a result of indicator experiments, the feeding basins of the Ghrudo and other springs have been significantly clarified. As it is confirmed, these springs are fed from the plateaus between the rivers of Katskhura and Sachkhere (Sareki, Darkveti - Zodi, Mghvimevi, Bunikauri, Tabagrebi, Zeda Rgani, and Rgani). Within these limits, a unified karst-hydrogeological system (with sufficient resources of dynamic water) seems to be formed, which is mainly being discharged in the springs with outlets in the Ghrudo Spring and its adjacent strip (Fig. 19). This fact is of great practical importance - it is possible contaminated waters to get into the Chiatura water supply system from any of the karstified places of the area within the mentioned limits.

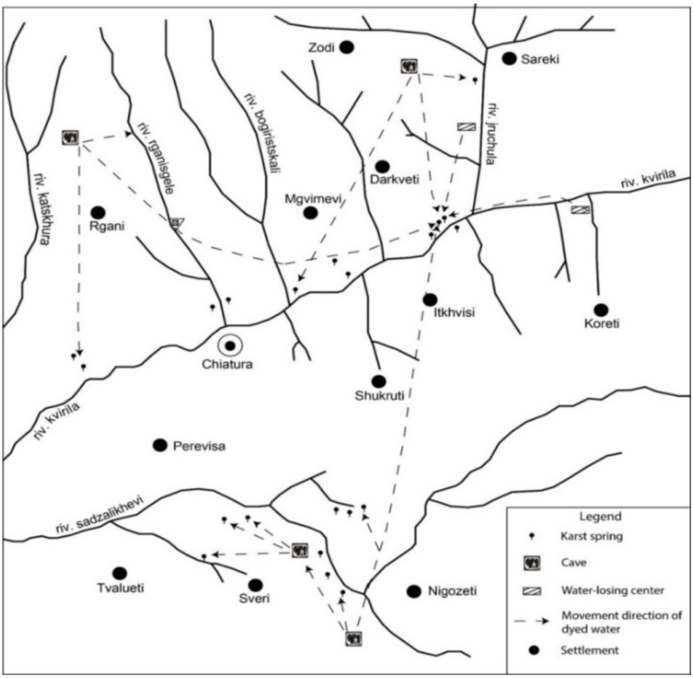

Figure 19. The scheme of underground streams' movement, obtained as a result of indicator experiments conducted on the Chiatura Structural Plateau.

3) In feeding of the mentioned system, as proved by the indicator experiments, the underground streams also participate, formed within the bosoms of the plateaus located on the left side of the Kvirila River (Itkhvisi, Shukruti, Perevisa, Sveri, etc.), as well as the waters, leaked from the riverbeds of the rivers of Kvirila, Jruchula, Rganisghele, etc.

4) Along with the common karst-hydrological system of Ghrudo, the Chiatura Structural Plateau is characterized by isolated fissure-karst water systems with very different hypsometric location and orientation.

5) Indicator experiments have undoubtedly confirmed that there are still unknown tectonic faults in the riverbeds of Kvirila and Rganisghele, as well as on the Rgani Plateau.

6) Indicator experiments in the bosom of the Rgani Plateau and underneath the Kvirila riverbed revealed that there is a hitherto unknown extensive water basin with difficult water exchange. It is possible that we are dealing with a promising area for drinking water. In this regard, we consider it advisable to conduct an advanced karst-hydrogeological survey of the Chiatura Structural Plateau using a wide range of geophysical and indicator experiments.

II. 6. d. Conditions of layout of underground karst waters

After discussing the results of the indicator tests, we consider it necessary to return to the problem of layout of underground waters on the of Zemo Imereti (Chiatura) Structural Plateau. The correct understanding of the layout conditions of karst waters, along with their great theoretical significance (which allows us to explain and guess many features of water content and karstification of karst massifs), also helps us to solve practical problems.

At the end of the XIX century and beginning of the XX century A. Grund (1903) and F. Katzen (1909) formulated the hypotheses of the uniform level of underground waters and isolated flows accordingly. Subsequently, these hypotheses developed as alternatives in both hydrogeology and speleology. Attempts were made to explain the above-mentioned conflicting theories by structural-geological conditions of the region (uniform level of underground waters is related to platform conditions and isolated flows are related to geosynclinal conditions - Gigineishvili, Tabidze, 1975; Tintilozov, 1976), different thickness of karstified rocks (the uniform level is related to “thin” karst and the isolated streams with "deep" one - Gese, 1965), with different stages of karst development (the uniform level is associated with "mature" and "old", and isolated flows – with "young" stages - Kruber, 1915).

Based on performed fundamental researches (Tintilozov, 1976; Gigineishvili, 1979; Kiknadze 1979), it has been identified that the Georgian orogenic karst district (Arabica, Bzipi, etc.) is mainly characterized by isolated (separated) fissure-karst flows, though the same researchers do not exclude the simultaneous existence of local districts of isolated streams and water accumulation sites within the same massif.

The results of speleogical researches, we have performed on the Chiatura Structural Plateau (platform karst) and individual indicator experiments, carried out in one hydrogeological season, evidence that there exist isolated flows. The indicator tests, carried out in the second hydrogeological season give different result, in particular, a wide spread of the dye and its simultaneous appearance in different springs flowing out at the bottom of the edge cliff of the plateau that corresponds with the hypothesis of the uniform level of karst waters.

To accumulation of water and formation of a single aquifer horizon within the Chiatura Structural Plateau greatly contributes its platform character, i. e. slightly sloping or horizontal bedding of weakly dislocated thin karstified rocks, as well as the structural peculiarity of the water retaining horizon and the conditions of water discharge from the underground basin. It is noteworthy that the Kvirila River and its tributaries above Chiatura do not cross the limestone cover to its base - the Likhi peneplain. Therefore, all the morphologically distinguished plateaus on the both sides of the Kvirila River have a common limestone foundation (socle), which, together with its structural fpeculiarities and all the above mentioned conditions, creates favorable conditions for the formation of a uniform level of underground karst waters. The tendency of emergence of a uniform level (integral system) of karst waters is also observed at early stages of karst development, which is indicated by the location of the entrances and springs of multi-tiered horizontal caves at almost one hypsometric level.

Therefore, along with isolated (insulated) underground basins and hydrodynamic systems, which are typical for the orogenic karst districts of western Georgia, in the eastern peripheral part of it, in particular, in the conditions of the platform karst, developed in the limits of the crystalline massif of Dzirula, the existence of uniform level of underground waters is confirmed. Thus, based on the researches, it may be noted that the nature of circulation of underground water is determined by the structural peculiarities of karst regions, although the age of karst may make a significant adjustment to this regularity.

At the initial stage of karstification, isolated underground communications (systems) are formed under different structural conditions, which over time tend to reach a uniform level. The uniform level of underground waters in the platform karst is established much earlier than in the orogenic one. In the latter, the mentioned hydrodynamic situation can occur only at the last stage of the evolution of the underground basins in the presence of favorable conditions. It should be noted that the orogenic karst of western Georgia has not yet reached this stage.

II. 6. e. Hydrodynamic zones of fissure-karst waters

Infiltration and the area infiltration of surface waters take place by certain steps or zones in the depth of karst massifs, the number and character of which depend on the thickness and layout of karst rocks, geotechnical and geomorphological conditions of the massif, the degree of relief fragmentation, the movement of the earth's crust, location of the area toward the erosion basis, etc. (Maksimovich, 1963, 1969; Dublyanski, Kiknadze, 1984).

Based on the schemes of hydrodynamic zones presented by D. Sokolov (1962), G. Maksimovich (1963), Z. Tintilozov (1976), V. Dublyanski (1977), T. Kiknadze (1979) and other researchers and based on the material obtained in consequence of our many years' researches, within the Chiatura Structural Plateau we have distinguished the hydrodynamic zones of: aeration or vertical circulation, seasonal fluctuations of levels, complete saturation and depth circulation. Within the aeration zone, in its turn, the subzones of surface circulation, hanging water circulation, descending vertical and subhorizontal circulation are distinguished (Fig. 20).

In the aeration zone (I), there is a downward movement of karst waters, which are fed by infiltrative and influential meteoric and surface waters. Absorption of surface waters is mainly associated with tectonically weakened areas, as well as karst forms (sinkholes, ponors, and caves). The karst processes in this zone entirely depend on the said precipitations and therefore their intense course coincides with the periods of abundant atmospheric precipitations and snowmelt. Therefore, the intensity of karst processes in the aeration zone is characterized by seasonal rhythmicity, which is also reflected on the springs related to this zone. The lower boundary of this zone conventionally corresponds to the surface that underground waters reach during the period of maximum elevation of the levels. In the aeration zone wells, shafts and abysses are formed. The 100-meter-deep Pirana Abyss is completely developed in the aeration zone. The thickness of the aeration zone within the study area is mainly 150-200 meters.

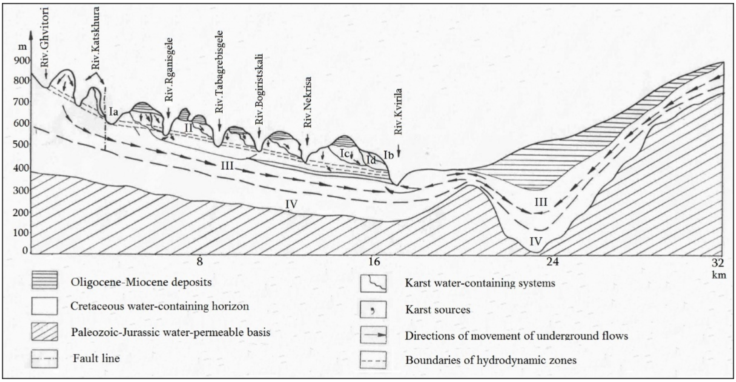

Figure 20. Scheme of karst-hydrogeological basins and hydrodynamic zones of karst waters on the Chiatura Structural Plateau. Hydrodynamic zones: I-aeration, II-levels' seasonal fluctuation, III-complete saturation, IV-deep circulation;
Subzones of: I^a-surface circulation, I^b-hanging waters' circulation, I^c-descending vertical circulation's, I^d-subhorizontal circulation.

The surface circulation subzone (I^a), allocated by us in the aeration zone, is supplied directly by the atmospheric waters. In this subzone, part of the atmospheric precipitations evaporates, and part of it generates surface flows, especially on the substrate built of Tertiary sediments. In the areas, where the latter is washed away and the Upper Cretaceous limestone layers are exposed on the surface, the water obtained from atmospheric precipitations, except of evaporative loss, completely leaks into the cracks developed in the limestone layers of this age and disappears into the depth through underground channels.

In the subzone of the surface circulation, on the limestone surface, these waters form surface karst forms - corries, sinkholes, and karst wells transforming into depth forms, which are so widely represented here (Figure 25). In the aeration zone, there is a sharply distinguished subzone of circulation of the hanging waters (I^b), which conditions the outflow of low-debit springs on the plateaus of the study area and the slopes of the canyons. At the same time, there are both permanently and periodically active hanging springs. The latter are especially abundant during prolonged rains or spring snowmelt. Hanging springs are mainly associated with the outlets of relatively hardly soluble rocks.

The subzone of the descending vertical circulation of underground waters (I^c) is distinguished by wide distribution in the aeration zone. We consider Z. Tintilozov's (1976) and T. Kiknadze's (1979) views about the existence of sub-horizontal movement areas of underground water flows (especially in the case of the platform karst) within the aeration zone (especially on its lower floor) to be quite correct. On the lower floor of the aeration zone within the Chiatura Plateau the existence of a sub-horizontal circulation subzone (I^d) of underground waters is also confirmed (Figure 25), which sometimes causes a significant reduction in their velocities. For example, caves of Namdzvleviklde, Shvilobisa and others are developed entirely in the aeration zone and are represented by profiles of vertical and subhorizontal circulations. The aeration zone covers most of the relict caves of the region, from which currently waters are no longer discharged. Notable among them are: Rganiklde, Tsilto III, Gvarjilasklde, Nakhiznebi, Sachinkia, Nigozeti, Bnelaklde and others.

Within the Zemo Imereti Structural Plateau, on the border between the aeration zone and the full saturation zone, there is a seasonal level fluctuation zone (II), which is characterized by seasonal variability of the levels of karst waters. As D. Sokolov (1962) notes, this zone has a transitional character depending on the bordering hydrodynamic zones and the levels of underground waters (and the latter depends on climatic conditions), sometimes joining the aeration zone and sometimes – the full saturation zone. Therefore, as stated above, the hydrodynamic zones of underground waters are closely related to each other. For example, the waters of the aeration zone from the seasonal fluctuation basin can enter the full saturation zone and participate even in feeding of the deep circulating zone flows (Fig. 21).

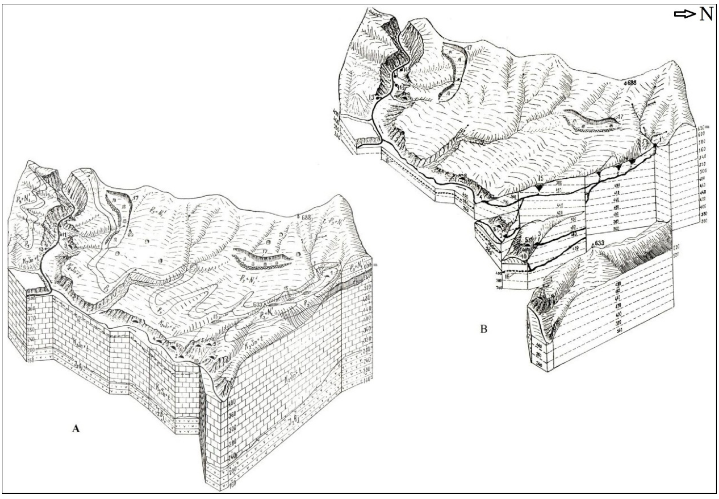

Figure 21. A) Geological conditions of development of karst phenomena; B) Hydrogeological situation in the Darkveti-Zodi Plateau (block-diagrams).

In the study area, high activity of karst, and a full range of karstification in general, as well as some periodically or permanently active karst springs are associated with the zone of seasonal fluctuation of levels. The increase or decrease of the debit of these springs lasts for several weeks, depending on the duration of the wet and dry periods. The thickness of seasonal fluctuations in levels within the structural plateau should be measured in 2-3 tens of meters that is indicated by a significant seasonal fluctuation in levels at almost all major karst springs (Ghrudo, Monasteri, Lezhubani, Tiri, etc.) (Table 8). In addition, during the flooding period, as recorded by field researches, the headwaters of some springs temporarily go up several tens of meters. This fact indicates that at the boundary of the aeration and complete saturation zones, cavities of significant volume are developed, where water levels, with respect to the abundance of atmospheric precipitations, markedly vary. The main reason for the rise of groundwater levels in karst cavities is not only the poor permeability of the cracks, but also the colmatation of waterconducting ways.

Full saturation zone (III) is spread at the level of the Kvirila River bed or a little lower in the study area. In this zone the karst waters move in a horizontal direction. Its lower boundary is mainly determined by the location of the local erosion base or the presence of water retaining sublayers. In this zone horizontal caves develop. With it are also connected permanently active and abundant debit springs (Ghrudo, Monasteri, gryphon beyond Kvirila, etc.), at the expense of which Chiatura and its surroundings are mainly supplied with water. The waters formed in the full saturation zone discharge as vaucluse springs at the level of the main river, or even go below this level and appear in daylight as pressure springs, which is also confirmed by the results of indicator experiments (Lezhava, Gigineishvili, Tintilozov, 1989). The outlets of the above-mentioned pressure waters are mainly connected with the locked karst systems and the distribution areas of the Barremian limestones. These latters are good collectors of underground waters.

The outlets of the pressure waters were discovered by us on the banks of the rivers of Katskhura, Rganisghele and Jruchula gorges, where the existence of extensive basins of underground waters with difficult water exchange is expected. These basins are, in our opinion, promising areas for getting of drinking water. The formation of streams in the complete saturation zone is facilitated by significant altitudinal difference between the atmospheric water absorption and discharge areas (up to 600–700 m), which conditions hydrostatic pressure in the cracks; in addition, the general sinking of karst rocks from the peripheries of the structural plateau to its center. The latter mainly determines the directions of movement of underground karst waters within the structural plateau.

The spread of limestones below the local erosion base (Kvirila River) at important depth (160–200 m) and the unified limestone basis within the Chiatura Structural Plateau indicate that there should be a deep circulation zone too. This is also confirmed by the results of performed drilling works. For example, according to the fund works of G. Kuchukhidze (1986) and other authors in Sachkhere wells (absolute height of bore-hole/shaft - 450 m), at the depth of 362 to 382 m from the surface (70 m absolute height) in Upper Cretaceous limestones, it was identified that there is an aquiferous stratum of 20 m thickness, where water stream discharge was equal to 3.1 l/sec. In the

Merjevi well, at a depth of 385-415 m interval (at 113 m absolute altitude), it was identified to be a 30 m thickness aquiferous stratum with discharge of 65 l/sec. Unpublished data of G. Mamulia and T. Gambashidze are also interesting. During the drilling activities, conducted by the mentioned authors at significant depths of Jruchula and Kvirila riverbeds, aquiferous horizons were found. Pumping of waters from these horizons had no effect on the regime of Ghrudo and other important vaucluse springs, and the debit remained unchanged. Thus, the regime observations have identified not only the presence of depth circulation but also the fact that Ghrudo and the vaucluse springs associated with the complete saturation zone, have no direct hydraulic connection with the depth circulation zone.

II. 7. The role of soil-vegetation cover in karst formation

In the study area, according to M. Sabashvili's (1965) Georgian soil zoning scheme, three types of soils of hilly foothills and mountain-forest zones are distinguished: humus-carbonate skeletal soils, medium and low-thickness forest ash-grey soils, and light and podsoled forest ash-grey soils.

Humous-carbonate soils are widely represented up to 900-1000 m height. Their distribution corresponds to the distribution areas of limestones, carbonate sandstones, and marls. Depending on the chemical composition of the limestones, as well as on the geomorphological, climatic and other conditions, humous-carbonate soils have very diverse character. Among them, in the study area dominate small thicknesses (40-50 cm) and usually strongly skeletal, as well as leached varieties, occupying the north-western part of the area and the Chkherimela River gorge. On the clays and sandstones there are found forest ash grey soils (average thickness 50-60 m). The ash grey soils of the forest have a predominant distribution in the mountain-forest zone. From here, forest ash grey soils of medium and small thickness are mainly characteristic of the lower part of the mountain-forest soils zone and are found in the territory of the Zemo Imereti Plateau up to 1000-1500 m altitude. In the same zone, humus-carbonate soils are associated with limestone distribution areas.

The relief and climate conditions in the foothill and partially in the lower mountain belt are quite favorable for economic activity, that is why the natural vegetation almost nowhere is preserved intact and is presented by the secondary oak grove - oriental hornbeam vegetation (oriental hornbeam is particularly characteristic of the strip of limestone distrbution), often with secondary meadows or cultural vegetation.

E. Sokhadze (1958) indicates the degradation of forests in the study area. According to the mentioned researcher, in the karst relief zone between the villages of Mandaeti and Sveri (600-700 m above sea level), the forest developed on the humous-carbonate soils is very much destroyed by cutting down. In the surviving forest groves, the trees and plants are represented only by oak. The shrubbery tier is relatively rich, where the predominant species are azalea, oriental hornbeam, dog-rose and others. Sometimes the shrubbery tier is also completely destroyed and the grassland forms a dense cover (95% of the entire cover). A similar picture is presented on the southern slope of the Modinakhe hillock, built of limestones, on Sareki, Darkveti, and other plateaus. The limestone canyons of the rivers of Kvirila, Sadzalekhevi and their tributaries are distinguished by some peculiarities. Here are presented complex combination of different elements, such as forest, steppe mountain xerophytic, etc.

As it is known, the effect of soil-vegitation cover on karst formation is dual: on the one hand, enriching the natural waters with carbonic acid and organic acids, significantly increases their aggressiveness and corrosion ability and, consequently, the intensity of karst formation processes. On the other hand, the soil-vegetation cover prevents the above process as it weakens the clay aluvion erosion, washing of the clay-corked ponors, does not allow the formation of strong water streams and prevents the development of surface karst forms.

During the last 5-6 decades, as a result of destructive exploitation of manganese deposits, sand quarries and of nature in general, on a significant area (2640 hectares) of the Zemo Imereti

Structural Plateau, soil cover, forest massifs and pastures have been destroyed. Meadowland has been destroyed, and even the mother rock is often disturbed and dislocated. Due to all this, activation of karst processes in the limestone distribution zone has increased, which is manifested by intensive infiltration of aggressive surface waters into newly opened cracks. Soil-vegetation destruction, soil and mother rock disorder have contributed not only to the activation of karst processes, but also to the turbidity-contamination of karst waters used for drinking (Lezhava, 2015; Lezhava et al., 2017a, b).

II. 8. Technogenic factor and karst formation

In Georgia, human influence on the course and intensity of karst processes, and on the anthropogenization of terrain in general, is nowhere as pronounced as on the Chiatura structural plateau. Here, the coefficient of technogenic impact on nature in the manganese ore region has long exceeded the admissible norms. The coyoting of manganese dramatically enlarged the karst areas involved in the economic activity and, consequently, the karst-related negative phenomena: deformations of the terrain in the manganese distribution area became systematic, and exodynamic processes became unusually active. Turbidity and pollution of capping springs, used for drinking has reached dangerous levels.

Among the technogenic factors of karst formation the most important for the study area are: 1) alteration of natural terrain, rock structure and properties, associated with Chiatura manganese mine exploitation by tunneling and quarrying, as well as agricultural and construction works; 2) an overall increase in water aggressiveness, caused by the contamination of air, natural waters and soil cover with aggressive components of technogenic origin.

Upper Cretaceous limestones over a significant area of the Chiatura Structural Plateau are covered by Oligocene-Miocene sandy-clayey layers (maximum thickness - 260 m in Merjevi-Modzvi surroundings), causing cumbering of the water circulation at depth and hence, supposedly, slowing down of speed of karstification. In those areas, where the sheeting cover is crushed, karst processes are intensified. By destruction and disintegration particularly are affected those areas, where the works for the manganese mining are conducted.

The exploitation of manganese ore in Chiatura has a history of more than 130 years. The total length of artificial tunnels in the area of 150 km^2 has reached 400 km today. Frequent and powerful explosions in the mines significantly contribute to the widening or formation of fissures in the limestone and the activation of karst processes. In addition, due to the rotting of bracing beams in abandoned mines, there are frequent arch collapses, which lead to the cracking and destruction of the massif formed by the Oligocene-Miocene suites, severe deformation of terrain, development of landslides and erosion processes, as well as drying up of water bearing horizons (especially Chokrakian) and drastic change in the hydrodynamic situation of region in general. By means of the vertical fissures, developed in cosequence of break down, the Karaganian-Konkian, Chokrakian and Oligocene-Lower Miocene aquifers, separated by waterproof layers, became hydrodynamically connected to each other and all of the above mentioned horizons in their turn became hydrodynamically related to the Upper Cretaceous limestones, located under them (this is due to the fact that there is not a single common clearly expressed waterproof layer in the region).

Due to all the above mentioned, in such areas, atmospheric precipitations directly influence the limestones and the karst processes are activated. This process is particularly intense on the Perevisa and Rgani plateaus, where the manganese suites lie directly on the uneven surface of the Upper Cretaceous limestones. The development of collapsed cracks has also led to massive drying of wells, made by the population in the Oligocene-Miocene sediments and also that of springs.

The thickness of the disturbance zone caused by the collapse of the abandoned tunnels of the mines is measured in tens of meters. Particularly pronounced and at the same time widespread collapsed forms can be found in the central part of the Zeda Rgani Plateau, in the western part of the Mghvimevi Plateau, in the upper reaches of the basins of the rivers of Korokhnali and Samarkali. A dense network of collapsed cracks is also developed on the plateaus of Rgani, Mghvimevi, Itkhvisi and Perevisa. Here the horizontal amplitude of the cracks varies from 0.5 to 1.5 2 m, and the visible depth reaches 2-3 m.

Open pit mining on the Chiatura Structural Plateau began from 1950, destroying not only land cover, forest massifs and pastures on a significant area (2,640 hectares), but also modified the relief. In the context of coyoting demolition and relocation of approximately 5 million m^3 rocks (Gongadze, 1982; Davitaia, 1988) is needed annually. The area occupied by waste rocks is currently 10% of the study area (the volume of waste rock embankment in the Nikrisa River valley is 3.5 million m^3).

Open-pit mining of manganese is facilitated by the horizontal and shallow layout of quite thick ore-bearing layers (at the depth of 10-45 m from a surface). The open excavation works to extract manganese in this way results in removal of layers, located on limestones and activation of karst processes, which is manifested by the intense infiltration of aggressive surface waters into newly opened cracks. Extensive and powerful explosions produced here significantly contribute to the expansion of old cracks or emergence of new ones. In the south-western and eastern parts of the Darkveti Plateau, as a result of open processing of manganese, the Oligocene-Lower Miocene deposits above the limestones have been almost completely removed. Numerous sinkhole-like forms have formed in the ruined waste rocks, from the bottom of which water leaks into the limestones. A similar picture is presented on the plateaus of Mghvimevi, Itkhvisi (Fig. 22), Perevisa, Rgani and others. On Perevisa and Rgani plateaus, manganese deposits are often located directly on the Upper Cretaceous fissured limestones (Fig. 23, 24), making the water absorption process more intense. In addition, in open-pit areas, heavy rains cause intense leaching of substances and leaking of polluted water through the kracks directly into karst springs, often followed by turbidity of Chiatura drinking waters.

Figure 22. Processing of manganese ore in the open quarry on the Rgani Plateau.

Figure 23. Industrial badlands.

Figure 24. The open quarry.

On the basis of the experiment such connections were identified between the sinkholes and Ghrudo Spring formed on the top of manganese mining wastes horizons on the Darkveti Plateau, as well as between the Lezhubani Spring and the mining wastes exposed as a result of the open excavation works in the south-eastern part of the Rgani Plateau (Lezhava et al.,1989, 1990; Lezhava, 2015).

Mineralization of the underground karst waters of the study area as is shown by the laboratory study of the samples, is 1.5-3 times higher than the similar indicators of the neighboring karst areas. The reason for this is mainly the wide distribution of open pit mines of manganese ore in the feeding basins of underground karst waters. In the open quarry areas, as mentioned above, there is an intense washing of substances from the loosened rocks during the heavy rains. For this reason, on the left side of the Kvirila River, where the open quarries are relatively less presented, karst waters are about twice less mineralized than on the right side ($\sum_i$ 422 and 712, respectively). At the same time, mineralization is particularly high in those vaucluse springs and underground streams in the watercollection basins of which the manganese open quarry processing is currently intensively carried out.

Destruction of natural vegetation cover in the surface basins and surrounding areas, where the springs are fed, the destruction of meadowland, over plowing of surfaces, have significantly enhanced soil washing and increased the amount of solid runoff in streams. In addition, industrial and housing construction is widespread in the region. Roads were laid in the valleys of the Kvirila River tributaries. Upper Cretaceous limestones are intensively used as a good building material. All of the above mentioned works are accompanied by explosions of various strengths, which contribute to the opening-expansion of old cracks or emergence of new ones and the activation of karst phenomena.

Pollution of the atmosphere, natural waters and soil cover with aggressive components of anthropogenic origin have essential and permanently increasing effects on the activation of karst processes.

Frequent explosions in quarries in the study area have contributed not only to the deformation of the terrain and formation of cracks, but also to air pollution. For example, according to T. Kutsia (1989), 4 tons of dust and manganese are released into the air every day as a result of explosions in quarries. In the polluted water mass of 180,000 m^3, poured from the manganese washing factories into the Kvirila River, there are 5,000 tons of contaminated drifting particles each year. The actual concentration of drifting particles and petroleum products in purified water (which is 3995 mg/l and 24 mg/l, respectively) is many times higher than the maximum allowable (6.0 mg/l and 0.3 mg/l respectively) norms (Davitaia, 1988). The soil and ground are often polluted with industrial and agricultural/economical wastes. For example, the wastes of an animal slaughterhouse in the Jruchula River bed was scattered directly on the cracked limestones, while the waters leaking from the Jruchula riverbed as determined by field research, are connected to the underground basin of Ghrudo. Rganisghele bed was heavily polluted with essential oil factory wastes and asphalt workshop oil products. The limestone quarry was also being developed in the bed (Fig. 25).

Figure 25. The limestone quarry.

Currently, these workshops are no longer functioning, but the manganese extracted from the mines is washed away in the riverbed and the water flow is still heavily polluted (Fig. 26, 27).

Figure 26. Rganisghele, polluted with manganese.

Figure 27. Jruchula River, polluted with industrial wastes.

The waters, leaking from the bed of the mentioned river, as it was identified by the indicator experiments, are directly connected with the Monasteri and other karst springs involved in the Chiatura water supply. The fuel oil spilled on the territory of Sachkhere cotton spinning factory penetrated the Ghrudo Spring through underground karst waters during the rainy season and for several days caused serious delays in Chiatura water supply. Currently, the open pit mining of manganese in the vicinity of the Pirana Abyss is intensive, which is an additional contributing factor to the turbidity of the Monasteri Spring and other springs (the connection is identified by means of our indicator experiments).

Sometimes karst sinkholes and wells are used by locals for garbage disposal. Such "storehouses" have been observed in many places on Rgani, Bunikauri, Darkveti, Sveri and other plateaus, the connections of which with the Ghrudo, Monastery, Kldekari, Tiri and other springs, involved in the Chiatura water supply, were identified on the basis of indicator experiments. The karst sinkholes on the Rgani Plateau, which are also connected to the Lezhubani Spring, involved in the water supply, were used as landfills for Chiatura (on our recommendation, this problem has now been settled). Therefore, the unreasonable human action creates a risk of the organic and bacteriological contamination of the karst waters of the study area.

The above-mentioned industrial and agricultural wastes, which contain organic and mineral acids, phenol, nitrobenzene, chlorine, hydrogen sulphide and other substances, got in the air, water and soil, contribute to the dramatical increase in aggressiveness of natural waters and in particular of the karst waters, which in its turn causes activation of karst processes. One of the main sources for the formation of aggressive waters in karst waters is carbon dioxide (CO_2), the size of which in the study area according to studies (Aroshidze et al., 1984) is 6-8 mg/l.

Thus, destructive, unplanned exploitation of the manganese ore and nature in general, along with other negative consequences, was followed by faster absorption of atmospheric precipitations under ground and the technogenic activation of karst. Because of all this, as laboratory research has confirmed, the mineralization of karst waters in the manganese region has increased. The content of manganese and boron in the waters has also increased. Hydrogen sulphide also appeared in some streams. The springs are increasingly polluted and become turbid. Severe ecological conditions have been created in the basins of karst springs, which are widely used for water supply in the city. All this puts on the agenda the need to implement a wide program of karst-geological surveys on the Chiatura Structural Plateau in the future too.

II. 9. Karst (chemical) denudation

Determination of the intensity of karst denudation, which allows the prediction of karst development, is one of the debated problems of karstological studies.

The problem of karst denudation is poorly handled in general, that is explained by the complexity of the issue. The methods and ways used today to assess the intensity of denudation are not yet finally refined. For this purpose, it is necessary to identify the true boundaries of the rivers' topographic and underground basins area, to determine the amount of atmospheric precipitations, runoff and evaporation indexes, to take into consideration the mineralogical and chemical properties of karstified rocks, etc. At the same time, it is difficult to obtain a somehow complete picture by means of single or episodic observations on the actual rates of denudation. Such findings about the regime of karst rivers and karst springs, whether year-round or not, should still be based on seasonal observation materials.

We can disscuss about the itensity of denudation and its general regularity based on the materials we have today, which were gained in consequence of many years field, experimental and laboratory researches. Rock destruction and transfer of destruction products are determined by the value of ion runoff:

$$Ru=31.54\ QC \quad (1),$$

where Ru – is an ion ruonoff, t/per year; Q – is a flow discharge, m^3/sec; C – is an ion concentration, mg/l.

In the evaluation of chemical denudation in karstology, various modifications to this (1) formula are used. Mostly they are based on the amount of runoff and the calcium content in it. The intensity of karst denudation in the study area we have calculated by means of formulas of A. Kruber (1915), J. Corbell (1959) and M.Pulina (1968).

One of the first to calculate karst denudation was A. Kruber (2). The mentioned author and J. Corbell (3) determine the rate of chemical denudation by the amount of dissolved calcium carbonate. Their formulas look as follows:

$$Q=31.54 \cdot 10^3 \cdot n \cdot a \quad (2),$$

where Q- is a mass of output $CaCO_3$, kg/year; n-is a discharge, l/sec; a - is a $CaCO_3$ content, g/l.

$$X=\frac{4ET}{100} \quad (3),$$

where X – is a rate of karst denudation, m^3/km^2 per year or mm/per millennium; E- is a height of the runoff layer, dm; T- is a Calcium carbonate content in water, mg/l; $\frac{4}{100}$ – is a coefficient of transfer of weight units in the volume units.

Somewhat different formula is suggested by M. Pulina (4). It looks as follows:

$$D=0.O126 \cdot V \cdot \Delta T \quad (4),$$

where D-is a karst denudation rate, m^3/km^2per year or mm/per millennium; ΔT-is a mineralization of karst waters ($\Delta T = T_1 - Ta$, where T_1- is a mineralization of karst waters; Ta-is mineralization of atmospheric precipitation); V- is a runoff module from l/sec.km^2.

From the results, obtained from the above mentioned three methods, in our opinion, the results obtained by the karsthydrometric method proposed by Pulina, is the most appropriate to the actual situation, since it considers the mineralization of atmospheric precipitations, the neglecting of which gives an error of 8-12%. Not only the amount of ions presented in the water but also the total mineralization (mg/l) are calculated. Therefore, during the analysis we mainly rely on the results obtained by the formula of M. Pulina.

A number of works were dedicated to the issues of karst denudation in Georgia (Jishkariani, 1970; Abashidze, 1973; Gabechava, 1978; Kiknadze, 1979; Kochetov, 1983; Tintilozov, 1976, 1988). In this regard, no similar research has been conducted on the Zemo Imereti platform karst (structural plateau).

As it is known, the intensity of karst processes largely depends on the physical-geographical and geological conditions of the region. In the karst massifs of Georgia, along with the increase in height, the amount of atmospheric precipitations and runoff modulus increase, contributing to activation of karst processes. J. Corbell's (1959), and later M. Pulina's (1968) observations have confirmed this poit of view on the example of the karst regions of the temperate and subtropical zones of the Eurasian continent. According to their calculations, with the increase in altitude, the precipitation and runoff increase too, and therefore, the rate of karst denudation increases appropriately on the regular basis. Namely, by increasing annual precipitations in the foothills by 100 mm in average, the intensity of karst denudation increases by 4 m^3/km^2, and at high karst conditions it increases to 8 m^3/km^2 (Pulina, 1968).

What is the situation in the Zemo Imereti (Chiatura) Structural Plateau, i.e. in the region of platform karst? Based on the comparison of atmospheric precipitations amount and evaporability data, it can be mentioned that the annual runoff balance within the karst zone of the study area is positive everywhere (Kordzakhia, 1961, 1962), which results in an active course of karst processes throughout the year, especially during the cold season. It appears that the aforementioned regularity may be corrected by technogenic factors and play a stimulating role in the activation of karst processes, as it confirmed by our researches.

On the basis of the materials obtained in consequece of our researches, the intensity of karst denudation on the Zemo Imereti Structural Plateau was studied (calculated) for the first time; the results are presented in the Table 18. The data obtained are partly based on the episodic observations, although chemical analyzes of the vaucluse springs and surface currents have been repeated several times during different seasons of the year. In addition, detailed hydrochemical studies of karst waters were conducted, and regime observations on karst springs were carried out. By means of laboratory and experimental methods the true boundaries of the topographic and groundwater basins' areas of the rivers were established, and so on. At the same time, for resolving a number of issues of karst genesis (migration of substances, formation of composition of underground karst waters, and so on), the karst water chemical (namely, surface streams', karst springs and cave streams' macro and micro elements) composition and hydrochemical regime were identified by means of stationary observations and laboratory studies (Supatashvili et al. 1990; Lezhava, 2015).

As it is known, the intensity of karst denudation is significantly influenced by the nature of atmospheric precipitations, karst rock fissility, lithology, etc. According to our results, we can discuss some of the regularities characteristic of the Zemo Imereti Plateau karst massif. In particular, there is a close relationship between runoff and karst denudation, which lies in the fact that karst denudation increases together with the increase in runoff (Table 18).

Table 18. Intensity of karst denudation on the Zemo Imereti Structural Plateau.

Name of a river or a spring	Watershed area, km²	Water discharge l/sec.	Flow rate/modulus, l/sec. km²	Total mineralization, mg/l	$CaCO_3$ content, mg/l	Amount of dissolved $CaCO_3$, kg/day	Total amount of dissolved substance (ion flow) kg/day	Total amount of dissolved substance (ion flow) kg/year	Karst denudation, m³/km² per year		
									According to Kruber	According to Corbell	According to Pulina
Ekvtimesklde (cave)	0.7	1.0	1.4	409	139.5	12.0	18	6570	1.5	2.2	5.6
Namdzvlevisklde (cave)	0.5	1.0	0.5	318	116.2	10.0	10.5	3650	1.2	0.5	1.5
Kldekari (cave)	3.8	45.0	11.8	531	210.0	34.0	1287	468755	102.0	30.5	60.8
Nekrisa (river)	12.9	260.0	20.2	959	268.8	251.7	16850	6150250	762.0	67.7	190.6
Ormoebi (cave)	0.5	0.5	1.0	1932	213.1	0.3	75	27375	1.1	25.5	19.1
Shvilobisa (cave)	1.1	7.5	6.8	368	115.0	3.1	109	39785	9.0	9.6	24.0
Jruchula (cave)	2.5	5.0	2.0	469	245.0	4.4	116	42340	13.1	5.9	9.0
Karianiklde (cave)	4.8	250.0	52.0	240	125.0	112.5	3024	1103760	327.3	82.0	117
Shekiladzeebisklde (cave)	0.6	16.0	26.6	349	183.0	10.5	206	75190	31.4	60.8	84.0
Rganisghele (river)	13.0	320.0	24.6	276	126.0	145.1	2101	766865	452.7	39.0	64.2

The distribution of karst denudation by height is also interesting. Namely, In the research region increase in karst denudation intensity is observed together with an increase in absolute height. For example, karst denudation rate in the basin of the Namdzleviklde Cave underground stream, flowig at 570 m above sea level, is equal to 1.5 m^3/km^2 per year; in the Shvilobisa Cave (612 m above sea level) underground stream- 24 m^3/km^2 per year, in the Shekiladzeebisklde Cave (860 m above sea level) – 84 m^3/km^2 per year, and in the Karianiklde cave (1300 m above sea level) underground stream basin - 117m^3/km^2 per year.

The intensity of karst denudation is also different for different stratigraphic horizons of limestones. Relatively low denudation rate (1.5–5.6 m^3/km^2/year) was observed in the areas, built of the Middle Miocene limestones and marls, average denudation rate (9.0–60.8 m^3/km^2/year) – built of the Upper Cretaceous limestones, and the highest denudation rates (84–117 m^3/km^2/year) – in the areas, built of Barremian limestones. I.e., the cleaner the limestones are, the more is the intensity of karst denudation. Surface streams are also characterized by high intensity of denudation rates (Nekrisa River - 190.6 m^3/km^2 per year; Rganisghele River - 64.2 m^3/km^2 per year).

As the hydrochemical studies of karst waters have shown, the mineralization of underground karst waters is 1.5-3 times higher in the study area than the analogue indicators of neighboring karst regions. The reason for this is not only the complex lithological-stratigraphic structure of the region, but also the wide distribution of manganese ore open quarries (Fig. 28). In the open quarry areas (especially during heavy rains) there is intense washing of substances from loose rocks (Lezhava et al., 2017a, b; Lezhava et al., 1991).

Figure 28. Karst relief modified by anthropogenic impact on the Zemo Imereti Structural Plateau.

Because of the abovementioned reason, karst water mineralization in the open quarry areas of the Zemo Imereti Plateau varies between 500-712 mg/l^{-1} and sometimes reaches abnormally high values (∑¡ 1052-2290 mg/l^{-1}) (Supatashvili et al. 1990; Lezhava, 2015).

The sharp increase in the total mineralization of springs also conditions an increase in the intensity of karst denudation. That is why there are a number of deviations in the regularity mentioned above. For example, the Ormoebi Cave underground water stream discharge is the lowest among the streams we have studied, although karst denudation indicator (19.1 m^3/km^2 per year) is much higher than that of the streams, having more discharge rate that can be explained by the high mineralization indicator of the Ormoebi Cave underground stream ($\sum_i$ = 1932 mg/l). By the same reason should be explained high karst denudation rate (190.6 m^3/km^2 per year) of the Nekrisa River, which is also fed by high mineralization karst springs and cave streams ($\sum_i$ 1052-2290 mgl^{-1}, correspondingly). Such high rates of mineralization, in this case, are also mainly due to the wide distribution of manganese open quarries in the feeding basins of underground karst waters. The impact of high mineralization is also noticeable in the distribution of karst denudation by height.

Based on the available research materials, it can be noted that by karst denudation rates (surface 64.2-190.6; underground 1.5-117.0 m^3/km^2 per year) Zemo Imereti Structural Plateau exceeds Apkhazeti (in upper karst strip surface and underground karst denudation values are correspondingly 75-108 and 30-45, and in the foothills 38-58 and 12-0 m^3/km^2 per year) and Askhi (59 m^3/km^2 per year) karst massifs (Kiknadze, 1979; Jishkariani, 1970). In our opinion, the high intensity of chemical denudation rates on the Zemo Imereti Structural Plateau are conditioned by common growth of aggressivity of waters, high mineralization (manganese district karst water mineralization is 1.5-3 times higher than analogue indicators of the karst regions of Georgia) and intensive washing of substances related to technogenic factors (especially open mining of manganese ore).

In order to avoid negative consequences of study area karst massives' agricultural development, we consider it necessary to take into account and predict the karst denudation.

CHAPTER III.

SOME RESULTS OF ELECTROMETRIC STUDIES

Electrometric methods of research are widely used in the detection and tracing of covered structural units. The mentioned methods are widely used for revealing karst cavities, fault lines, underground flow directions, etc. In this regard, together with the staff of the TSU M. Nodia Institute of Geopysics (Jashi, Amilakhvari, Zardalishvili) we studied the territory of the Sachkhere cotton spinning factory located on the Zemo Imereti Structural Plateau.

Sachkhere cotton spinning factory is located on the left terrace above the Kvirila River floodplain, on the foundation of a strongly karstified limestone. An indicator experiment conducted in one of the karst ponors found by us (Lezhava, 2015) recorded the mixing of the polluted waters of the Sachkhere cotton spinning plant with the Ghrudo underground basin, involved in the Chiatura water supply, which created a great ecological threat.

The purpose of the researches was: identification of the thickness of the horizons above the limestones in the geological context and their differentiation according to the specific electrical resistance (ρ); revalation of fissured structures; identification of the direction of filtration flows, as well as the clarification of some of the viewpoints, we had expressed.

The following modifications of electrometric methods of research were used to solve the mentioned problems: vertical electric sounding (VES); electric profiling by the intermediate gradient method; and Natural Electric Field Method (NEF). Optimal expansion of the feeder and receiver electrodes was selected and the electric parameters of limestones and younger sediments were identified. The placement of dots and profiles on research objects is shown in the (Fig. 29).

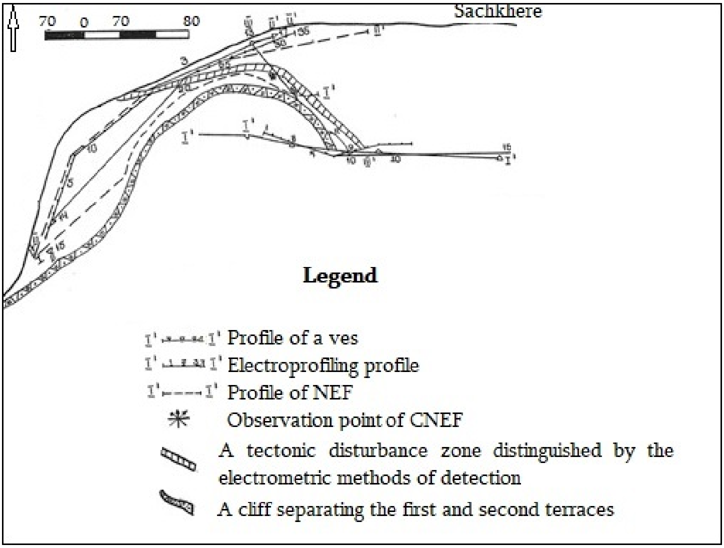

Figure 29. Geoelectric profile I-I^{I}.

According to the works, carried out, three geoelectric profiles were made. The I-I^{I} profile (length 680 m) runs along the second above floodplain terrace of the Kvirila River (Fig. 30). Here the outcropping of limestones, is seen up to the 9th VES by visual observations. According to 6-7 VES-es, a three-layer profile (K-type curves) is obtained, where the first layer, with a thickness of 5-6 meters and a specific electric resistance of 10-15 ohm.m, corresponds to the alluvial-deluvial formations of the Qarternary period. The second layer of geoelectric profile, with a thickness of 70 m and a specific electric resistance of 250-300 ohm per meter, should correspond to the limestones. In addition, we would like to note that such resistance is somewhat low for limestones and it can be caused by water content. We have identified the parameter (ρ) of limestones, spread in the vicinities of Sachkhere, on the Sareki Plateau, which is equal to 500-600 ohm.m. The second layer of horizontal distribution over the geoelectric profile overlaps the 50-60 ohm.m resistance environment. It must correspond to the Bajosian porphyritic suites (tuffs, tuff-breccias, and porphyrites).

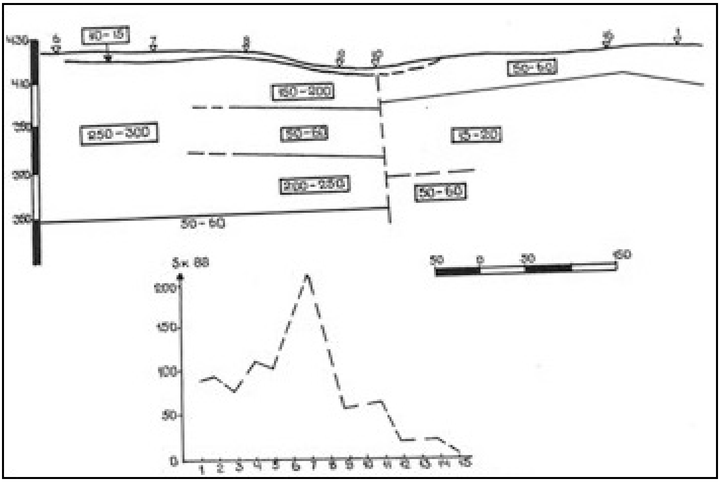

Figure 30. Electrical profiling with the intermediate gradient method.

As the Figure 29 shows, five-layer geoelectric profile (KHK-type curves) is obtained at the corresponding points of 8-9 VES-es. The second layer (limestones) separated by 6-7 VES-es undergoes differentiation according to the specific electrical resistance, in particular, a relatively low-ohm environment with a thickness of 20 m (ρ = 50-60 ohm per meter) is distinguished in it.

A completely different geoelectric profile is obtained in consequence of interpreting of the 10, 16, and 1 VES-es. In particular, according to 10 VES, 4-layer profile is made, where the layer with a special electrical resistance of 10-15 ohm.m overlaps the 15 m thick layer, the fixing of underlayer of which was not possible according to 16 and 1 Ves-es. From a geomorphological point of view, we can think that the 4th layer, separated by the 10th VES corresponds to limestones, whose relatively low specific electric resistance (50-60 ohm.m) is apparent.

Based on the geoelectric profile, the impression is created that a fault line should have passed between the points of 9-10 VES-es. This view is made convincing by electric profiling, carried out by means of the intermediate gradient method (AB/2 - 100 m, MN/2 - 10 m, step - 20 m). The layout of the points, studied by means of electric profiling in space, is oriented towards the VES points, which allows to have an idea about changes in horizontal direction electroconductivity of the rocks located in the profile at a depth of 40-50 m (at this depth the resistance of the rocks is recorded by the results, obtained by the intermediate gradient method). The electric profiling curve shows that the apparent electrical resistance of rocks up to the 11th point of observation varies within about 100-200 ohm.m, and then till the end of the profile it varies within 17-20 ohm.m. As can be seen from the Figure 29, the electric profiling data are in good agreement with the geoelectric profile, built according to the VES-es. Based on the results of the electrical profiling, we consider that a fault line should be passed between the 11th and 12th points of the observation, which is marked on the geoelectric profile.

Geoelectric profile II-II^{I} (length 640 m) runs along the first terrace of the left bank of the Kvirila River. Due to the interfering factors, sounding between the 14th and 3rd points of the VES was not carried out, therefore, the geoelectric profile on this sector is somewhat schematic. The second layer, separated according to the 15th and 14th VES-es, which has a specific electric resistance of 400-450 ohm.m and thickness of 30 meters, corresponds to limestones. Therefore, the resistance of limestone in these areas is approximately equal to the value idetified by the parametric measurements. According to the 3rd, 13th and 17th VES-es a two-layer profile is made, in which the low resistance (10-15 ohm.m) of the second layer indicates that no limestones are found in these places within the sounding.

The results of electric profiling show a similar picture. In particular, at the corresponding points of the 15th and 14th VES-es, and in 100 meters east of it, the apparent electric resistivity varies within 100 to 200 ohm.m; after that, up to the 17th point of observation it is equal to 40-50 ohm.m, and by the end of the next profile its value does not exceed 10-25 ohm.m (resistance is somewhat increased at the last three points of observation). Therefore, a fault line was drawn on the geoelectric profile, according to which the presence of limestones at visible depths for zoning to the east of the 17th point of the profiling was not observed (Fig. 31).

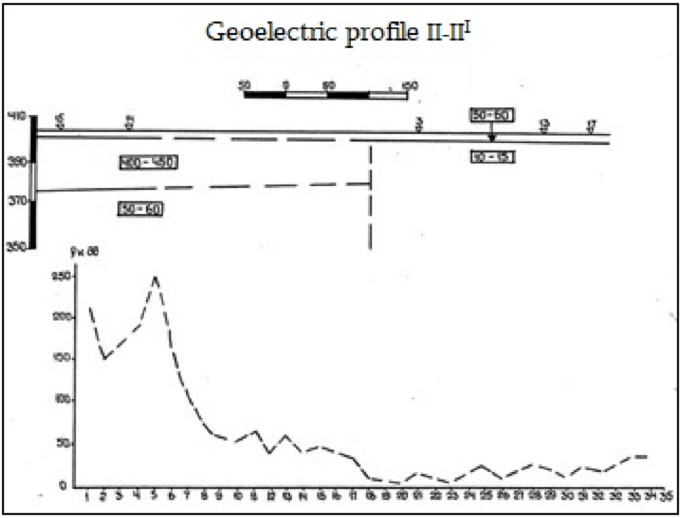

Figure 31. Electric profiling by means of the intermediate gradient method.

According to the carried out works, a geoelectric profile III-II[I] (length-300 meters) was built. It shows that the limestones to the north-east of the 12 VES do not extend to the visible depths for sounding. As long as no electric profiling has been carried out along the geoelectric profile, the exact location of the fault line between the 13-12 VES points is not shown on the geoelectric profile (Fig. 32).

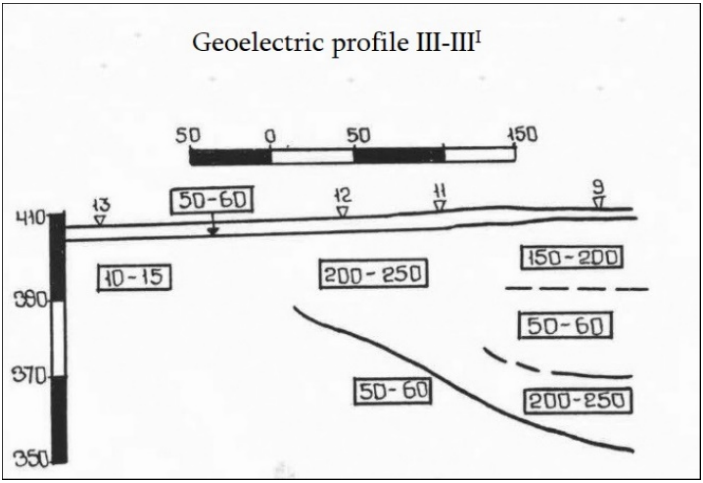

Figure 32. Geoelectric profile III-III[I].

Based on the interpretation of the obtained material and taking into account the geomorphological picture of the study area, a fault line was drawn, which shows that the distribution of limestones to a depth, fixed by means of sounding to the north-east of it, has not been observed. In the fault line, limestones are heavily crushed and cracked, and many foci of water absorption are developed (one of which is the above-mentioned foci). Supposedly, the filtration waters follow exactly this fault line.

In order to identify the direction of filtration flows, the two profiles were examined by the natural electric field (NEF) method, during which the step between the observation points was 20 meters. The location and direction of the intense flow of filtration stream along the profile of the natural electric field I-I[I] are shown by arrows (Figure 35), which is in good agreement with the geomorphological understandings. Interestingly, at point 35 of the observation, there is a branching of the flow in the opposite to each other directions (Fig. 33).

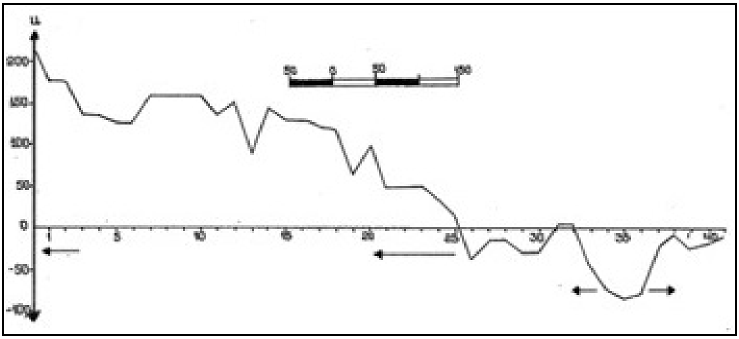

Figure 33. Natural electric field along the profile I-I^{I}.

The above mentioned fact makes even more convincing the existence of watershed of the hydrogeological basins in the profile we have noted (Lezhava, 2015).

It is even clearer to determine the direction of filtration according to the profile II-II^{I} of the natural electric field (Fig. 34).

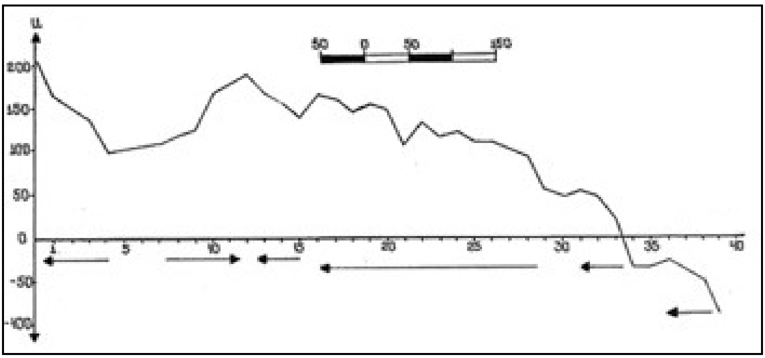

Figure 34. Natural electric field, profile II-II^{I}.

At one point between the 12 and 13 points of the VES, the variability of the natural electric field with four azimuths was observed that clearly determined the predominant direction of filtration at this point. By combining the values of the observed potentials on the same expansions, it can be said that the ideal picture has been obtained (Fig. 35), where at almost all expansions (at appropriate depth) the filtation takes place in a north-northwestern direction.

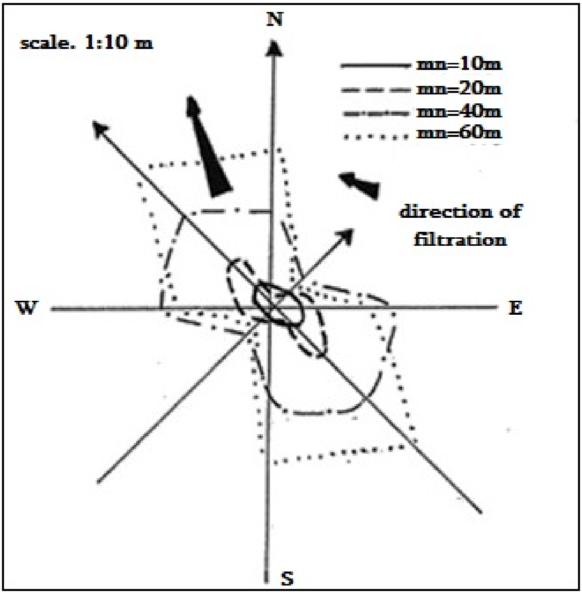

Figure 35. Circular natural electric field (CNEF).

Thus, in consequence of geophysical surveys it was identified that: the most of the area occupied by the Sachkhere Cotton spinning Factory is built of heavily cracked and karstified limestones (thickness ranges within 20-35 m), which, in its turn, is covered with weakly cemented 3-6 m capacity alluvial-deluvial deposit layers. This area is crossed diagonally by a fault line, which, to some extent, is reflected in the relief; along the fault line fecal factory waste waters are being filtered, which leads to strong pollution of Ghrudo and other karst springs involved in Chiatura water supply.

Based on the carried out researches, a recommendation was prepared, according to which the source of the Ghrudo was removed from the drinking waters and currently it is used only as technical water.

CHAPTER IV.

MORPHOLOGICAL PECULIARITIES OF KARST RELIEF

The genesis of karst forms and their subsequent evolution are closely related to the erosive-corrosive impacts of the waters and the flow movement conditions. The erosive-corrosive action of the waters, flowing on the ground surface, produces landforms such as corries, sinkholes, dead gorges, caverns, etc., and wells, shafts, abysses and caves are related to the vertical and horizontal circulation zones of fissure-karst waters.

The karst terrain of the study area repeats those general patterns, which are characteristic to typical karst areas. These regularities are: the presence of the most intense karstified areas in the hollows of dead valleys or slightly sloping plain surface; the selective nature of karst forming is related primarily to tectonic fractures, the close relation of karst forms' morphology with stratigraphic and lithological features, etc.

IV. 1. Surface karst forms

From the surface karst forms for the study area are characteristic - corries, dead valleys (ravine-like depressions) and sinkholes.

Corries on the Zemo Imereti Structural Plateau are relatively underdeveloped, which is explained by the fact that there are mainly covered types of karst. In the bare and half-swale karst distribution areas, there are mainly channelled and fissure corries, which are related to horizontal or subhorizontal surfaces. Their depth is 1-10 cm, length from 1 to several tens of meters, and width from 1-2 cm to 0.5 meters. The origin of the corries, represented on the surface of significant inclination is related to the impact of fast-moving water jets on the karstifying surfaces (in addition, organic acids play an important role) and is sometimes characterized by significant depths (0.3-1.0 m). Their bottom is everywhere filled with soil-vegetation cover.

The well-marked corrie fields are represented in the surroundings of the villages of Sveri, Mandaeti, Uchameti and at Chkherisghele (right tributary of the Chkherimela River) headwaters.

On the slopes of the canyon type gorges, crushed small corroded holes are widespread that sometimes look like honey combs. Their origin is explained by the chemical action of aggressive water (carbon dioxide).

Dead valleys, which are represented by ravine-like depressions and end up at different altitudes from modern river valleys. At their bottom, in the riverbeds spurt vaucluse springs.

The bottom of the dead valleys and the lower part of the slopes are composed of Upper Cretaceous limestones, and the upper part – is composed of Tertiary clays and sandstones. These depressions currently lack surface flows and are damp, and at the same time they are fertile places. Therefore, they are used for arable farming. At the bottom of the dead valleys sinkholes are developed, separated by low hummocks from one another. In some sinkholes there are lakes. Dead valleys are presented throughout the Chiatura Structural Plateau with more or less intensity and are mainly associated with tectonic faults. They are widely distributed on the plateaus of Darkveti-Zodi, Bunikauri, Gundaeti, Bazaleti-Ghoresha and Rgani. A whole system of dead valleys is developed on the Rgani Plateau.

At the initial stage (when the rivers flowed on substrate, built of Tertiary rocks), the origin of these dead valleys should be related to the erosive action of the rivers, but later on, as they escaped Turonian-Danian limestones, the waters began to leak into them, finally causing the rivers to dry up or move to lower stages and at their bottoms started development of sinkoles. At the following stage, as the Kvirila River was accomplishing the intensive depth erosion, it elaborated deep canyon-like gorges. That is why these lowlands are now so high above the foot of the Kvirila valley. A good example of this is a stream flowing at 100 meters deep (20-25 l/sec. water debit) in the Pirana abyss, which is located at the head of one of the dead valleys on the Rgani Plateau and in the past was a head of a paleoriver. Now it is a displaced to the depth underground stream (to what had contributed the tectonic crack, passing here), which partly flows under the mentioned dead valley and comes out to the daylight as a vaucluse spring, called Tiri, and the main underground water flow going along the tectonic fault line, bypasses the Rganisghele riverbed from the bottom and manifests itself in the Monasteri spring, what was confirmed by means of indicator test. L. Maruashvili (1958) and Sh. Kipiani (1959) consider the dead valleys to be originated from the former hydrographic network.

Sinkholes are widely distributed on the limestone plateaus of the study area that are mainly associated with plain and slightly sloping surfaces, as well as with dry valley bottoms. In section they have generally conical, rarely asymmetric shape, and in plan- circular or elliptical shape. From a genetic point of view, there can be distinguished suctional and collapse, i. e. gravitational sinkholes. Sometimes they pass into karst wells, shafts, and downhill caves. There is a close connection between sinkholes' shape and genesis. The collapse sinkholes have steep slopes, and the suctional ones - relatively inclined slopes (fig. 36).

Figure 36. The sinkholes in Zemo Imereti Plateau.

Within the Chiatura Structural Plateau, sinkholes are developed in Upper Cretaceous and Tertiary carbonate rocks. The diameters of the sinkholes, related to the Tertiary limestones are on average 2-5 m, depth is 2-3 m, and far below the morphometric indices of those, related with Upper Cretaceous limestones (diameter from 5 to 25-30 m on average, depth from 3 to 7-10 m).

The villages of Sveri, Tskhrukveti, Mandaeti, Rgani, Bunikauri, Sarkveltubani, Zodi, Ghvitori, Kvatsikhe, Sakurtskhle, Marelisi, Moliti and Bazaleti-Goresha surroundings are distinguished by the density of the sinkholes. There are 15-25 sinkholes developed per every 1 km^2 here. The amount of sinkholes, related to the Tertiary limestones in the western part of Darkveti, are 20-30 per 1 km^2. The diameter of one of the sinkholes, located west of the village of Rgani, reaches 200 meters. The intense development of sinkholes along with the strong cracking of karst rocks should be explained by the very favorable conditions of area infiltration. The accumulation of sinkholes along the fissures is clearly shown on the map we have drawn based on the analysis of aerial imagery.

On the structural plateau of Chiatura, buried karst sinkholes can be distinguished that Sh. Kipiani (1959) firstly paid attention. This researcher has described well-marked buried old karst forms on the Rgani Plateau. Here karst sinkholes are filled with Oligocene sandstones and manganese ore. Besides the sinkholes, there are also buried karst wells on the Chiatura Plateau. For example, in the territory of the mine № 5 in the east part of Rgani Plateau, where the manganese ore lies directly on limestones, a few years ago at one site during the opening works, the rocks collapsed and the old buried well was opened, but the mentioned well was subsequently refilled with barren rocks. There can be found similar buried karst forms on other plateaus of Zemo Imereti. It is also noteworthy that karst forms (sinkholes, wells, caves, etc.) are being extensively buried under the barren rocks left after extraction of manganese in Chiatura manganese region.

IV. 2. Underground karst forms

IV. 2. a. Morphological - morphometric characterization of karst cavities

The total number of karst cavities we recorded and studied within the study area exceeded 110, of which 40 were firstly found by us. Their total length is 17000 m, depth - 580 m, floor area - 51, 846 m^2, and total volume of cavities reaches - 232, 285 m^3.

The studied cavities are mainly developed in thick-layered and massive Upper Cretaceous limestones (90% of the total amount), out of 95 horizontal and angled caves, revealed here, 20 caves are less than 20 m in length, 34 ones - from 20 m to 100 m, 33 ones - from 100 m to 500 m, 7 ones - from 500 m - up to 1000 m, and 2 ones - more than 1000 m. Among the other karst cavities, there are represented 8 wells, 6 shafts and 1 abyss (Table 19).

Table 19. Morphometric characterization of karst cavities of the Zemo Imereti Structural Plateau.

Karst region	Number of caves			Caves			
	Horiz. and inclined	Vert.	Total	Length, m	Depth, m	Area, m^2	Volume, m^3
Zemo Imereti Plateau	95	15	110	17000	580	51846	232285

The morphological features of karst cavities are mainly determined by the thickness and nature of fissility of the karstified rocks, the erosive action of the flowing stream in them, the aggressivity, and so on.

In the work we used the morphological classification of karst cavities, proposed by Z. Tintilozov (1976), based on which we give below a general characterization of the underground karst forms distributed in the study area.

I. Among the vertical cavities wells, shafts and abysses are represented. They are usually associated with tectonic disturbances and developed on the bottom and slopes of surface karst forms (dead valleys, sinkholes), as well as on the steep slopes of rivers (the cavities, represented here, are mainly related to the discharge cracks). Until recently, only 4 vertical cavities were known in the Zemo Imereti karst region. As a result of our field research, their number has increased to 15. The underdevelopment of great depths vertical cavities on the Zemo Imereti Structural Plateau should be explained by the relatively small thickness of karst rocks (200-300 m) and platform-like structure.

In the study area mainly are developed the vertical cavities of collapse (gravitational), collapse-corrosive and corrosive-erosive origin. Most of karst wells are characterized by almost equal cross-section and small depth.

The karst shafts are distinguished by branches and alternating of well cascades with horizontal corridors (Fig. 37). The latter is often oriented parallel to the tectonic faults, creating collapses and significant extensions in the intersection areas of the cracks.

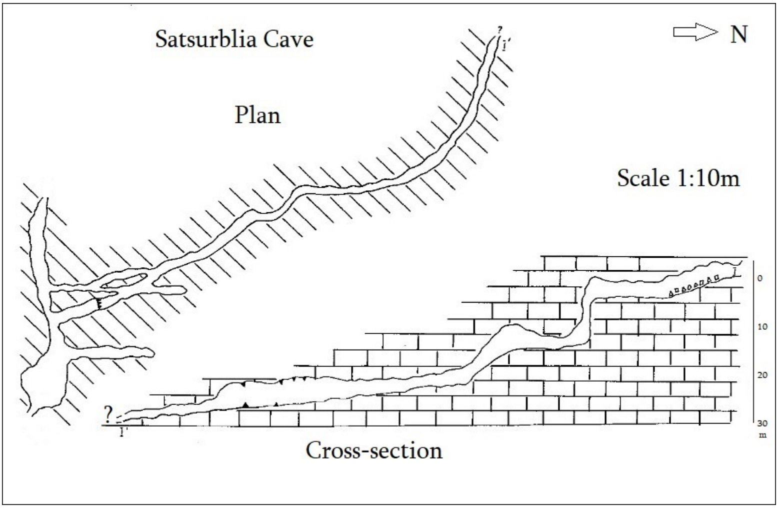

Figure 37. Satsurblia Cave.

Their origin is related to the turbulent movement of the waters, which affects the limestones in the form of corrosion and erosion. The role of collapse (gravitation) is also great. The latter often make this or that cavity available for viewing. For example, the Namdzvleviklde was known for some time as the horizontal 85 m long karst cave (Tintilozov, 1959), which opens at a height of 20 m above the Tabagrebisghele River level. During field researches, at the base of Tabagrebis' plateau, in the karst sinkhole we tracked down a ponor, from which we reached the above-mentioned cave after overcoming the vertical and horizontal sections. Thus, today the cave of Namdzvleviklde is a permeable mine with a length of 566 m. Also, due to the recent wide collapse of the ceiling, it became possible to penetrate into the Chiatura100's shaft (Fig. 38).

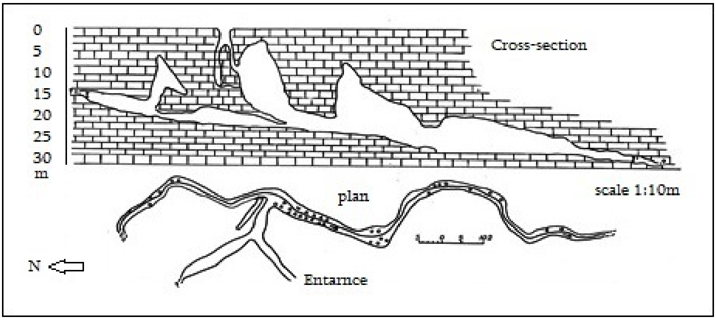

Figure 38. Chiatura-100's Shaft.

There is one abyss in the study region - Pirana. Its depth reaches one hundred meters. The Pirana Abyss is located on the Rgani Plateau and is developed along tectonic fissure in the Upper Cretaceous thick layer limestones. The initial section of the abyss is relatively narrow, sloped and easy to overcome, which in its turn moves into the steep and hard-to-overcome part (Fig. 39).

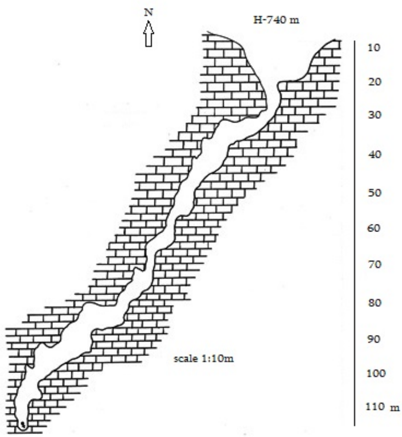

Figure 39. Pirana Abyss.

It develops quite high (5-10 m) vertical steps in depth, which alternate with narrow corridors. The bottom is characterized by a common sloping (45-60^0). The height of its highest vertical section (80-90^0) reaches 15 meters. There is a well-distinct crack in the ceiling here. On the bottom and walls of the abyss, there are traces of water flowing from the ceiling in the form of grooved surfaces. In it, due to the action of periodic flows, there are found no speleothems. For the same reason, mechanical precipitations is also weakly expressed and is preserved only in the form of ruined material at relatively horizontal sections. At the bottom of the Pirana Abyss, where the ceiling height reaches its maximum index (17-18 m), flows a fairly large stream (at a depth of 100 m from the surface). It enters from the north by three branches through the crack existing in the limestones, after passing a distance of 10-12 meters the stream is lost with noise in a narrow crevice, yet inaccessible for human.

II. Horizontal and sloped caves. On the Zemo Imereti Plateau, there are mainly horizontal and sloped underground cavities (there are also permeable and closed, ascending and descending, watery and dry ones), which sometimes reach significant lengths too. For example, the total length of the tunnels, studied so far in the Shvilobisa Cave, is more than 1 km, the length of the Data cave is 2 km, and the total length of the Zakariasklde Cave (820 m), Shekiladzeebi's (740 m), Varsima's (720 m), Taroklde (627 m), Samertskhleklde I (425 m), Kotiasklde Cave (280 m) and some other caves reach several hundreds of meters.

The cave horizons are represented by 4-5 tiers on the slopes of the dissected canyon like valleys (Kvirila, Jruchula, Sadzalekhevi, etc.) of the Zemo Imereti Structural Plateau; at the same time, the individual cave has 2 and sometimes 3-storey structures. For example, Shvilobisa, Zakariasklde and Tsilto III are three-storey caves. Well-defined two-storey caves are: Nekrisa, Ormoebi, Dzudzuana and Kudurebisklde (Fig. 40, 41, 42, 43, 44).

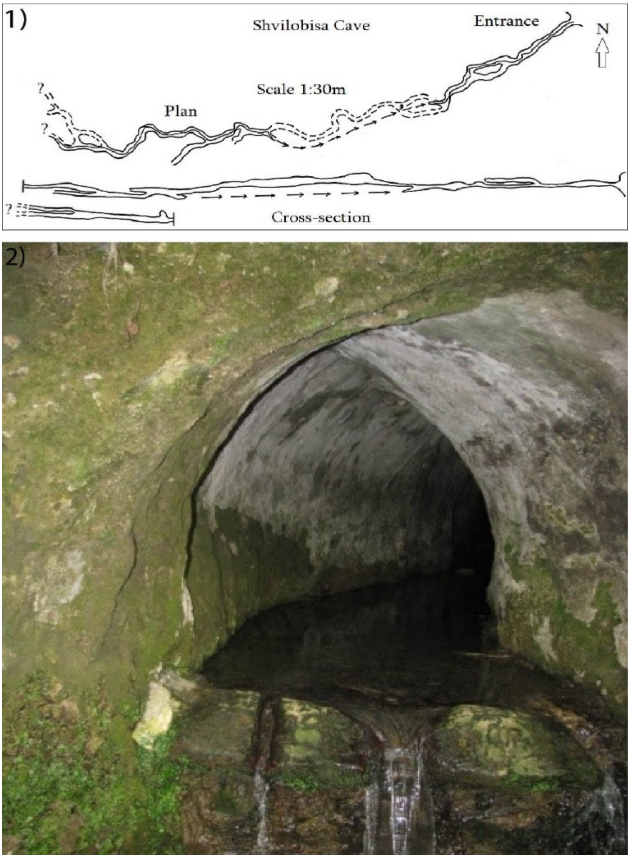

Figure 40. Shvilobisa Cave:
1) Plan and cross-section. 2) Cave entrance.

Figure 41. Zakariasklde Cave: 1) Longitudinal section. 2) Cave entrance.

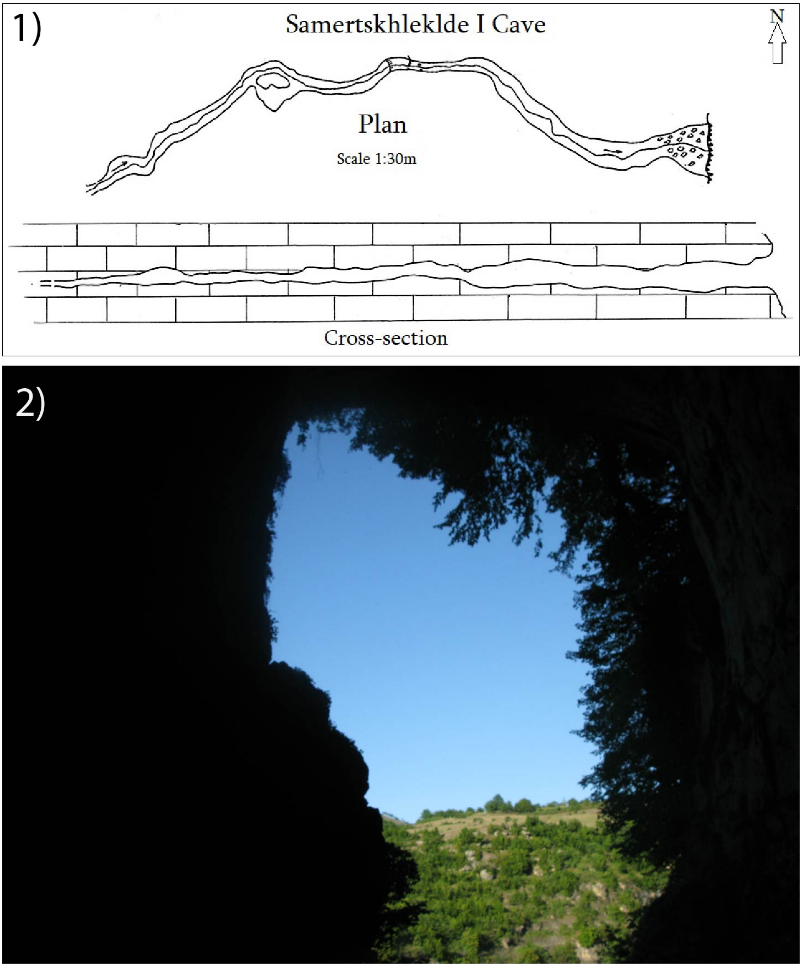

Figure 42. Samertskhleklde I Cave:
1) Plan and cross-section. 2) Cave entrance (view from inside).

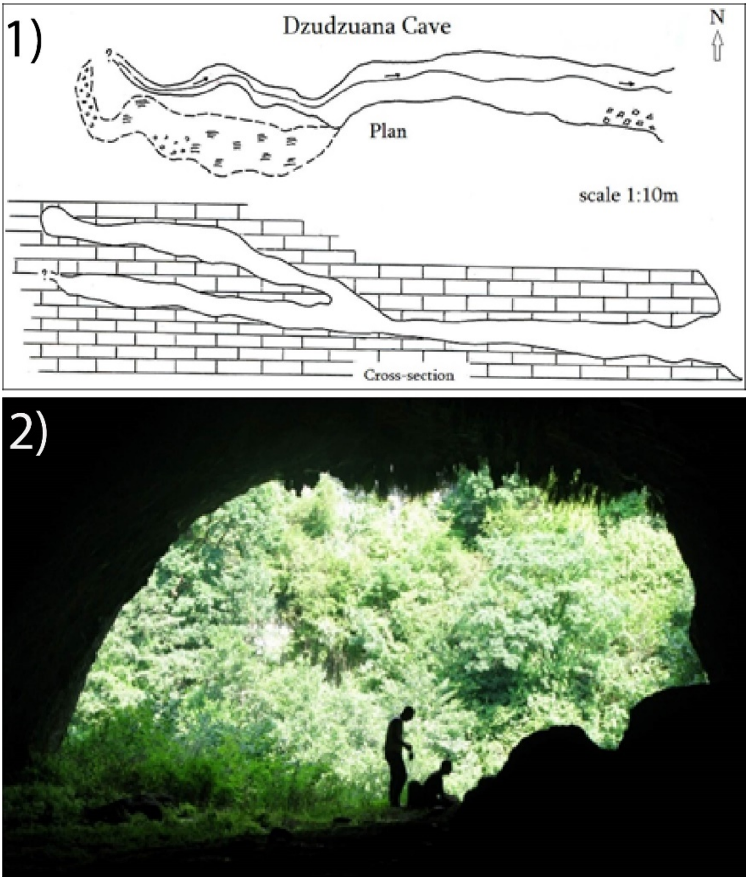

Figure 43. 1) Plan and cross-section.
2) Cave entrance (view from inside).

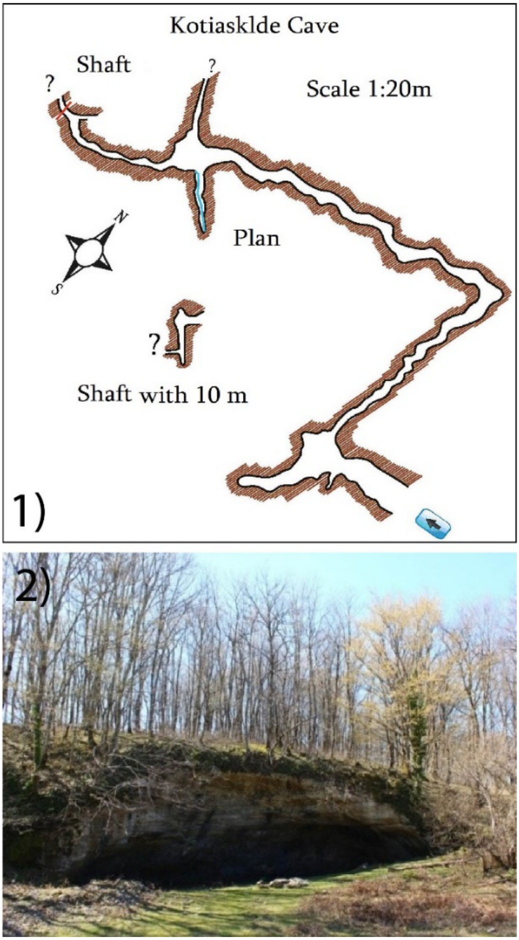

Figure 44. Kotiasklde Cave:
1) Plan of the cave. 2) Cave entrance.

Particularly impressive are the speleotems of the caves of the study area, which are distinguished by the originality and diversity of the forms. Rganisklde, Cherula, Ormoebi, Tuzi, Bochoklde, Sachinkia, Zakariadzisklde, Data, Kotiasklde and other caves are noteworthy in this regard. The caves of Varsima, Tuzi, Samertskleklde I, Taroklde, Tsintskila and Ormoebi are characterized by abundance of mechanical deposits. There are also cavities, completely devoid of speleothem forms, such as Bujas Dasakargavi, Jikhura, Patara Sadatviaklde, Mujireti, Tsilto III, Gvarjilasklde and others. In some parts of the Pasieti, Namdzvleviklde and Taroklde caves, the growth of speleothems has stopped. The cave deposits are relatively broadly described in the corresponding chapter.

In many caves of the study area there are preserved some of the most thick suites of cultural layers, which substantively help us not only in the restoration of our country's historical past, but also in the dating of underground cavities and in general, restoration of the region's palaeogeographical picture.

The caves of the karst massif are also distinguished by a different thermal regime. Intense movement of air takes place in the through caves (Patara Sadatviaklde, Namdzvlebiklde, Khalipauri, Nakhiznebi, etc.). In some of them (Warsima, Namdzleviklde) the sharp difference between the cave and the surface air temperature creates strong air currents, while in the so called clogged caves (Taroklde, Bnelaklde, Rganisklde, Sadatviaklde) complete darkness reigns and the air is still too. The results of observations on microclimate elements in some of the caves, are given in the Table 20.

Table 20. The results of meteorological observations in the karst cavities of the Zemo Imereti Structural Plateau.

№	Cave name	Entrance height above sea level, m	Distance of the observation point from the entrance, m	Air temperatur e t⁰ C	Absolute humidity, mm	Relative humidit y, %
1	Dzudzuana	440	116	13.9	11.6	98
2	Ormoebi	450	210	13.2	10.7	94
3	Taroklde	485	605	13.6	11.6	99
4	Karianiklde	1300	90	9.6	8.7	99
5	Bujas Dasakargavi	1415	280	8.9	8.1	98
6	Chiatura-100	430	150	11.3	7.1	98
7	Kotiasklde	710	100	9.7	8.4	95
8	Nigozeti	680	100	9.7	8.4	95
9	Sabikistskaro	665	130	9.5	7.6	98
10	Samgleklde	445	60	13.5	-	95

The karst phenomena of the study area are not deprived of the organic world either. For example, in the Taroklde, Tuzi, Samertskhleklde, Tsilto III and other caves, green vegetation with weak stems can be found far from the entrance. In many caves (Ormoebi, Samertskhleklde, Samgleklde, etc.) mushrooms grow on the guano of bats.

The cave fauna, which resembles the Mediterranean fauna, is mainly represented by crustaceans, woodpeckers, spiderlikes, mollusks, beetles, ringworms and insects (Barjadze et al. 2015). There are quite a lot of bats in the caves of Ormoebi, Samertskhleklde, Ghamurebi and Patara Sadatviaklde. Among the horizontal and sloped caves in the study area we can distinguish the following subtypes:

A) Rocky shelter – is well defined on the steep banks of the rivers of Kvirila, Jruchula, Sadzalekhevi and their tributaries. Their formation is closely related to the action of both water currents and external dynamic (weathering, etc.) agents. Among the rocky shelters there should be noted Jruchula, Sameleklde and Fardulisklde ones (Fig. 45).

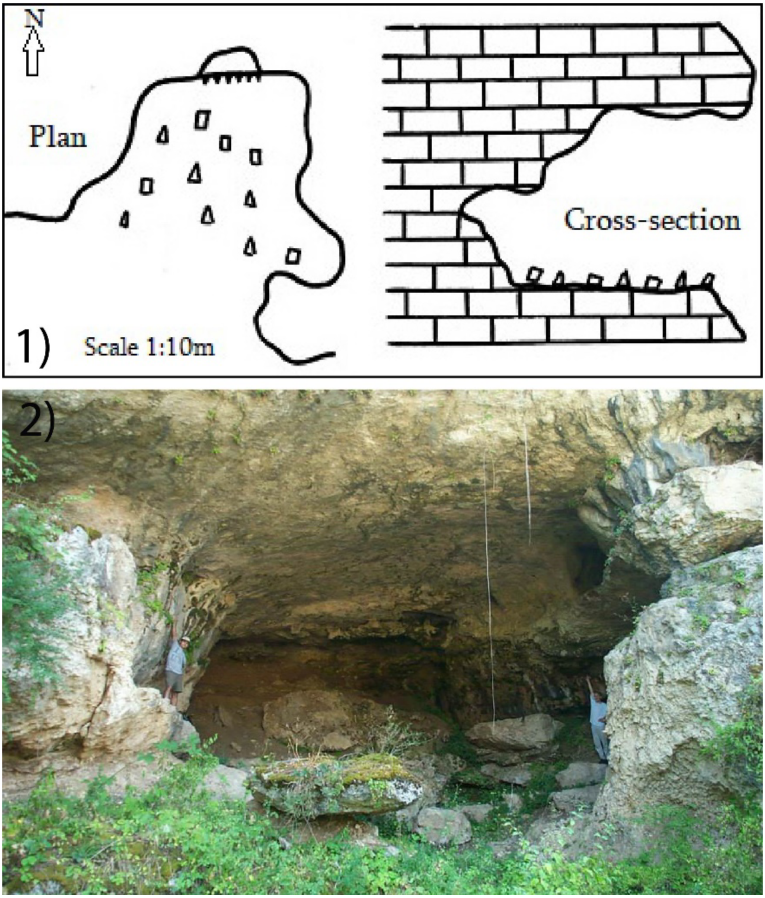

Figure 45. Jruchula Cave: 1) Plan and cross-section. 2) Cave entrance.

B) Cave-halls – are represented by only one hall. In this regard, the typical cave-hall is Gvarjilasklde, Mghvimevi, Cherula, Samertskhleklde II, Sakajekari, which are characterized by small dimensions. Paleolithic dwellings have been found in the important parts of cave-halls and rocky shelters (Fig. 46, 47).

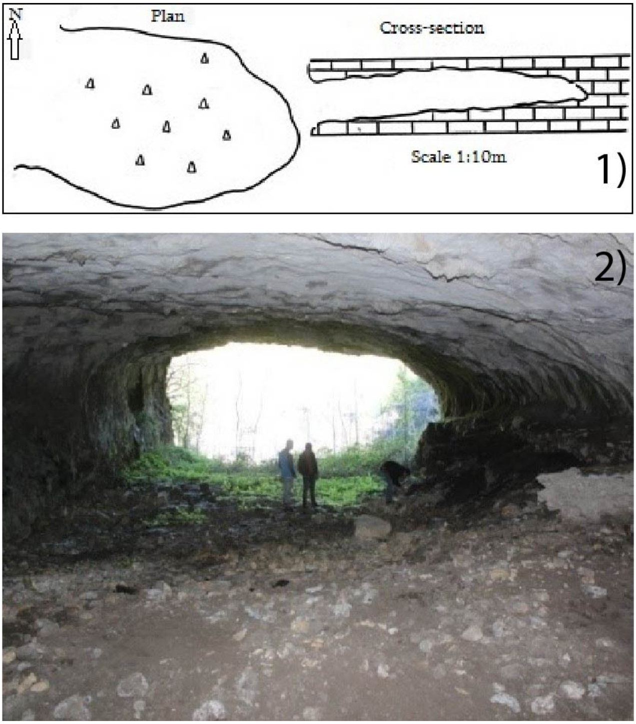

Figure 46. Gvarjilasklde Cave:
1) Plan and cross-section. 2) Cave entrance.

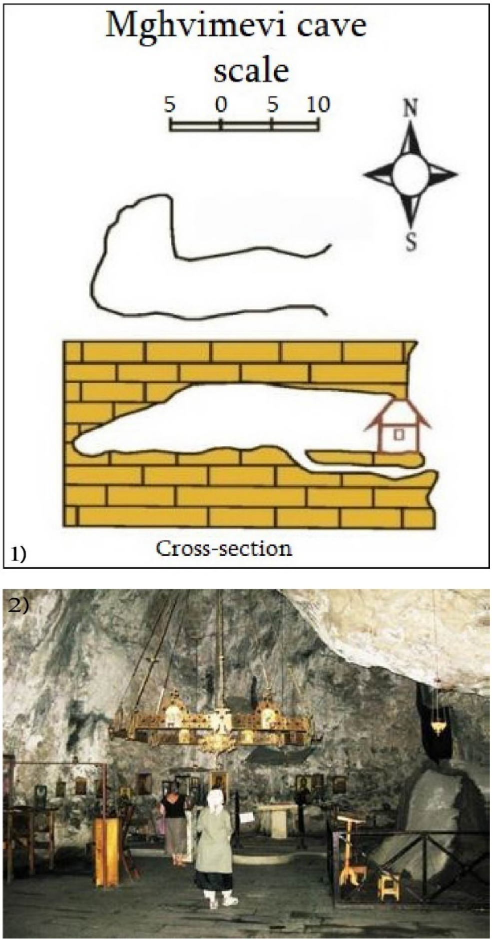

Figure 47. Mghvimevi Cave: 1) Plan and cross-section. 2) Cave hall.

C) Tunnel and corridor-like caves, as the name suggests, are represented in the plan by linear or meandering corridors (tunnels). The only difference between them is in the size of the cross section. These caves are often devoid of branchings, and the length of water or periodic water corridors and tunnels reaches several hundreds of meters (Fig. 48, 49).

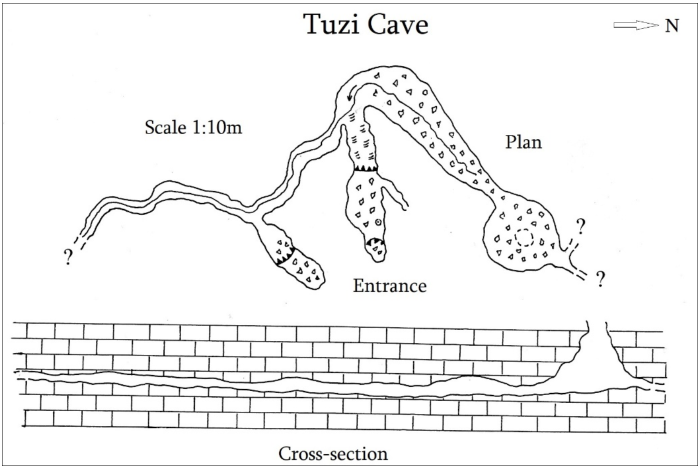

Figure 48. Tuzi Cave (corridor-like caves).

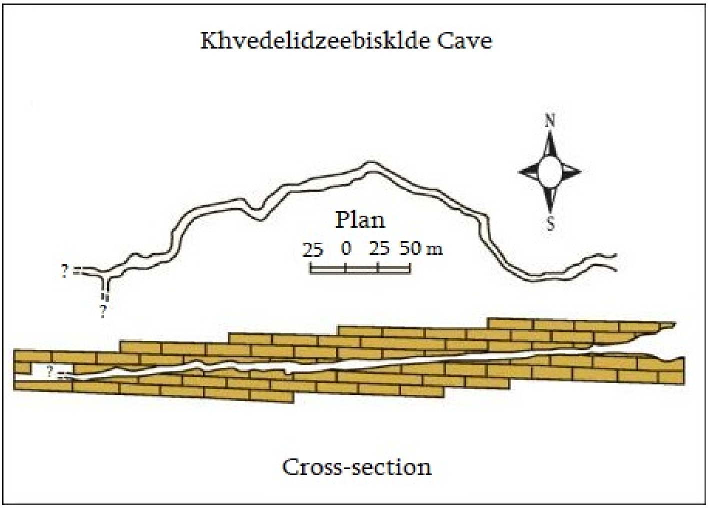

Figure 49. Khvedelidzeebisklde Cave (Tunnel-like cave).

We consider the opinion of Tintilozov (1976) to be quite correct that the main features of this type of cave morphology are determined primarily by the presence of cracks and the degree of openness of the latter, then the debit of water flowing into the cave, errosion ability and solubility.

Tunnel-like caves are characterized by small cross sections and relatively low ceilings. Such caves are often devoid of halls. Unlike tunnel caves, corridor caves are represented by relatively large cross-sections along the entire length. They are characterized by high and wide exits, halls and sometimes branches. In addition to the above, there are caves, where tunnel and corridor sections alternate.

IV. 2. b. Genetic types of cave sediments

The following genetic types of sediments are represented in the caves of the study area: chemogenic, water-mechanical, boulder-piled, organogenic, remnant and anthropogenic.

Chemogenic sediments are represented by significantly deformed, washed, and in some places weathered speleothems, as well as the speleothems in process of growing. Notable among them are stalactites, stalagmites, columns (stalagnates), helictites, carpetings and calcite remnant crust, left on the walls, dam-gours, appeared on plained and sloped surfaces, etc.

The caves of Rganisklde, Bochoklde, Cherula, Samchinkia, Zakariasklde, Data Cave, Dzudzuana, Tsilto and others (Fig. 50, 51, 52) are distinguished by the abundance of speleothems.

Figure 50. Data cave.

Figure 51. Zakariasklde Cave.

Figure 52. Samchinkia Cave.

Rganisklde is an interesting, washed away with excess water and grooved cave; its speleothems (as well as the whole cave) bear clear traces of the combined effects of erosion and corrosion. It is notable that it is difficult to find in Georgia a cave, analogous to the Rganisklde Cave by the rate of the growth of speleothems. Dropping of calcite-saturated droplets is intense here, that is why new deposits are often found on the cut tips of stalactites as a result of impact of temporary floods. The rate of appearing of speleothems is particularly impressive in the last hall, where small stalagmites have been already developed on the fragments of the stalactite that fell from the ceiling. The separate small halls of the Rganisklde Cave and its narrow corridors are richly decorated with calcite speleothems of various shapes, sizes and colors (white, brown, and yellowish). With these forms, the cave is so full that movement in it (moreover without damaging speleothems) requires great smartness and flexibility. The height of the stalagmites and columns, which create the "impassable forest", reaches 1.5-2.0 meters. The beauty of the cave is also the "hanging forest" of helictites, developed in the cozy place of the last hall.

The length of the flat and clustered stalactites in Cherula Cave reaches 1-1.5 m and is characterized by dryness. In the same cave thick deposits of amorphous calcite, or travertine are developed, which rises up like stairs and finally joins the ceiling. The surface of the travertines is complicated by embroidered edgings and small recesses (micro gours), in which water is gathered. There is erected a massive stalagmite of up to 7 meters high. Almost similar picture is presented in the Ormoebi Cave, where the length of the "twin" stalactites above the lake is 1.3 meters, and the height of the cypress-shaped stalagmite in one of the halls reaches 6 meters. The caves of Bochoklde, Tuzi, Satchinkia, Sadatviaklde, Zakariasklde, Data’s and other caves, which are represented by “forests” of stalactites and stalagmites of different colors with serrated speleothems (Sadatviaklde Cave), crystal white “folded up curtains”, candle-like (Tuzi Cave), spaghetti-like (Sadatviaklde Cave) and skittle-like (Tuzi Cave) stalagmites, helictites (Rganisklde, Tuzi and Sadatviaklde caves) and others are distinguished by ability and originality of speleothems. In the Bochoklde Cave, the length of the stalactites descending from the platform, protected from temporary flood, reaches 2-2.5 m in some places, and the height of one of the stalagmites is 6 m, and its circumference - 2.5 m.

Separately should be mentioned calcite dripped dams – gours, presented from aqueous solutions. The deformed squares of the flat gours are systematically affected by the flood streams in a number of areas of the Khalipauri Cave, and thin plastic clay is deposited on them. Shekiladzeebisklde (Guburebi) is a very interesting cave, where the gours are developed on both horizontal and sloped surfaces. Here, the 2.5-meter-wide corridor is divided into about 30 small puddles by dripped dams along 300-400 meters, the depth of the puddles vary within 30-60 cm, and the shape is circular, often elliptical (in the area of embedded in the dams lakes, the fall of the corridor is 7 meters). The width of these lakes is 2-2.5 meters, the length is 3-10 meters, and the distance between the calcite dripped dams is from several meters to about ten meters. The step cascade of relatively closely to each other located miniature gours (diameter 20-40 cm, depth 10-25 cm) is presented in one of the significantly sloped branches, developed in the last section of the cave. More than two dozen miniature lakes were counted here at a distance of 30 meters (the bottom fall on this distance reaches about 8 meters). The stepped cascade of dripped dams is also well represented in the Bochoklde Cave, which is why in the depth the bottom of the cave gradually rises staircase stepwise and takes a person into a fabulous world. The distance between these steps is almost equal (40-50 cm), and the gaps between them (depth 15-25 cm, diameter 40-50 cm) are filled with fresh cold water.

Water-mechanical sediments are formed in the underground rivers and lakes (autochthonous), also enter from the surface (from the outside) through ponors and entrances (allochtonous). Sometimes they are mixed with other sediments. This group includes river (alluvium, gravel, sand, silt) and lacustrine-colmatage (clay-sand fraction) sediments. The coarse cobble alluvion is well represented in the Varsima Cave, which, during floods, is brought through ponors with penetrated water from the surface streams' beds. Aluvium consists of more or less rolled limestone fragments, the dimensions of which mostly range from 5 to 15 cm.Noteworthy is the well-processed (medium-sizes 5-6 cm diameter) alluvium of the paleoriver, traced in the terrigenous sediments' profile, we have made at the entrance of the Rganisklde Cave. Here also are distinguished solitary large inclusions in the form of well-treated 15 cm diameter round stones. River breakstone, sand and silt are more or less intensely presented in the most of the caves in the study area (in almost all caves). lacustrine-colmatage sediments reach particularly significant amounts in the cave of Karianiklde (clay thickness reaches 0.5 m), Sakajekari, Tcherula andOrmoebi caves. In the latter, the clay-sand fraction and silt reach 20-25 cm at the bottom of the lake, which is impounded with ruined material. Intense settlement of lacustrine-colmatage sediments also occurs in descending caves, which experience periodic flooding with water. The narrow holes in such sack-shaped caves (Satsurblia, Menapiradzeebi, Rganisklde) cannot let pass the fallen water quickly, and the clay-sand particles brought by the latter are subject to sedimentation at the bottom.

As it is confirmed by the accomplished researches (Tintilozov, Tvalchrelidze, Lezhava, et al., 1991), in the caves of the study area, autochthonous water-mechanical sediments are relatively widespread and more or less amount of them is found in all caves. Often, autochthonous water-mechanical sediments are presented along with allochtonous (e.g., at the entrance to Dzudzuana Cave, the thickness of autochthonous and allochtonous terrigenous sediments reaches 3.5 m, in Ortvalaklde Cave it reaches 4 m) and in the entrance of Rganisklde Cave only allochtonous water-mechanical sediments of significant thickness (70-160 cm) are developed. we have studied the water-mechanical sediments in more detail in the caves of Rganisklde, Tsilto III and Khvedelidzeebisklde, we will talk about below.

Boulder-piled sediments. A large part of caves in the study area (especially those located at intersections of tectonic faults) have collapsed in the wake of intense ascending tectonic movements. Therefore, today in a significant part of the caves there are the products of the demolition of ceilings and walls, or boulder-piled sediments. Particularly notable in this regard are Samertskhleklde, Taroklde, Namdzvleviklde, some districts of Tsona and several parts of Rganisklde, Ormoebi, Tsintskila, Varsima, Sakajekari, Tsilto III, Patara Sadatviaklde,Cherula and Tuzi.

By approximate calculation the volume of collapsed limestone blocks in the first hall of the Tuzi Cave should exceed 3,000 m^3, and the total volume of the cave collapsed material should be at least 9,000 m^3. The volume of individual boulders in the caves of Samertskhleklde, Varsima, Tsona and Taroklde reaches 8-12 m^3. The collapsed material is mainly old, as evidenced by the thick layers of clay deposited on them (Rganisklde, Shvilobisa, Ormoebi and other caves), the fine-grained erosion crust (Cherula Cave), the flattened surfaces and the strong stalagmites (Pasieti, Rganisklde, Tcherula and other caves); there can be found relatively young collapsed material too. Particularly noteworthy in this regard are the Tuzi and Varsima caves, which have been intensively destroyed throughout their lengths. Here, among the stone-collapsed materials, there are stalactites of significant size, which are cut off from the ceiling, but still well preserved, as well as fallen stalagmites. Separate boulders are stuck in the ceiling in some places. Stone falls continue in these caves today, and thus traveling is dangerous in them.

Organogenic sediments. The caves of the study area contain organogenic layers too – heap of guano and bones of bats. Significant deposits of guano can be found in the caves of Patara Sadatviaklde, Ormoebi, Ghamurebi and Samertskhleklde I. The caves, which were used as dwellings by primitive humans, contain a great amount of animal bones. In this regard, should be noted - Deviskhvreli, Jrutchula, Ortvalaklde, Samertskhleklde, Gvarjilasklde, Mghvimevi, Dzudzuana, etc. Bones of many species of animals have been found in the cultural layers of Deviskhvreli, Jruchula, and other caves (Ljubin, 1989). Notable among them are the bison, the cave bear, the cave tiger, the noble deer, the Eastern Caucasian goat, the wolf, the fox, the rabbit, the beaver, the badger, weasel, the wild boar, the forest cat, the roe deer, the giant deer, the mountain goat/ibex, and so on. In recent years, N. Tushabramishvili (2012) excavated a large number of animal bones and the remnants of the ancient human in the cave of Undosklde.

Remnant sediments. These sediments are formed at the expense of insoluble wastes in limestones. In this regard, in the caves of the study area, the remnant (plastic) clays are notable, a significant mass of which enters through the infiltration waters. Remnant clays in pure form are very rare, and their significant deposits are mainly related to the corrosive caves or separate dry corridors and halls in caves, where the predominant role belongs to corrosion. In this regard, the caves of Jikhuri, Tsilto III, Gvarjilasklde and others are worth to be noted. The mentioned remnant sediments in most of the caves are to some extent mixed with water-mechanical and piled materials.

Anthropogenic sediments. In the study area, the dwellings of primitive human are traced in about two dozen caves. Among them are the Moustier (Jruchula and Ortvalaklde), Upper Paleolithic (Deviskhvreli, Mghvimevi, Samertskhlaklde, Dzudzuana, Gvarjilasklde and Sareki,) and many Epipaleolithic dwellings.

Study of anthropogenic deposits in caves, along with pure archeological, is of great palaeogeographical and biostratigraphic importance. For example, falling out of the final part of Acheulean-Mousterian and Upper Paleolithic layers from the section of anthropogenic deposits of Tsona Cave, (absolute height 2100 m) developed on the Kudaro karst massif, bordering the Zemo Imereti Plateau (the layers of the mentioned age are represented by the 70 cm thick sterile layer) the researchers (Kalandadze, 1962, Ljubin, 1969; Maruashvili, 1959; Tsereteli, 1970) associate completely with a sharp deterioration of climatic conditions (Riss and subsequent Würm Glacial Stages), which has made mountainous caves (Racha Range) unusable for permanent residence. After the sterile layer, the Mesolithic and Eneolithic deposits continue the section, which indicates the fact that people settled here again (this time they live periodically). It is noteworthy that in the caves located in the zone of the structural plateau of Zemo Imereti, which have not been affected by glaciers, there are quite thick, mainly Upper Paleolithic cultural deposits. All this suggests that the primitive human, living in the caves of the above-mentioned Kudaro massif, in the neighborhood, were forced to come down (south) due to the severe cold and find shelter in favorable climatic conditions. For example, the thickness of the Upper Paleolithic deposits in Dzudzuana Cave is 3.5 meters, in Ortvalaklde Cave it is 4 meters, and in Jruchula Cave at a number of places it reaches 6 meters.

The accumulation of such thick cultural strata in the caves of Zemo Imereti should have started in the middle Pleistocene, because by this time a number of caves (e.g., Rganisklde) had already been formed (Tintilozov et al.,1991; Lezhava, 2015;

IV. 2. c. Caves - Unique archaeological monuments

Due to its geographical location, the territory of Georgia is a crossroad between Europe and Asia. The geographical situation (the main range of the Caucasus) protected the Caucasia and, in particular, Georgia from the effects of glaciation. Biogeographical refugiums were created here, where the oldest species of flora and fauna continued to exist longer than in other regions (Lezhava et al. 2016).

The territory of present-day Zemo Imereti platform karst (Chiatura Structural Plateau) also represented the refugium, which has survived from the Upper Pleistocene epoch to the present day. It has been a crossroad inside the territory of Georgia since the ancient Stone Age. The environment, rich with flora and fauna, the abundance of natural shelters (karst caves, hollows, sheds) and the abundance of the sources of raw materials, needed to make arms, have conditioned the fact that this region (ancient Stone Age, including the Middle Ages) is one of the most intensively developed in Eurasia and is outstanding with the density and number of monuments (primary human settlements are traced into about two dozen caves).

In the Lower Paleolithic era, already at least about 0.5-0.4 million years ago, humans lived mainly on the plateaus, near the flint mines (Homo erectus and also anatomically modern humans). The use of caves by primitive humans began about 275,000 years ago (Jruchula Cave, Neanderthals). One of the cave monuments in Georgia– Undo Klde is located in the platform karst region of Zemo Imereti, where the remains of wall art have been found. Here is also a dwelling of one of the latest Neanderthals (Ortvalaklde years 50-36,000) (Tushabramishvili et al. 2015), and the earliest Upper Paleolithic stratum (Homo sapiens) – years of 42,000. This area may have been inhabited by Neanderthals and modern humans; this is one of the most important research subjects of the Old Stone Age. Both (Middle and upper Paleolithic) layers have been found in the Undo Klde, in the caves of Bondi and Ortvalaklde. Remains of the world's oldest flax and yarn (35,000 years) have also been found in Bondi Cave and Dzudzuana Cave.

The presence of all stages of prehistory in the karst caves, developed on the territory of the Zemo Imereti Platform karst, makes possible the restoration of all the first stages of human appearance in Eurasia, development of his settlement, his culture (material and spiritual), which in turn makes possible study of origin of humanity and the main issues of its evolution. Caves and caverns have been human dwellings in almost all chronological stages of prehistory and history. In the Middle Ages, the population lived mainly on the plateaus, and caves and caverns in the canyons of the Kvirila River basin were used for escape shelter or for religious purposes. This is confirmed by the newly discovered and newly established Mghvimevi and other monastic complexes, which date back to the 5th-6th centuries (Chipiani Klde, the caves in the vicinity of the Mgvimevi monastery, etc.), (fig. 53).

Figure 53. Complex of Mgvimevi monatery.

IV. 2. d. Chemical components of stalactite concretions

The study of composition of stalactite concretions gives quite interesting information on the inter-phase redistribution of chemical elements in the process of sedimentation in natural waters, on the chemism of seepage waters into fissures and on the paleogeographical conditions of speleo lithogenesis. From these perspective abundant and diverse stalactite concretions represented in the karst caves of Georgia haven't been studied yet. So far only morphological peculiarities of the origin of the stone filter of stalactites and stalagmites have been studied. stalactite-stalagmite dripstone deposits were studied and in some cases main components of these concretions were identified (Tintilozov, 1976; 1983).

Macro and micro chemical composition of stalactite concretions in the karst caves of the Zemo Imereti Structural Plateau (platform karst) have been studied by us. (Tusi, Shvilobisa, Ormoebi, Dzudzuana and Samerthkhle Klde) (Davitaia et all., 1998). Light white and yellow concretions have been chosen for the analysis. Chemical analysis was performed in the Laboratory of Analytical Chemistry of Ivane Javakhishvili Tbilisi State University under the guidance of Professor Guram Supatashvili. Chemical analysis was carried out by the method of application (Knipovish & Morachevski, 1959); sulphate composition was defined by the turbidometer method (Supatashvili & Takaishvili, 1995), with consideration of calcium concentration background. Aluminum and magnum were identified by the photometric method with application of chromazurol - S and yellow titanium (Knipovish & Morachevski, 1959; Nemodruk et al., 1982). The samples were heated beforehand up to 800°C for identification of spatial chemical composition of stalactites. It was technically simpler than to take a sample from the obtained mass.

Investigation of the micro and macro chemical composition of stalactite concretions in the karst caves of Georgia showed that they contained 98.50-99.23% of basic components (Tables 21, 22). The same situation is observed in other karst caves of the world (Tintilozov, 1976; 1983). The volume share of the mass dissolved in the acid is 0.5-0.7%. Low content of Na_2O and MgO is noteworthy too. We assume that the composition of Na^+ in stalactites is due to heterovalent isomorphism, which is stipulated by closeness of radiuses of Ca^{2+} and Na+ ions (1.04 and 0.98 angstrom, respectively). The shortage of magnum in stalactites can be explained by the soluble ability of its carbonate (L = 4 * 10 $^{-5}$) and a low-quality sedimentation of $CaCO_3$. Aniogenic elements - SO^{-2}_4 and $SiO3^{2-}_3$ are represented in stalactites as admixtures. The low composition of sulphates is quite logical, because anions are more poorly sorbed than carbonates; in addition, ionic radiuses of SO_4 and CO^{2-}_3 are absolutely different (2.30 and 1.85 angstrom). The lack of sulphates in stalactite concretions can be explained by their low concentration in the karst waters of western Georgia (4.0-11.0 mg/1) (Supatashvili et al., 1990). It is assumed that stalactites formed in gypsum rocks and recharged by sulphate waters in some karst caves of Chiatura region (Ormoebi, Dzudzuana, and Samartskhle Klde) will be enriched by SO $^{2-}_4$ ($SO^2_4$1120-1302 mg/1 (Supatashvili et al., 1990).

Table 21. Mean chemical composition of stalactities.

Component	%			Component	% 10^{-3}		
	Min.	Max.	mean		Min.	Max.	mean
CaO	51.39	55.96	55.37	Fe_2O_3	1.1	7.3	2.7
CO_2	42.50	43.91	43.56	Al_2O_3	3	82	18
MgO	0.00	0.16	0.06	CuO	0.0	0.5	0.2
Na_2O	0.00	0.17	0.11	MnO	0.00	0.06	0.02
SiO_2	0.01	0.18	0.09	SO_3	0	70	28

Unlike carbonate rocks, composition of silicium in stalactites is low 33.4% of the total silicium in acids is represented in solution form (extremums: 9.2-53.4%, n = 8).

Table 22. Mean chemical composition of stalactites from different caves.

Cave sample	n	%						%10^{-3}			%
		CO_2	CaO	MgO	Na_2O	SiO_2	SO_3	Fe_2O_3	Al_2O_3	CuO	
Akhali Athos-1	7	43.45	55.14	0.05	0.08	0.16	0.02	4.9	30	0.34	98.94
Akhali Athos-2	6	43.56	55.40	0.04	0.06	0.06	0.03	1.9	19	0.30	99.17
Tuzi-1	4	43.36	55.26	0.07	0.05	0.08	0.02	3.1	13	0.04	98.86
Tuzi-2	3	43.61	55.62	0.08	0.07	0.06	0.02	2.9	9	0.04	99.46
Shvilobisa	2	43.38	55.12	0.03	0.03	0.09	1.9	0.05	7	0.21	98.71

A strange way of formation of stalactite concretions indicates that the only possible way of getting microelements into them is sedimentation or sorption.

In the process of distribution of microelements, preference was given to the absorption process, because the quality of sedimentation along with other factors is proportional to sediment forming velocity. On the basis of stalactite growth rate sedimentation velocity of $CaCO_3$ is very low.

To estimate the role of sorptive process in the formation of microchemical composition of stalactites we studied the influence of different factors on Cu^{2+} sorption raised by stalactites (Table 23).

Table 23. Alteration of chemical composition of stalactities in New Athos cave system along the length.

Section from top, cm	CO_2	CaO	MgO	Na_2O	SiO_2	SO_3	Fe_2O_2	Al_2O_3	CuO
0-5	43,45	55,41	0,10	0,04	0,18	0,02	7,3	15	0,50
5-10	42,50	54,40	0,06	0,04	0,17	0,01	3,6	17	0,44
10-15	43,73	55,64	0,12	0,04	0,13	0,03	4,4	16	0,28
15-22	43,01	54,82	0,06	0,03	0,12	0,02	6,6	24	0,28
0-7	43,40	55,31	0,02		0,14	0,01	7,3	23	0,30
7-12	43,88	55,00	0,02		0,16	0,02	2,5	19	0,25
12-18	43,46	55,39	0,02	0,06	0,08	0,02	1,5	20	0,34

For construction model suspension 200 gr of raised and screened stalactites were added to 50 ml.gr twice distilled water and 20 mkg of Cu^{2+}. Suspension of pH was modified within 8.0-8.3 limits and specified by carbonate system. In model systems the phase balance is reached in 30-45 minutes and 70-83% favorable condition of Cu^{2+} is sorbed in solution. As it was expected sorption share of Cu was considerably depended on the specific surface of absorber. According to the composition of karst waters, HCO_3 can perform the role of natural ligand. It turned out, that the concentration of HCO in the karst waters has no sorptive effect upon copper. Under natural conditions the limiting factor of Cu^{2+} sorption upon stalactites will be its low concentration in recharged springs and limited specific surface of a stalactite (3-5 mkg/1) (Table 24).

Table 24. Alternation of chemical composition of stalactities in longitudinal section (%10^{-3}) 1-outer layer, 2-middle layer, 3-inner layer.

Component	New Athos – 2.3			Tuzi – 1.3			Tuzi – 2.2	
	1	2	3	1	2	3	1	2
Na_2O	50	60	60	50	50	30	80	70
Fe_2O_3	2,0	0,5	0,7	3,6	2,7	1,9	2,9	2,8
Al_2O_3	22	24	15	11	10	8	16	11
CuO	0,43	0,21	0,19	0,04	0,03	0,02	0,04	0,03
SiO_2	82	60	56	66	57	57		
SO_3	26	22	20	20	16	15		

In contrast to deposited carbonate rocks and travertines formed by mineral waters, the formation of stalactites occurs at ultra-low speed in the solution with low concentration of microelements. Thus the concentration of FE $^{3+}$, Al $^{3+}$, Cu $^{2+}$, and Mn2^{+} is 10 times less in them. Hardly absorbed ions (Na^+, $SO^{2-}{}_4$) are exceptions, volume share of which in carbonate rocks, travertines and stalactites is practically the same (Table 1) (Voitkevich et al., 1977).

Thus, the chemical composition of stalactite concretions along their length is stable (Table 3) due to identical composition of the recharged solution on the whole parameter, though, in the longitudinal section of concretions the content of admixture increases from the centre to periphery (Table 4). This happens due to the increase in sedimentation process of stalactite formation or the change of chemical composition of recharged solution. The latter is more probable and acceptable.

IV. 2. e. The results of lithological study of cave terrigenous sediments

General information about the evolution and the age limit of the karst caves of the limestone strip of Georgia can be found in the works of L.M. Maruashvili (1963), A.D. Kolbutov (1961), Sh.I. Kipiani (1974), Z.K. Tintilozov (1959, 1976), etc. However, the issue under discussion is complicated, poorly developed and still controversial.

Paleontological, palynological, and archaeological studies allow us to judge approximately only about the upper age limit of cave development, when the cave is mostly already formed. The cultural layer presented in the cave seems to allow this; though, we should pay attention and take into consideration the period of time that elapses from precipitation of the terrigenous sediments to the complete disappearance of the flow in the cave, after which the cultural layer accumulates. This period covers an important period of the geological epoch and contains an interesting information.

One of the main methods of identification the evolution of karst cavities is the lithological study of the terrigenous (especially allochtonous) sediments presented in these cavitiess, which aims at: 1. identification of the feeding provinces of terrigenous sediments and the ways of transportation of the materials; and 2. explanation of the peculiarities of the sedimentological processes taking place in the cave on the basis of lithological information, taking into account the paleogeographical condition of the region.

In the karst caves there can be found such cozy areas, where the accumulation of terrigenous sediments continues uninterruptedly from their appearance to the present day or in extreme cases, the ancient sediments are preserved. If we separate such areas in the caves and determine the age of the sediments here, then we will be able to approach the upper limit of the age of origin of the cave. The study of terrigenous sediments also allows us to identify the regularity of sediments' accumulation in caves and generally restore the paleogeographical situation.

In connection with this, we have conducted a lithological study in the terrigenous sediments in the karst caves of the Zemo Imereti Structural Plateau, which has not been carried out here before.

For the research we have selected three caves located at hypsometrically different levels: Rganisklde (absolute height above sea level 740 meters, relative height - 80-90 meters), Khvedelidzeebisklde (absolute height above sea level 415 meters, relative height - 3.5 meters) and Tsilto III (absolute height above sea level 620 meters, relative height - 90-100 meters).

During the expedition works, we used various research methods in the above-mentioned caves, including: litho-stratigraphic, chemical, and X-ray structural analysis methods. We made terrigenous setiments' profiles. We deepened all the profiles to the bottom of the cave (to the mother rock), which allowed us to study the entire cycle of sediment accumulation. Lenses, concretions and insertions were distinguished in the layers. We took samples from the walls of the cave (at different levels) to identify the genesis of the deposited clay mixed with breakstone. We evaluated the quality of processing of psephitic inclusions in the terrigenous material by means of Khabakov's 5-point system. Petrographic analyzes of the psephitic material, obtained in the profiles of the above-mentioned sediments, as well as the chemical and X-ray structural analyzes of the aleurolitic-pelitic material were carried out to identify the feeding provinces of terrigenous sediments, presented in the caves (Fig. 54).

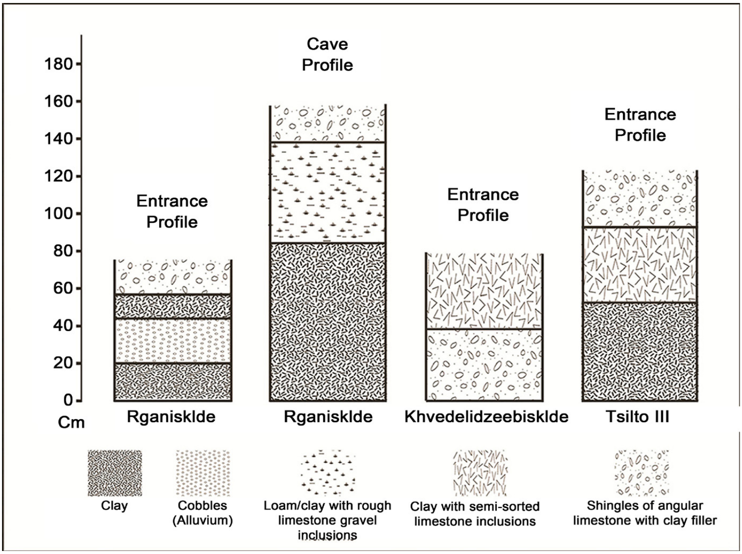

Figure 54. Lithological profiles of sediments from the three studied caves indicating the stratigraphic depths and characteristics of the sediment sequences for Rganisklde, Khvedelidzeebisklde and Tsilto III caves.

In the **Rganisklde Cave** two profiles have been made: at the entrance (Fig. 55) and in 50 meters from the entrance (Fig. 56). At the entrance the profile thickness is 70 cm and it is made of four layers (Fig. 57).

Figure 55. The entrance of the Rganisklde Cave.

The first layer (characterization of the layers is given from bottom to top) is represented by 18 cm thick orange clays and fine-grained 2 cm thick dark orange clay lens. The second layer with the thickness of 25-30 cm, with mostly well-treated (average sizes 5-6 cm in diameter) alluvium. There are also some large (15 cm in diameter) inclusions in the form of well-processed round stones. The filler is represented by clay, which is 10-15% of the whole layer. In the same layer, 2-3 cm thick middle layer of clay with manganese is distinguished. The next layer (the third one) is built of gray clays (thickness 12 cm) with brownish lenses without inclusions. The fourth layer, with dark gray clays, reaches thickness of 25 cm. Unprocessed limestone gravel inclusions as well as coal inclusions are also found.

In the Rganistskali Cave, in the profile excavated 50 meters from the entrance, sediments are represented by three layers of 160 cm thickness: the first layer (thickness 80 cm) is built of khaki fine grain clays without inclusions. Four specimens were taken here: one at the base of the layer, the second - 40 cm from the base, the third - 80 cm from the base (in the contact line), and the fourth from the pocket (60 cm from the base). The second layer is brownish and consists of a clastic, angular limestone breakstone with no visible traces of processing. It is a weakly weathered material and comprises 80-85% of the whole layer. Clays play the role of fillers. The third layer is represented by 25 cm dark brown clay and small inclusions of weathered breakstone. Small concretions of manganese are found.

In the front part of the **Khvedelidzeebisklde Cave** one profile of 84 cm depth was made, where two layers are distinguished: the first - is represented by brownish-gray clays and weakly treated limestone gravel inclusions (4-5% of the whole layer), and the second layer includes blackish clays (coloring is conditioned by manganese), weakly treated limestone gravel (10% of the whole layer) and small-scale (1-1.5 mm) manganese concretion inclusions (Fig. 56).

Figure 56. The Khvedelidzeebisklde Cave.

At the entrance of the **Tsilto III Cave** one profile was made. Its Thickness is 130 cm. There are distinguished three layers. We took one sample from the characteristic point of each layer. The first layer is represented by 52 cm thick brownish (brick color) clays, where the black-colored manganese middle layer is clearly distinguished. The second layer (40 cm) is mainly built of grayish clays. There are concretions of manganese and inclusions of clay lenses, as well as limestone gravel. The latter bears little trace of processing and is 5-6% of the entire layer. The third layer is represented by 38 cm thick dark gray clays and angular limestone gravel insertions. Limestone gravel comprises 10% of the entire layer. Coal inclusions are also distinguished here, so supposedly it is a cultural layer (Fig. 57).

Figure 57. One of the entrances of the Tsilto III Cave.

Chemical analysis of cave terrigenous sediments confirms that the chemical composition of sediments in the caves, studied by us, is almost the same. Exceptions are: 1) high percentage of MnO in Khvedelidzeebisklde Cave in the samples 11 and 12, which is caused by the washing down of manganese in the cave; 2) the percentage increase of P_2O_5 in Rganisklde Cave deposits in the 7th and 4th samples seems to be due to the presence of organic waste; 3) the low percentage of CaO in the 3rd, 6th (Rganisklde), 11th and 12th (Khvedelidzeebisklde) samples is caused by the withdrawal of these latter by running water during their sedimentation period (Table 25).

Table 25. Chemical analysis of aleuro-pelitic material.

Cave name	Tsilto III		Khvedelidze-ebisklde		Rganisklde (Section in 50 m from the Entrance)						Rganisklde (profile in the Entrance)			
Layer sample №	14	13	12	11	10	9	8	7	6	5	4	3	2	1
SiO_2	44.56	39.92	39.51	54.14	37.07	41.68	39.71	-	36.57	-	30.17	61.00	48.15	56.81
Al_20_3	9.66	7.83	8.51	11.42	12.58	10.90	15.91	-	30.08	-	5.97	14.50	10.29	13.03
Fe_20_3	5.32	14.35	3.82	6.05	3.95	3.97	4.30	-	3.95	-	1.93	2.49	2.47	4.34
$Ti0_2$	0.49	0.38	0.74	0.57	0.46	0.37	0.35	-	0.77	-	0.18	0.56	0.30	0.51
Mn0	0.90	0.57	26.71	8.93	0.34	0.40	0.19	-	0.09	-	0.21	0.04	0.30	0.06
P_20_5	0.22	0.28	0.25	0.18	14.24	0.10	0.16	-	0.15	-	7.88	0-17	0.45	0.22
$S0_3$	0.04	0.05	0.15	0.40	0.11	0.05	0.08	-	0.03	-	0.07	0.03	0.06	0.04
Ca0	17.99	17.90	2.99	2.23	9.26	19.16	15.43	-	1.35	-	20.58	4.95	18.98	7.31
Mg0	1.67	1.47	1.79	1.36	1.36	1.35	1.03	-	0.45	-	2.44	1.30	1.31	1.01
K_20	2.46	2.03	2.25	2.07	2.92	2.73	2.06	-	2.11	-	2.37	4.43	3.43	5.08
Na_20	0.70	0.74	0.15	0.88	0.55	0.89	0.37	-	0.35	-	0.37	0.41	0.58	0.75
Loss by heating	14.07	12.52	9.10	7.24	10.96	15.76	16.26	-	10.40	-	23.86	7.48	12.58	8.78
Fe0	0	0	0	0	0	0	0	-	0	-	0	0	0	0
Moisture	1.91	1.96	4.04	4.52	6.20	2.64	4.14	-	13.68	-	3.98	2.64	1.10	2.06
$C0_2$	0	0	0	0	0	0	0	-	0	-	0	0	0	0

Rentgenostructural/XD analysis of cave sediments reveals that their mineral composition does not differ significantly from each other. The only exception is the mineral illite, which is found in all layers of the Rganisklde Cave. It is a product of the decomposition of volcanogenic rocks (Table 26).

Table 26. XD analysis of terrigenous sediments.

Cave name	Sample №	Mineralogical composition
Rganisklde	1	Quartz, Feldspar, Illite, Montmorillonite
	2	Quartz, Calcite, Illite, Montmorillonite
	3	Quartz, Feldspar, Carbonate, Montmorillonite
	4	Calcite, Quartz, Illite, Montmorillonite
	5	Vermiculite type clay, Montmorillonite
	6	Expanding Hydromica, Illite, Montmorillonite
	7	Very fine grained clay
	8	Calcite, Quartz, Illite,
	9	Calcite, Quartz, Illite, Montmorillonite
	10	Quartz, Illite, Montmorillonite, Calcite
Khvedelidzee bisklde	11	Fine-grained rocks, Quartz, Feldspar, Calcite, Montmorillonite
	12	Very fine-grained substance
Tsilto III	13	Quartz, Calcite
	14	Quartz, Calcite, Feldspar, Hydromica
	15	Quartz, Calcite,Montmorillonite

Almost all layers of cave sediments are deposited in either running or standing water, as evidenced by the sharp separation of the layers from each other by both - color and granulometric composition. The boundaries of the strata in the stagnant water are almost horizontal and rectilinear, and those of deposited in the running water, are nonrectilinear.

From the palaeogeographical point of view the Rganisklde Cave is the most important in the study area. We suggest that by taking into consideration the geological and geomorphological location of the region, as well as the hypsometric location of the stratified primitive (Mousterian) human dwelling cave-Ortvalaklde (590 m absolute and 35 m relative height) can be reconstructed Rganisklde Cave palaeogeographical picture (Fig. 58).

Figure 58. Ortvalaklde Cave (Tushabramishvili et al., 2015).

It appears that at the end of the Middle Pleistocene and the beginning of the Upper Pleistocene, a paleoriver overflowed the top of the Rganisklde Cave, as evidenced by the leveled terraced stair that is located 100-110 meters higher than the Rganisghele riverbed and 25-30 meters higher than the cave. From the terraced surface of this paleoriver, through karst ponors and fissures, the river alluvium got in the cave. This assumption is confirmed by the petrographic composition of the round stones in the Rganisklde Cave (quartz-porphyry, andesitic porphyry, quartzitic albitophire, quartzitic sandstone), which is brought by the river from the Racha Range (porphyritic suite of Jurassic age). At this time, the plateau seems to have held relatively low hypsometric levels and represented the accumulation district of alluvial sediments,brought from the surrounding orographic units (Dzirula-Chkherimela and Likhi ranges, the Greater Caucasus and the Lesser Caucasus).

Such palaeomorphological conditions are also substantiated by well-rolled round stones of crystalline rocks traced on the plateau's wavy and plain watersheds (Maruashvili, 1958). The karst of the southern slope of the Racha Range and the limestone strip of Ertso-Tsona (accordingly the caves too) are significantly older than the karst of the Zemo Imereti Plateau, which is clearly reflected on the modern relief. For example, as a result of strong and long-lasting denudation, on the southern slope of the Racha Range, on the porphyritic suite (Bajocian Age), the younger sediments almost are not preserved, and in the surroundings of Ertso-Tsona the remnant limestone relief is developed.

The fact of water loss directly from the riverbed (we are talking about the river Rganisghele riverbed) still occurs today (Lezhava et al., 1989, 1990). It should be noted that the terrace surfaces are poorly expressed on the Chiatura Structural Plateau, while the alluvium of the paleoriver has not been traced in the caves so far. The alluvium of the paleoriver, we traced in the Rganisklde Cave, carries important information for determining of the evolution of caves or the paleogeographical situation.

Based on the obtained materials, it can be assumed that by the action of infiltration flows terrigenous material of a significant thickness was accumulated in the Rganisklde Cave. Later, when the paleo river was deeply cut and the entrance to the cave was liberated, this material was brought out. The total unloading of terrigenous material of the cave did not take place. Only the lower part of it (only in some sections of the cave) is preserved. This should be due to the strong compaction of sediments, which was facilitated by the high carbonate content of the round stone filler and the morphological conditions of the cave.

At the following stages of the cave development, there was an active action of periodic flows, which in its turn was reflected in the cyclicity of sediment accumulation. The cyclical nature of the subterranean sediments is confirmed by the fragments of limestone gravel mixed with clay on the walls of the cave (at different levels, sometimes near the ceiling), as well as new deposits on the fractures of stalactites. The genesis of the latter can be explained by two circumstances: a) the breakage of the lower parts of the stalactites may occur with relatively rapid passage of periodic turbid currents; or b) if stalactites have long been immersed in clay and sand-gravel sediments, then it is possible to assume their decomposition by chemical processes. Studies show that after removing (washing) the subterranean sediments from the cave, the appearance of dripstones activated. Indeed, some stalactites appear to have several stages of growth, which in our opinion is an indicator of the cyclicity of these phenomena.

From the palaeogeographic point of view, Dzudzuana Cave also provides interesting material in which the cultural layers start directly from the bottom of the cave (Meshveliani et al., 1990).

This is conditioned by the fact that after the river had cut down deeper its bed, the entrance of the cave was completely unloaded and even settled by a primitive human (in the Upper Paleolithic). As mentioned above, the complete unloading of the Rganisklde Cave did not result in complete undloading from terrigenous sediments. Based on the analysis of lithological research of terrigenous sediments and the peculiarities of cave morphology, it should be assumed that the cave was formed at an earlier geological stage than the terrigenous sediments' age we have obtained. Intense deposition of these sediments began after the paleo river connected to the cave with karst holes, with a sharp decrease in the flow rate of the cave. In the beginning, it seems that the clay fraction was deposited, then a larger fraction was formed as a result of the expansion of the holes.

It should be noted that the study of anthropogenic sediments in caves along with pure archaeological ones, is of paleogeographical and biostratigraphic importance. For example, from the **Tsona Cave** (absolute height 2100 m), located near the Kudaro Massif (southern slope of the Greater Caucasus), near the Zemo Imereti Structural Plateau, are missing the final part of the Acheulian-Mousterian and the Upper Paleolithic layers (layers of this age are represented by a sterile layer of 70 cm thickness). The researchers Kalandadze (1969), Lyubin, (1969, 1989), Maruashvili (1959) and Tsereteli (1970) attribute this fact to the sharp deterioration of climatic conditions (Riss and subsequent Würm glaciation) in consequence of which the highland caves (of Kudaro Massif and Racha Range) have become useless for permanent residence. After the sterile layer, the Mesolithic and Eneolithic deposits continue the profile, indicating the fact that people settled here again (this time already live periodically).

It should be noted that in the caves located in the low and foothill line of Zemo Imereti, which have not been affected by glaciers, are represented quite thick, mainly exactly Upper Paleolithic cultural sediments. All of this suggests that primitive humans were forced to come down from the middle and high mountain limestone massifs (south) due to the extreme cold and find refuge in favorable climatic conditions. For example, thickness of the Upper Paleolithic sediments in Dzudzuana Cave is 3.5 meters, in Ortvalaklde Cave it is 4 meters, and in Jruchula Cave in some places it reaches 6 meters.

Thus, the existing archeological data and lithostratigraphic analysis of cave sediments allow us to prove that the formation of caves on the Zemo Imereti Plateau was mainly at the end of the Middle Pleistocene and the beginning of the Upper Pleistocene, and on the southern slope of the Racha Range and the lower Ertso-Tsona area (southern slope of the Caucasus) – in the Lower Pleistocene.

Based on the complex study of the sediments of karst caves, it seems that in the near future, climatogenic layers of autochtonous cave sediments, cult caves and other monuments will be revealed also on the Zemo Imereti Structural Plateau, the study of which will precise matters of dispute of the anthropogenic paleogeography,which once were highlighted on the example of Tsutskhvati caves (Maruashvili, 1978).

IV. 2. f. Conditions of the origin of karst caves

Peculiarity of the relief of the Zemo Imereti Structural Plateau, in particular, dense and deep (100-300 m) segmentation, sharp separation of plateaus, their height distribution (400-800 m), plainy surfaces (6-12^0), as well as climatic conditions, positive annual runoff balance and the hydrological regime together with the structural-tectonic conditions of the karstified rocks, building the substrate, creates very favorable conditions for development of karst caves.

The structural-tectonic conditions of the karstifed rocks, the substrate is built of, play a special role in the origin and development of the karst caves of the Zemo Imereti Structural Plateau. Unlike the geosynclinal karst zone of Georgia, the formation of this region took place in the platform conditions. The existence of a solid platform conditioned the relatively simple tectonic structure of the Zemo Imereti Plateau. Namely, the quiet sub-horizontal layout of the Cretaceous and Tertiary formations (total thickness - 500-550 m) located on the Hercynian platform and the predominant development of the cracks of layering, which contributed to the formation of hydrodynamic zones and the wide development of sub-horizontal caves (85% of caves are sub-horizontal).

The study area is located in the vertical uplifting zone. The modern geomorphological cycle (origin and development of erosive, karst and other forms) began after the Miocene on the Zemo Imereti Plateau and its surrounding regions (Maruashvili, 1958, 1971). Post-Miocene tectogenesis was strong in the Caucasus folded zone, and activity on the Zemo Imereti platform was mainly manifested in vertical (epirogenetic) uplifting, which was accompanied by small disruptions of local significance and wavy foldings.

Aplifting, started in the post-Miocene period in the study area, still continues. Neotectonic movements obviously played an important role in the evolution of the region's erosion divisions and karst formation processes, as well as in the evolution of vertical hydrodynamic zones of fissure-karst waters. Following the ascending tectonic movements, the rivers developed deep canyon-like gorges (tectonic faults played an important role in the origin of canyon-like gorges and determining of the direction of the rivers), by this creating favorable conditions for deep circulation of waters. Wide spreading of disjunctive dislocations on the Zemo Imereti Plateau has led to the formation of independent streams, the common base of which is the Kvirila River. In addition, at the present stage, the ducts of separate karst caves and vaucluse springs, formed at the early stages, have been unified into Ghrudo hydrogeological system, as evidenced also by our indicator experiments (Lezhava et al., 2015, 2017a). It is still inaccessible today, though the development of karst voids in its basins has intense character.

The ascending tectonic movements did not seem to be going on continuously, and their period was replaced by the delay epochs, as indicates the storey-like distribution of caves in the gorges of the rivers of Kvirila, Jruchula and others (Fig. 59).

Figure 59. a) Sameleklde and Taroklde Caves; b) Jruchula Cave.

At the same time, the delay epochs seem to have been short, to this point the wide spreading of the tunnel (or hole) type undeveloped caves and the weakly (at the same time, fragmented) terraced steps in the river gorges. Based on the analysis of the actual material, the predominant distribution of sub-horizontal caves in the stratiform limestones on the Zemo Imereti Structural Plateau should be explained by the wide distribution of horizontally layered cracks along the strata. Opening of the mentioned cracks is connected with the discharge of internal strain caused by washing away of the suites, located above the limestones and deep erosive segmentation of the massif. Along with the horizontal cracks of layering it should be also noted a wide distribution of intrasuites vertical cracks (especially in the suites close to the surface), karstification of which leads to the development of small-height steps in the caves.

Thus, the quiet layout of the suites on the Zemo Imereti Structural Plateau determines the long-term impact of water on the rocks along the layering cracks and development of sub-horizontal caves; and the vertical cracks in the layers contribute to the development of branches from the main cavities, and also to penetration of water into the horizontal cracks in the layers below. This should be the reason for such wide distrbution of the step-like and multi-storey caves on the Zemo Imereti Structural Plateau.

IV. 2. g. Some issues of evolution of karst caves

The genesis of karst cavities remains a topic of discussion to this day. One group of researchers give an advantage to the genesis of caves only in the phreatic zone (Grund 1903, Davis 1930, etc.), the other - in the vadose one (Katzer 1909, Martel, etc.), and most of them believe that cave genesis begins during the phreatic regime of waters and ends in the vadose one (Korbell, Maruashvili, Gvozdetsky, Maksimovich, etc.).

The reference to the leading process (agent) in the cave genesis is also discussed. One group of researchers considers pressure or free erosion as a leading agent, the other group - corrosion (nival, mixed, condensing, etc.), and the third group considers the combined impact of corrosion and erosion on karst rocks, but it should be noted that it is still under discussion, which of them is leading.

The actual material we have accumulated over the years on the Zemo Imereti Plateau, in particular, the morphological analysis of underground cavities, the study of their hydrogeological features and research of connections with surface karst forms, indicator experiments, borehole data, and so on, allows us to conclude that the genesis of underground karst forms is closely related to tectonic fissuring and comes along together on the surface and in the depth of the karst massif. At the same time, more favorable conditions for the cave genesis are created with the formation of concentrated streams, which is mostly characteristic of the phreatic regime. Such a regime can be established below the main drainage levels and above these levels too (Lezhava et al., 2019).

At the contemporary stage of development, as mentioned above, cave genesis occures simultaneously in the zones of depth circulation, seasonal fluctuations and aeration of complete saturation levels. Therefore, underground karst forms of relief develop by corrosive, erosive (pressure or free erosion), and gravitational influence in different hydrodynamic zones.

Based on the materials obtained by us, it can be noted that some caves of the study area are in the fissured, hollow or canal stages of the phreatic epoch of development, as evidenced by the borehole data (Kuchuchidze et al., 1986; Mamulia and Gambashidze, 1964) and existence of underground karst streams under the beds of contemporary rivers (Lezhava, 2015; Lezhava et al., 2015). In the vadose epoch of cave formation, as it is known, cracks and karst cavities are freed from constant pressurized waters and undergo the influence of infiltration-area infiltration-condensation streams. Hydrogeologically, it corresponds to the zone of active water exchange or aeration.

From the vadose epoch on the study area there are well expressed the vaucluse, fissured-corridor, stream-corridor and periodically stream-corridor stages. The vaucluse stage, by which starts the vadose epoch of cave development, is a time of substantial change in the life of the cave. It begins with the opening of the cave, i. e. in its lower end opens a free exit, which leads a cave stream to the surface of the earth, in the environment of normal atmospheric pressure. The flow of the subterranean stream increases dramatically, causing the erosion to intensify, collapsing, and the longitudinal profile of the cave tends toward the equilibrium curve. At this stage, individual areas of karst cavities are characterized by phenomena of complicated water discharge, especially during heavy atmospheric precipitations, when water levels rise significantly in karst cavities. The vadose stage is well expressed in the basins of the ducts of Ghrudo, Monasteri, lezhubani, Tiri, Kldekari, Bondi, and other vaucluse streams before reaching the surface.

The beginning of the stream-corridor stage is connected with the weakening of the intense mechanical erosion in the cave, which may be due to the development of a balance profile or a sharp decrease in flow in the cave. Cave corridors and halls mainly are already developed at this stage. Most of the cavities are filled with air, development of speleothems is intense, destruction continues. The latter can lead to emergence of an impounded lake and accumulation of clay (e.g., the caves of Karianiklde and Ormoebi). In the second half of the stage, alluvial and other materials accumulate. The caves Bochoklde, Shvilobisa, Patara Sadatviaklde, Khvedelidzeebisklde, Shekiladzeebisklde, Varsima, Kudurebisklde, Ekvtimesklde, Data, Dzudzuana, Nikrisa and others are in the stream-corridor stage.

Periodically stream-corridor phase begins with the disappearance of a constant flow in the cave. During this stage, there is a periodic action of temporary (connected with rain and snowmelt) floods. At this stage is a significant part of the caves of the study area - Taroklde, Samertskhleklde, Bnelaklde, Jikhura, Sachinkia, Piraghiaklde, a part of Rganisklde and others. The vadose epoch is replaced by the dry epoch, which is represented by a single dry-corridor (orhollow-corridor) stage. It starts after the complete disappearance of water streams in the cave. Erosion ceases in the cave, and the corrosion is mainly caused by the chemical action of water on the walls as a result of the condensation of steam in the warm air entering from the outside. There starts the accumulation of gravitational, remnant, anthropogenic and zoogenic material, which eventually leads to the filling-transformation of the cave. Development of the speleothems ceases. Examples of the caves at the dry-corridor stage are Jruchula, Sameleklde, Samgleklde, Gvarjilasklde, the front part of Rganisklde, Tsilto III, Ortvalaklde, Ghvitori, Kozmani, Deviskhvreli, Mghvimevi, Bogirisklde, and etc. (Fig. 60).

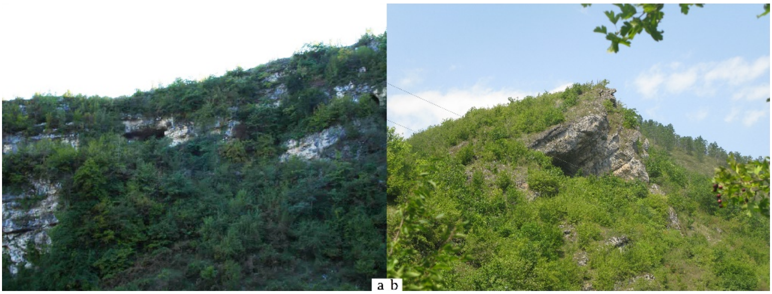

Figure 60. a) Jruchula Cave. b) Sameleklde Cave.

It is noteworthy that the abovementioned individual stages of a cave development last for tens and hundreds of thousands of years. For example, according to the palaeozoological and archeological documents, the dry-corridor stage in the Tsona Cave, adjacent to the study area, began 100-300 thousand years ago (Lower Paleolithic, Acheulean-Mousterian ages), and in the Zemo Imereti platform karst region - 40,000 years ago (Lyubin, 1969, 1989; Tushabramishvili et al., 1990). The sequence of these stages, or the disruption of the normal process of cave development can be caused by tectonic movements, destruction of individual parts of the cave, human intervention, and other reasons. Intense ascending tectonic movements and short time delay epochs, highlighted by a number of researchers (Maruashvili, 1958; Tintilozov, 1959, 1963), mainly led to the storey-like location of caves at different stages of evolution on the Zemo Imereti Structural Plateau. E. g., - Sameleklde and Jruchula, developed in the River Jruchula gorge, are at the dry-corridor stage, while Taroklde and Samertskhleklde are at the periodically stream-corridor stage. Located at a lower level, Khvedelidzeebisklde is at a stream-corridor stage, still invisible floor, located below it (the latter outflows in the form of pressurized water in the Jruchula riverbed) is at the vaucluse stage. Comparison of the absolute heights of cave entrances and karst springs' outlets (Fig. 61), as well as the relative heights of cave tiers and terraced steps developed in the individual river gorges (Table 27) allows us to assume that there should be at least 4-5 epochs of delay of ascending tectonic movements.

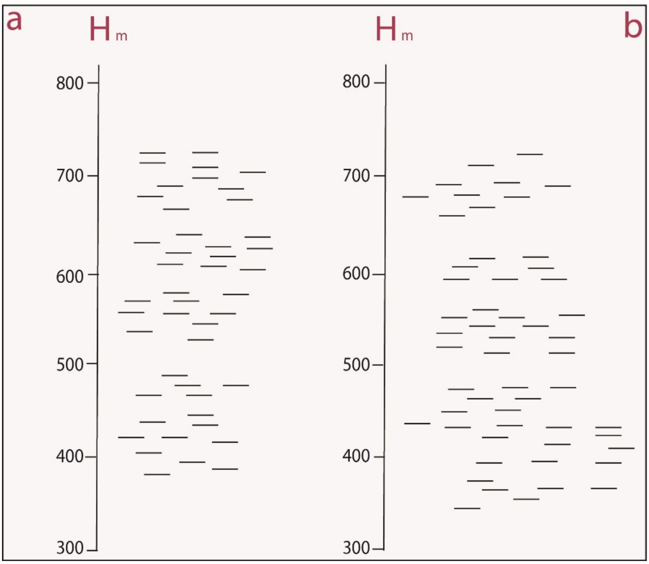

Figure 61. The scale of the distribution of the altitudinal steps of the entrances of the horizontal caves (a) and karst springs' outlets (b) on the Chiatura Structural Plateau.

Table 27. Terrace steps and horizontal caves altitudinal spread on the Zemo Imereti Plateau.

Comparative height of terrase steps, m				Comparative height of caves, m						
				River gorges						
Chiatura (Kuchukhidze, 1986)	Sachkhere surroundings (Devdariani, 1964)	Sachkhere-Chiatura section (according to the field researches)		Kvirila	Jruchula	Nekrisa	Rganis Ghele	Tabagrebis Ghele	Bogiristskali	Sadzalekhevi
5-10	2-4	4-7	I	Ghrudo-6 Parduli-5	Khvedeli-dzeebis-klde-4	Bregva-dzeebis-klde-7	Lezhub-ani-4 (vaucluse)	-	Bogiris-klde-5	-
20-25	8-12	15-20	II	Pasieti-12	Samerts-khleklde-14 Sareki-15	Dzudzu-ana-14 Nekrisa-18	Gvarjilask lde-15	Sakajekari -18 Nam-dzlevi-klde-20	Bogiris-klde-14	-
40-45	20-22	30-40	III	Mghvi-mevi-35	Jruchula-35 Samgle-klde-38 Samerts-khleklde (II)-32	Hollow on the opposite side of Dzudzuan a-33	Bnelaklde-30 Hollows on the opposite side of Bnelaklde-30-40 Or-tvalaklde-35-40	Judisa-30-35 Gela-33	Zekha-30-35	Jikhura-33 Sadatvia-klde-37
50-60	40-50	50-60	IV	Chipiani-klde-50	Taroklde-63	-	Hollows-50-60	-	Bochoklde-50	-
80-85	-	-	V	Ormoebi-75	Sameleklde -75-80	-	Rganis-klde-80-85	-	-	Sachin-kia-85 Nakhiz-nebi-82 Sadzro-khia-75

In the same cave, different sections of the cave may be at different stages of development at the same time. An example of this is Shvilobisa, where there are simultaneously stream-corridor and periodically stream- corridor stages. Also, the anterior section of the Rganisklde is at the dry-corridor, and in the depth - periodically stream-corridor stages.

The normal process of cave development can be disrupted by human agricultural activities as well. For example, we ourselves were direct eye-witnesses of filling of the Baratashvili mine and the manganese ore of the Pirana Abyss with the waste of dead rocks, when we worked in the field. Some of the caves (e.g., Kvatia) that were previously recorded and described can no longer be traced, as, we suggest, they were also filled with the dead rocks of manganese.

Thus, considering the study of karst cavities, as well as the hydrogeological situation, it can be noted that subsequent to the ascending tectonic movements (with small length delays) and relief fragmentation on the Zemo Imereti Structural Plateau, rapid displacement of karst waters to the hypsometrically lower levels took place. All of this has led to a halt of cave development at various stages, and the deeper displaced waters now flow out to daylight in the form of large vaucluse springs, or flow down below the base level and fill in the individual cracks. Through these cracks, as evidenced by indicator experiments and data from existing boreholes, happens not only the absorption of waters, but also the movement of their significant mass, and sometimes their discharge in the form of pressurized ascending waters into riverbeds.

At the present stage, separate karst caves, shafts, wells and vaucluse springs' ducts, formed at the early stages, have been merged into Ghrudo's integral karst aquiferous system (Lezhava, 2015). The lower, phreatic horizons of this system are currently inaccessible to humans.

Thus, it can be said that part of the karst cavities of the study area took their origin in the phreatic epoch, although traces of the action of pressurized streams of this epoch have been almost completely erased under the influence of vadose waters and other processes (erosion, collapses, speleothem formation, etc.). Exceptions are some cycled caves, located at high hypsometric levels (Tsilto III, Rganisklde, Samgleklde, Sakajekari, etc.), where signs of phreatism (tilt of the bottom of corridors in the depth, doors developed on the ceiling, smooth arches, important thickness of plastic clays, etc.) are well preserved. No less important is the action of free streams in the origination, development and transformation of the caves in the study area, which is indicated by the presence of the material of allochtonous origin in the terrigenous sediments of karst cavities we have studied (Lezhava, 2015; Asanidze, et al., 2017a), well expressed cut micromeanders (Shvilobisa, Chiatura 100) and so on.

CHAPTER V.

KARST MORPHOLOGICAL-GENETIC TYPES

Based on the classification of N. Gvozdetsky (1952, 1965, 1972, 1981), Z. Tintilozov and Sh. Kipiani (1981), the following morphological-genetic types of karst can be distinguished in the study area: covered, meadowland and semimeadowland, bare, and buried karst.

The Zemo Imereti Structural Plateau is a typical area of covered karst distribution. Here, over the important area of the territory, the Upper Cretaceous limestones are covered with Oligocene-Miocene clay-sand sediments of different thickness (from 5-10 m to 200 m). There, where the thickness of these Tertiary sediments is not big, dry ravines, suction, sometimes collapsible type sinkholes, caves and wells develop intensively. In this regard, the plateaus, developed on the right side of the Kvirila River, are especially distinguished. In the southern part of the Zemo Imereti Plateau, in particular, the Chkherimela River gorge, Cretaceous limestones are covered mainly with clayey-sandy deposits and deluvium brought by surface streams, which does not substantially prevent the infiltration of water into karst rocks. Here are mainly developed suction, rarely collapsible type sinkholes, dry ravines and small size horizontal caves.

Meadowland and semimeadowland karst occupy important areas on the Zemo Imereti Plateau. Here, on the edges of individual plateaus and on the slopes of the river gorges, limestones are often covered with soil-meadowland cover, where the predominant species are shrubs and herbaceous plants (Fig. 62). Various karst forms are associated with this type of karst:

sinkholes, dry ravines, caves, corries and open cracks. Cracks developed in the limestones are often covered with a small-thickness soil-meadowland cover.

Figure 62. Meadowland and semimeadowland karst.

Bare karst has limited distribution in the study area and mainly includes natural denudations of limestone, as well as the slopes of canyon-like gorges. Corries, cellular surfaces of various shapes, niches, wells, and caves are associated with this type of karst. Here, most of the caves are opened on the slopes of the gorges built of limestones.

Buried karst is significantly distributed on the Zemo Imereti Structural Plateau, although it has not been studied sufficiently yet. Analysis of the geological history of the area (Geology of Georgia, Vol. X.1964) testifies that during the geosynclinal and orogenic stages of development, continental delays occurred repeatedly, during which intensive washaway took place and, of course, karst forms were formed on the limestone surface. It is therefore not unreasonable that with these delays was associated the widespread development of karst surface and underground forms.

The buried karst forms on the Zemo Imereti Plateau were first noticed by Sh. Kipiani (1959). The mentioned researcher has described the sinkoles with corroded surfaces, which are filled with Oligocene sandstones and manganese ore. Such sinkholes are originated by the influence of chemical weathering. In addition to the sinkholes, here are found karst wells and corrie-like surfaces. There can be found many similar forms on other plateaus of Chiatura region.

Sh. Kipiani notes about the relatively old age buried karst forms in the vicinity of the village of Salieti, where in the Middle Liassic colored (red) limestones many sinkholess and cavities were traced. Karst forms of the same age are represented in the surroundings of Sakasrula-Bzhinevi and Shrosha, in the Dzirula Gorge, near the so called Trinity Bridge, etc. Intense karsication of Liassic limestones in the geological past is also indicated by the inclusions of unprocessed cobbles and boulders of Liassic red limestones in the porphyritic suites of Bajocian (Rakviashvili, 1985).

The formation of buried karst forms in the Zemo Imereti Plateau still intensively continues under the influence of technogenic factor, which is why many surface or underground karst forms are buried (this process is still going on) under the waste rocks, left after the extraction of manganese. Thus, along with the ancient (Jurassic-Cretaceous) and old (Paleocene-Eocene) age karst forms, buried in the study area, the young buried forms are also widely developed.

CHAPTER VI.

HISTORY OF KARST RELIEF DEVELOPMENT

The Zemo Imereti Structural Plateau has undergone a long and difficult period of geological development (frequent shifts of continental and maritime regimes), which is well reflected in modern relief. It is very important to note the fact that the relief developed in strip of the south slope of the neighboring Racha Range in geosyncline, and in the area of the basin of the Dzirula massif (Zemo Imereti Plateau) – in platform conditions. In the latter two genetically different relief groups are distinguished. In the Upper Cretaceous and Oligocene-Miocene sediments' distribution zone, buried peneplain (the denuded surface of the crystal massif lies at a depth of several hundred meters) is represented (Maruashvili, 1958). It extends from the both sides of the Kvirila River gorge from Sachkhere to the village of Jokoeti (approximately coincides with the Chiatura Meso-Cenozoic sedimentary basin) and is a classically expressed structural plateau (platform karst) and denudated part of the Dzirula massif, the Likhi Range, and the Dzirula-Chkherimela watershed are characterized by astructural morphology, and belong to stripped peneplain type.

The above-mentioned structural plateau underwent significant uplift at the end of the Tertiary and Quarternary periods, although the amplitude of the uplifts lags behind that of the stripped peneplain distribution districts, and both - the southern slope of the Racha Range. The development of the karst relief took place against the background of the geological development of the study area and the development and formation of the relief in general. Therefore, we will briefly dwell also on these issues in this chapter.

To clarify the geological history of the region, we used the works of V. Bogachev (1929), K. Markov (1931), P. Gamkrelidze (1964, 1969, 1975), I. Kuznetsov (1937), Al. Janelidze (1940 a and b), I. Kakhadze (1941, 1948), S. Chikhelidze (1948), O. Shiriashvili and Vashakidze (1972), Sh. Geguchadze (1973), G. Kuchukhidze (1986), etc.

The history of the development of the Pre-Jurassic period is still insufficiently studied not only for the study area, but also for the whole Georgia. One is the fact that a large part of the Zemo Imereti Plateau (Dzirula massif) was a land till the Middle Liassic Age and was undergoing washing away, and the southern slope of the neighboring Racha Range - submersion. The revival of volcanism takes place in the Liassic or Lower Liassic Age, resulting in sedimentation of tuffites with sandstone and clay lenses, indicating the continental nature of these layers.

The transgression of the sea begins in the Middle Lias and continues to Aalenian. The intruded sea does not completely cover the massif and there remain local land areas, from where the washing away continues. At this time, sediments of the coastal strip are deposited on the denudative-abrasive surface of the Dzirula crystalline massif. Gradually, the sea expands and deepens, resulting in sedimentation of colored limestones of several meters thick in the Middle Lias, which are well represented in the surroundings of Katskhi, Salieti, Shrosha, etc.

At the end of the Upper Lias, tectonic movements, which took place in Aalenian, cause the uplift of a significant part of the massif and turning into land, and in the following century - its washing away. It is probable that at this time karstification of the Middle Liassic red limestones should have started.

In Bajosian, a significant part of the massif still sinks and sea transgresses. At this time, submarine volcanism is occurring on the southern slope of the Racha Range and on the Dzirula Massif, as a result of which a thick (1.5-3 km in the Racha Range and up to 1 km on the Dzirula Massif) porphyritic suite is formed. A small part of the massif still remains land and its washing away continues.

A powerful mountain forming phase is manifested in Bathonian, which has led to the cessation of volcanism and increase of volume of the Georgian Block. As a result of these movements, all the main aspects of the structure of the study area were formed, such as faults and cover-type fold deformations. From this period, as a result of folding, the Zemo Imereti Plateau has completely turned into land and remains so until the Cretaceous period, and in some places even before the beginning of the Upper Cretaceous. The folds of the mountainous systems of the Greater Caucasus and the Lesser Caucasus, which were leaned against the crystalline massif from the north and south, overthrusts the latter. As a result of the Jurassic orophases, the southern slope line of the Racha Range (including the Ertso-Tsona area) was so consolidated that it would hardly respond to the subsequent mountain forming movements with elastic deformation and tension discharge took place mainly in the form of faults. Since this time, the geological development of the southern slope of the Racha Range and the Zemo Imereti Plateau are closely related.

Sea transgression took place again in the Lower Neocomian, but this time it occupied only a part of the Dzirula Massif, as evidenced by the presence of quartz cobblestones in all sections of the Cretaceous in the surroundings of Sachkhere. At this time the sea was invading from the north and west. Sea transgression reached the south-western and southern peripheral parts of the massif only in the Upper Hauterivian. In Albian Stage under the influence of Austrian orogenic phase, the sea is regressed. In this regard, island-like areas appear.

Thus, after the Bathonian mountain forming phase, the crystalline massif of Dzirula underwent an uplift and turned into a land. After the uplift, a new denudation cycle began, due to which the destructive processes during the Upper Jurassic and partly Lower Cretaceous periods (up to the Barem century) smoothed a significant part of the Zemo Imereti Plateau. At the same time, it should be noted that the Zemo Imereti Plateau after Bathonian orophase would have been inclined towards the Racha Range (north) and the rivers formed on its surface would have been flowed to the north - in the direction of this topographic surface inclination. This fact is confirmed by the topographic map of the upper tectonic (Mesozoic-Cenozoic) bedding of the Chiatura Structural Plateau, we have compiled based on the boreholes and geological profiles, where it is well seen that the total sloping of the surface of the Cretaceous limestone bedding is directed from south-west to north-east.

As a result of the ongoing denudative processes after the Bathonian orophase, the sedimentary (Jurassic) cover has been completely removed in some areas of the massif, which is proved by the fact that in many places the Cretaceous rocks lie directly on the crystalline massif. The structural integrity of the Middle Jurassic folds was also markedly impaired, as there was significant washing away in the Jurassic anticline strip. It is clear that at this time the carbonate rocks, in particular, the Middle Liassic red limestones, must have been karstified, as indicated by the sinkholes in the limestones of the mentioned age in the villages of

Katskhi, Salieti, Shrosha and other areas found by Sh. Kipiani. The unprocessed breakstone and boulders of the red limestones inserted in the Bajocian porphyritic suite in the vicinity of the village of Bzhinevi, as well as the karstified surfaces – corries and sinkholes, traced in the vicinity of the village of Rgani, which are filled with Upper Cretaceous sediments. Therefore, Sh. Kipiani correctly points to the the Jurassic-Cretaceous age karst on the Zemo Imereti Plateau, which, in our opinion, requires additional research.

During the Upper Cretaceous, two transgressions were observed: the Cenomanian Sea was intruded from the west, which is indicated by a gradual increase of the Cenomanian transgression in South Okriba from west to east. The Cenomanian transgression in the Lower Turonian was followed by a regression, caused by a weak orogenic phase, which in the Upper Turonian was changed again by a transgression and continued within the massif to the end of the Upper Cretaceous. At this time, the limestone is sedimented, in which today are developed karst phenomena. In the northern part of the Zemo Imereti Structural Plateau, in the surroundings of Katskhi-Salieti, Rgani, etc., the layers of the Upper Cretaceous limestones in some places directly are deposited on the Middle Liassic colored limestones and lead to the burial of the karst of the Jurassic-Cretaceous age, about which we have mentioned above.

In the Danian, the Dzirula Massif underwent uplifting and turned into a land. Its important part until Oligocene remained land. In the Eocene, on the geosynclinal basin of the southern slope of the Greater Caucasus, there are ascending movements that were changed into descending movements in the Middle Eocene. The latter caused a sea transgression only in the northern peripheral part of the Dzirula Massif. Achara-Trialeti geosyncline, located in the southern part of the region, also subsided in the Middle Eocene. At the end of the Middle Eocene, the tectogenesis phase was revealed in both geosynclines and led to the dislocation of sediments accumulated in them. In the Upper Eocene, the northern peripheral part of the Dzirula Massif and the Achara-Trialeti Geosyncline have subsided and the sea has transgressed, and at the end of the Upper Eocene, the land is still rising and expanding.

Therefore, after the sedimentation of the Upper Cretaceous limestones in the Paleogene before the sedimentation of the manganese layers, a significant part of the Zemo Imereti Plateau is a land and is intensively washed away. It is clear that during this time these limestones are being karstified and karst forms appear. As a result of the transgression of the Middle Oligocene, this karstified surface of the Upper Cretaceous limestones is covered firstly with conglomerates or sandstones, and then with layers of manganese ore. The layers of manganese ore in some places (Shukruti, Rgani, Perevisa plateaus) directly cover the karstified surfaces of the Upper Cretaceous limestones. Thus, in the study area, we have a karst of the Lower Tertiary (Paleocene-Eocene) age too.

The Middle Oligocene sea transgression continues also in the Miocene and reaches its maximum development in the Lower Sarmatian century. The Sarmatian Sea invaded Zemo Imereti from the Racha Syncline and from the west, from the Chiatura side. The coastal nature of the sediments confirms that this transgression covered a significant part of the massif. The Chiatura Sedimentation Basin has emerged. Along with the mentioned basin, there was a land in the south-eastern part of the massif, which included the lower strips of modern Likhi and Dzirula-Chkherimela (Maruashvili, 1958). There was also a land on the southern slope of the Racha Range and in the area of Ertso-Tsona.

The latter entered the subareal phase before the Miocene – before the Styrian orophase (Kakhadze, 1948).

Therefore, in the Upper Miocene, sedimentation occurred simultaneously in the vicinity of Chiatura (structural plateau) and washing away – in its surrounding mountains (including also the Racha Range line), which is confirmed by the presence of crystalline rolled material in the structural plateau sediments.

Post-Miocene tectogenesis was strong in the Caucasus folded zone, and the activity of the platform massif was mainly manifested in vertical (epirogenetic) uplifting, which was accompanied by small faults of local significance and wavy foldings. Under the influence of ascending movements, the sea finally leaves the Zemo Imereti Plateau and the surrounding areas and enters the stage of subaeral development. As the beginning of this last tectonic act L. Maruashvili (1958) considers the Attic or Pre-Cimmerian mountain forming phase. During the same period, the last manifestation of magmatic activity would have occured, resulting in formation of Goradziri, Perevisa and other lacolith-extrusions. With this period is also associated formation of central types of structures (volcanic apparatus, isometric-shaped intrusions), we have identified by structural decoding of aerial imagery (Lezhava, 2015, Lezhava, et al., 2019b).

Post-Sarmatian foldings changed the peculiarity of the terrain of the Zemo Imereti Plateau and the surrounding areas as well as the distribution of the hydrographic network. At this time there is a strong uplifting of the Racha Range, which is why it turned out to be hypsometrically higher than the Zemo Imereti Plateau. It is clear that these circumstances have led to the emergence of new directions in the hydrographic network approaching modern conditions. Due to the inclination of the primary topographic surface on the southern slope of the newly uplifted Racha Range, the rivers were located meridionally. By simultaneously selective erosion they also took shape latitudinally. Direction of the rivers on the Chiatura Structural Plateau itself does not coincide with the primary inclination of the surface. After the final release from the sea, the sloping of the mentioned plateau surface was southwestern. The rivers also flowed in this direction. When they developed quite deep gorges, arch uplift took place, which led to the tilt of the Chiatura Structural Plateau to the northwest (Maruashvili, 1958). This uplifting does not seem to have brought about significant changes in the layout of the existing hydrographic network and they have continued to flow in previously elaborated channels.

Therefore, origination of hydrographic network within the structural plateau began at the end of the Sarmatian century, and much earlier in the Racha and Likhi Ranges line. In this regard, for the Zemo Imereti Structural Plateau as L. Maruashvili (1958) notes, the modern geomorphological cycle began at the boundary between the Lower Pliocene and Middle Pliocene (appearance and development of erosive, karst, and other forms continued during the Middle Pliocene, Upper Pliocene, and Quaternary), and to the southeast of the massif, in the outcropping areas of krystalline rocks and in the line of the southern slope of the Racha Range – in Lower Pliocene or maybe even earlier. This difference is clearly imprinted on modern relief too. For example, as a result of strong and long-lasting denudation on the southern slope of the Racha Range, on the Porphyritic suite (Bajocian), younger sediments almost have not been remained while in the south-eastern part of the massif and in the Likhi Range strip, as we have already noted, the Dzirula crystalline massif itself is outcropped.

The initial phase of the modern geomorphological cycle, within the structural plateau, was manifested by a weak incision of the hydrographic network. Plain relief takes on a slight hilly appearance. At that time, the structural plateau seemed to occupy low hypsommeric levels and was an area of alluvial sediments, brought from the surrounding orographic units (Dzirula-Chkherimela and Likhi ranges, the Greater Caucasus and Lesser Caucasus ranges). Such palaeomorphological conditions are substantiated by well-rolled round stones of crystalline rocks traced on wavy and plain watersheds (Maruashvili, 1958). This is also confirmed by the well-rolled round stones we have traced in the sediments profile at the entrance of Rganisklde Cave, which is brought from the Racha Range (Lezhava, 2015).

During the mentioned period, the rivers still did not reach the limestone within the structural plateau and there is no karstification there. Here, the depth of erosive section does not exceed a few tens of meters. In the uplifted old peneplain areas, the depth of erosive dissection at this time varies between 400-600 meters (modern dissection is 700-900 meters). In the Racha Range strip, in particular, in the area of Khreiti, Satsalike and Ertso-Tsona, which was earlier liberated from the sea, a significant deepening of hydrographical network was accompanied by an energetic course of karst processes. Therefore, the karst of the limestone belt of the Racha Range is significantly older than that of Zemo Imereti. This is confirmed also by the results of lithological research of terrigenous sediments conducted by us in the karst caves of the structural plateau of Zemo Imereti (Lezhava, 2015; Asanidze et al., 2017a, b). On the structural plateau of Zemo Imereti, after the network of gorges was cut into the limestone suites, and the Tertiary rocks, located on it, were washed away or thinned, favorable conditions for karstification were created.

In this regard, the second phase of the modern geomorphological cycle, which was related to the Upper Pliocene orogenic phase and which caused the uplifting of the plateau and depth erosion, associated with it, proved to be very fruitful for the Zemo Imereti Structural Plateau.

Intensive fluvial downcutting was accompanied by the revived action of underground waters and the processing of karst cavities. The hydrographic network, having reached down to the Upper Cretaceous limestone (which was karstified partially still in the Tertiary), began to leak into it. Terefore, some of the rivers dried up, the valleys stopped erosion development, and dead valleys were formed. At the same time, the Kvirila River and its main tributaries continued intensive erosion at great depths, resulting in elaboration of deep canyon-like gorges. These dead gorges (former rivergorges) are now distributed at different heights from the base of Kvirila River and its main tributaries. The results of the operation of such a former hydrographic network can be found in a great number on both sides of the Kvirila River on the Salieti-Sachkhere section. Along the ducts of the former hydrographic network (hanging dead gorges), intensive karstification was further carried out and sink holes appeared, which are so characteristic of the structural plateau of Zemo Imereti. Along with the cutting of rivers, the rocks that were less resistant to the protective surface-denudation agents of limestones (Oligocene-Myocene sand-clay deposits), were washed away. The reduction in the thickness of the sediments, located on the limestones, and their good water permeability have led to the wide development of suction karst sinkholes, which transfer surface water to a depth.

Intense ascending tectonic movements and short-term delay epochs conditioned storey-like layout of the caves, located on the structural plateau of Zemo Imereti, wide distribution of tunnel (or hole)-type undeveloped caves and also weakly expressed terrace-like steps (Lezhava et al., 2019a). The Kvirila River and its tributaries intense and uninterrupted downcutting created favorable conditions for the circulation of underground waters. In the produced cavities started to flow the underground streams of reduced mass. After the displacement of hydrographic network to depth, many caves stayed without water, and in some places, where an important mass could move to depth along the crack, the underground waters produced caves on the lower steps. In some cases, they even reached the level of the main river. As our indicator experiments have identified, the different conditions for the development of caves in the study area have determined the formation of independent streams of water, the common base of which is the Kvirila River. In addition, at the present stage, separate karst caves, shafts, wells and vaucluse springs' ducts, formed at early stages, have been unified into a single Ghrudo karst aquiferous system, which is still inaccessible to humans and in the limits of which continues development of karst cavities (Lezhava, 2015, Lezhava et al., 2015).

At the last stage of the modern geomorphological cycle (in the Holocene), temporary streams are a very important factor that is actively involved in creation and expansion of underground cavities. At present, as a result of human economic activities, the soil-vegetation cover of the study area has been completely or partially destroyed, and in connection with the extraction of manganese within the Chiatura Structural Plateau there is also the destruction of sheet cover, the genesis of cracks (as a result of collapse of mining arches and quarry explosions) and so on. All of this reinforces the rapid infiltration of atmospheric precipitations into limestones and activates karstification, and sometimes causes severe turbidity and pollution of karst springs.

CHAPTER VII.

PRACTICAL IMPORTANCE OF STUDYING KARST CAVES AND UNDERGROUND WATERS

Karst objects are unique recreational resources and can bring significant profit to the state in the case of reasonable treatment. The study area is no exception in this regard.

The practical use of karst has many facets. One of them is to equip the karst caves with amenities and put them in the service of tourism. It should be noted that in this regard many caves of the Zemo Imereti Structural Plateau (Karianiklde, Kotiasklde, Bochoklde, Mghvimevi, Rganisklde, Cherula, Ormoebi, Tuzi, etc.) have quite a solid potential (fig. 63).

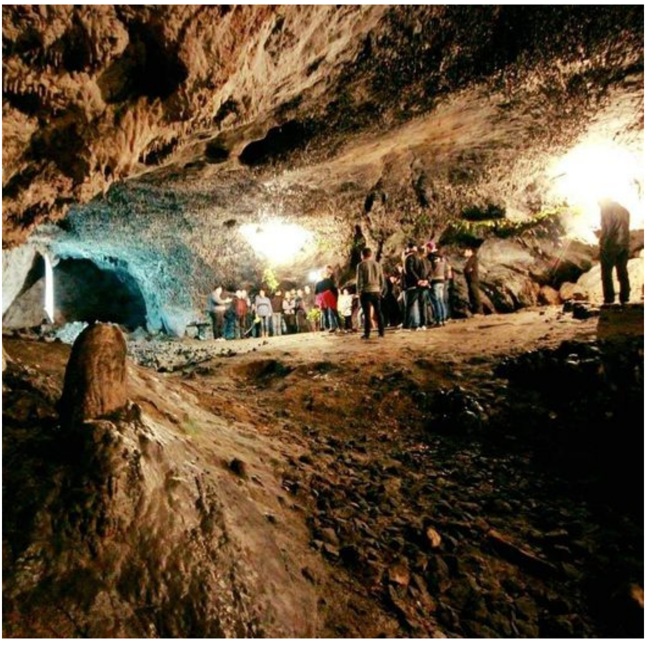

Figure 63. Kotiasklde Cave.

It is true that these caves are not comparable in to such well-known cave systems in Georgia as Akhalli Athoni, Prometheus, Abrskili, etc., but the abundance and originality of their speleothems give a wide perspective to the development of speleotourism.

In case of development of the mentioned spots, another interesting attraction will be added to the existing scheme of the tourist routes of Georgia - locked in the beautiful canyon of the Kvirila River a town of Chiatura with its network of cable ways, world-class deposits of manganese ore, natural and historical monuments, vaucluse springs and karst caves. The underground cavities of the region can also be used for educational-cognitive purposes. Getting acquainted with them will be of great help to students in studying the nature and history of their homeland. It is therefore advisable to include these objects in the school excursions and tourist hiking routes.

Recently, a number of countries around the world have been paying close attention to the cultivation of high-calorie, edible mushrooms-champignons in caves, the growth and development of which does not require daylight and additional heat. For their growth 12-15^{0}C air temperatures and 80-95% relative humidity is enough, which is characteristic of the most of caves.

For the first time in Georgia, mushroom greenhouses were created in the study area. About 3-4 kilograms of mushrooms were grown on manganese mining worked-out sites at the Kalinin district № 5 of the "Chiaturmanganganumi" Mining Plant in the 1980s. Today, this small-scale auxiliary farm is no longer in operation. In recent years, a mushroom greenhouse has been set up by local private entrepreneurs in the cave of Sakajekari (Sakachkari) (Chiatura municipality, right slope of the River Tabagrebisghele). Here was yielded an abundant harvest of mushrooms at minimal cost throughout the year. Due to the unfavorable conditions and lack of funds, the production of mushrooms in Sakachkari Cave is temporarily suspended. It is possible to arrange such greenhouses in many caves of Zemo Imereti, which will employ the population, provide income and will also contribute to the regional budget. In some of the caves studied by us (Taroklde, Samertskhleklde, Samgleklde, Kotiasklde, etc.) there are the best morphographic-morphometric and microclimatic conditions for the arrangement of "champignariums". The air temperature in these caves is quite high even during the winter (12-15^{0}C), which guarantees a fairly good harvest throughout the year under artificial lighting (only at night time).

Low and stable temperatures (+ 7^0- +12^0 C) karst springs, which are characterized by good transparency and purity, are successfully used for pond-trout farming. In such a farm, we can get 500 centners of trout per hectare during one vegetation period (Gigineishvili, 1979). Small areas of land are sufficient for trout farming, and various food products and residues of meat producion can be used to feed the fish.

Some karst springs of the study area can be used for pond-trout farming. For example, the Bondi cold (10.8^{0}C) and pure vaucluse springs, flowing out in the gorge of the Tsilto River, and the alternation of the narrow and wide sections of the gorge itself, create ideal conditions for the arrangement of a pond-trout farm here. Pond-trout farming can also be arranged at the base of Cherula (water temperature 9^{0}C), Tskhrapira (water temperature 8^{0}C) and other karst springs.

Currently, a mushroom greenhouse has been arranged in the Sakachkari (Sakajekari) Cave by local private entrepreneurs, which is successfully functioning and developing. Also, on the base of the karst stream coming out of the mentioned cave, a pond-trout farm is arranged (fig. 64).

Figure 64. 1) Sakachkari Cave.

2) Pond-trout farm arranged on the karst stream coming out of the Cave.
3) Mushroom greenhouse in the Cave.

The karst strams of infiltration origin are of great importance for the water supply of some settlements in the study area. For example, karst waters have a dominant position in the water supply of the population of the city of Chiatura and the surrounding villages. Out of the total discharge of the water pipe-line network, involved in the water supply, 800 l/sec. belongs to karst springs.

The Chiatura water supply system includes karst springs with such significant debit as: Monasteri, Lezhubani, Sakondria, Kldekari, Tiri, Chikauri and others. The villages located on the plateaus receive water with the help of water pumps from Katskhura, Eterzetebi, Cherula, Satave, Chkhakvi and other springs, which flow out abundantly in the gorges of the rivers of Katskhura, Rganisghele, Bogiristskali and Sadzalekhevi at different heights above river level. In the future, we consider it promising to use a number of sources, which are characterized by low temperatures, large debit and less fluctuations according to the seasons (chemistry has been studied) for the city of Chiatura and surrounding regions. Notable among them are: Tskhrili, Lezhubani II, Katskhura II and V, Tskhrapira, Karianiklde, Kvabisi, Tskhratskaro and other springs, the total debit of which exceeds 1 m^3. The promising areas for drinking water are represented in the gorges of the rivers of Katskhura, Rganisghele and Jruchula, where there are expected to be extensive groundwater basins with difficult water exchange (Lezhava, 2015).

Use of the large-scale potential of the karst of the Zemo Imereti Structural Plateau is an important resource for tourism-recreational and other economical purposes for the development perspective of this region. We consider the continuation of karst research in this regard in the future to be very important.

CONCLUSIONS

1. The materials presented in the monographic work enrich and expand the existing data and views about distribution of karst and karst phenomena of the only platform karst region of Georgia – Zemo Imereti Structural Plateau, their regional peculiarities, development conditions, age of karst forms, etc. This allows us to make a number of new conclusions of scientific-theoretical and practical significance.

2. The distribution area of the Zemo Imereti platform karst is a structural plateau morphogenetically, known as the Zemo (Upper) Imereti (Chiatura) Structural Plateau (500-900 m absolute heights). It is divided into many parts by the Kvirila River and its tributaries' (Jruchula, Nekrisa, Bogiristskali, Rganisghele, Katskhura, Buja, Sadzalekhevi, etc.) quite deep (100-300 m) canyon-like gorges. The gorges of these rivers separate from one another steep-slope plateaus with a flat surface, among which the noteworthy are as follows: Sareki, Darkvet-Zodi, Mghvimevi, Bunikauri, Tabagrebi, Rgani, Perevisa, Shukruti, Pasieti, Itkhvisi, Sveri, Merevi and other plateaus. A dense relief water absorbing network is developed on the surface of the plateaus, while the caves on the slopes are represented as floors. The platform structure played an important role in the origin and development of the surface and underground karst forms and underground karst flows.

3. The boundary of the Zemo Imereti platform karst is formed by the surface contact line of the Cretaceous limestones with older formations (Bajocian porphyritic suites – in the north and east, and Middle Paleozoic granitoids – in the south and west), which is the geological substrate of the karst. The presence of a solid Hercynian platform with a peneplainized surface in the study area conditioned the character of layout of Meso-Cenosoic formations on it (quiet, almost horizontal or slightly sloped layout of layers), represented by Valanginian-Hotrivian, Barremian and Turonian-Danian limestones, Tertiary clays and sandstones.The sedimentation of these deposits took place in platform conditions and therefore their total thickness does not exceed 500-550 m. The Upper Cretaceous thick-layer and massive limestones are relatively widespread and have significant thickness (250-320 m), which conditions morphological features of the surface and underground forms embedded in these series. The massiveness or layering of karstified rocks has a significant impact on the morphology of karst corries, sinkholes and cavities.

4. An important role on the tectonics of Zemo Imereti (Chiatura) Structural Plateau (platform karst region) played the condition that its base is a washed-away and consolidated part of the Block of Georgia (Hercynian plain), which strongly resisted the mountain-forming processes in the Tertiary period. It was this condition that stipulated the simple tectonic structure of the plateau, namely the quiet, almost horizontal, or slightly sloped layout of the Cretaceous and Tertiary layers. Nevertheless, the Meso-Cenozoic suites that build the substrate appear to have undergone the plicative and especially disjunctive dislocations. Intense tangential movements in the neighboring geosynclinal zones have caused geodynamic tension on the Zemo Imereti Platform. These movements are reflected on the Meso-Cenozoic sedimented cover, which is located on a solid foundation – by formation of faults, overthrusts, cracks, wavy folds, etc. Block-fault disorders, along with the intensive deep fragmentation, play an essential role in the karsto- and speleogenesis of the study area, determining their morphological features, hydrological-hydrogeological peculiarities of underground streams, and controlling their absorption hearths and their movement routes.

The existence of tectonic faults was also confirmed by the decoding of our aerial imagery conducted by us. For example, of particular interest are the intersection areas of the submeridian and sublateral faults, with which the groundwater outlets are associated, as well as the intensification of karst formation in general. The most important underground and surface karst forms, we have researched, are mostly related to tectonic fault lines.

5. The platform karst of Zemo Imereti, which is presented as a structural plateau, is distinguished by favorable morphographic-morphometric conditions. Dense and deep division of the integral plateau, sharp separation of individual plateaus, their altitudinal distribution (400-900 m) and flat surface (6^0-12^0 inclination), along with the structural-tectonic conditions of the karstified rocks, of which is built the substrate, also create quite favorable conditions for karst development.

6. The study area is provided with abundant atmospheric precipitations almost all year round. Most of the winter precipitations come in the form of rain. The annual runoff balance is positive everywhere, which is quite sufficient for the active course of karst processes throughout the year, especially during the cold period of the year.

7. Most karst springs belong to the descending type. There are ascending (pressure) springs that flow out mainly at the levels of riverbeds. The formation of the latter is related to the local lithological and tectonic conditions, as well as hydrogeological features. The springs, connected to the aeration zone, flow out from the river bed at different heights. Their debits mainly fluctuate up to 0.1 - 10 l/sec. Significant magnitude sources are associated with seasonal fluctuations in levels and full saturation zones.

8. The human influence on the course and intensity of karst processes in Georgia, and on the anthropogenization of the relief in general, is nowhere more well expressed than on the structural plateau of Zemo Imereti (Chiatura). Here, in the manganese ore region, the coefficient of anthropogenic impact on nature has long exceeded the permissible norms. The irrational, one can say, destructive exploitation of manganese and other natural resources has led to a sharp expansion of karst areas involved in agricultural activities, activation of karst phenomena, and consequently, negative phenomena related to karst. As the laboratory study (more than 200 samples were examined) confirmed, the mineralization of karst waters in the manganese region is 1.5 - 3 times higher than similar indicators in other karst regions of Georgia. At the same time, the content of manganese and boron in the karst waters increased. Some streams also contain hydrogen sulfide. Many springs and aquifers have dried up. Turbidity-pollution of sources became more frequent. Severe ecological situation was created in the karst spring basins used for drinking in the city of Chiatura and the surrounding villages.

9. Groundwater tracing experiments were conducted to determine the feeding basins, traffic routes and discharge centers of underground karst flows, which, together with scientific, had a great practical importance. Its aim was to solve or predict in Chiatura and its environs a number of water supply problems, related to the complicated geo-ecological situation. Analysis of cartographic materials and boreholes data, we have used as the basis for compiling the general scheme of the hydrogeological situation of the Structural Plateau (platform karst) (two hydrogeological basins were identified), which was practically confirmed by indicator experiments.At the same time, it was found that the directions of movement of underground karst flows from the periphery to the center within the structural plateau (platform karst), are determined by intermittent dislocations together with the total subsidence of karst rocks.

In consequence of indicator experiments, the contamination centers of a number of sources (e.g., Ghrudo, Monastery, Tiri, Kldekari, etc.) were identified. The feeding basins of the Ghrudo and other springs have been significantly specified. As evidenced, these springs are fed from the plateaus located between the Katskhura River and Sachkhere, as well as the groundwater flows formed in the bosom of the plateaus, located on the left bank of the Kvirila River and the water leaking from the beds of the rivers of Kvirila, Jruchula, Rganisghele and others. Within these boundaries, an integral karst-hydrogeological system (with sufficient dynamic water resources) seems to be formed, which is mainly discharged in Ghrudo and in the springs, flowing out in its surrounding strip. This fact has a great practical significance - from any karstified place of the territory within the mentioned borders, it is possible for the polluted water to get in the water supply system of Chiatura and nearby villages. Along with the integral karst-hydrological system of Ghrudo, the Zemo Imereti platform karst is characterized by isolated fissured-karst water systems with very different hypsometric location and orientation.

Under the Rganistskali riverbed a large hitherto unknown water basin with difficult water exchange was revealed. It is not excluded that we are dealing with a promising area for receiving of drinking water here.

10. The properties of the substrate-building formations of the study area, as well as geomorphological conditions and tectonic features, determine the existence-distribution and movement character of the hydrodynamic zones of karst waters. Evolution of karst cavities of Zemo Imereti platform karst is closely related to fissured - karst waters of the hydrodynamic zones (aeration, seasonal fluctuation of levels, full saturation, circulation in depth).

11. Due to the strong impact of human economic activity and the karst denudation rates on the Zemo Imereti Structural Plateau (surface denudation 64.2 - 190.6; underground denudation 1.5-117 m^3/km^2 per year) exceed the similar rates of the karst massifs of Apkhazeti and Askhi.

12. The total number of karst cavities recorded and studied by us within the study area exceeded 110, of which up to 40 were first detected by us. Their total length is 17, 000 m, depth - 580 m, bottom area – 51, 846 m^2, and the total volume of cavities – 232, 285 m^3. The studied cavities are mainly developed in thick-layer and massive Upper Cretaceous limestones (90% of the total number). From 95 horizontal and sloped caves - 20 are less than 20 m long, 34 - from 20 to 100 m long, 33- from 100 to 500 m, 7 - from 500 m - up to 1000 m, and 2 - over 1000 m long. Other karst cavities represented here include 8 wells, 6 shafts and 1 abyss.

Such a wide spread of sub-horizontal, stepped and multi-storey caves is conditioned by the platform geotectonic situation, in particular, by the sub-horizontal layout of limestones on the steep massif, the widest distribution of layering cracks and to some extent delayed upward movements in comparison with the southern slope of the Caucasus.

13. Based on the existing classification schemes, in the karst caves of the study area the following genetic types of sediments were identified: chemogenic, water-mechanical, boulder-piled, organogenic, remnant and anthropogenic.

14. Based on lithostratigraphic (granulometric, mineralogical, petrographic, X-ray structural) analysis of terrigenous sediments of karst caves conducted by us, it is confirmed that a significant part of

the caves in the study area has passed a phreatic stage of development. However, to date, the traces of pressure flows action have in most cases been erased under the influence of vadose waters and other processes (corrosion, destruction, speleothems development, etc.). Periodic flows play an active role in the following stage of cave development, which in turn is reflected in the cyclical nature of sediment accumulation.

Thus, the morphological analysis of the karst caves in the study area allows us to prove that in their evolution the influence of the phreatic, vadose, and dry ages are reflected. However, it is identified that the evolution of caves does not proceed in the same way even within the same karst massif, which is related to the disruption of the normal course of cave development under the influence of tectonic movements or other conditions. At the modern stage of development, the phreatic regime is well expressed in the Ghrudo basin, while in the caves, which are located at high hypsometric levels and have passed the cycle, the traces of both vadose and dry epochs are well preserved.

15. The development of karst relief took place against the background of geological development of the study area and the development of the southern slope of the Caucasus in general. Intense ascending tectonic movements (after the Sarmatian century) and the epochs of short delay mainly conditioned the floor layout of the caves here, the wide distribution of undeveloped tunnel-type caves, as well as weakly defined terrace steps.

Currently, the horizons of caves at different stages of evolution are located on the slopes of the canyon-like gorges of the structural plateau (platform karst) of Zemo Imereti (Chiatura) by 4-5 tiers. Comparing the relative heights of the cave tiers and terrace steps developed in the individual river valleys allows us to assume that the epoch of delay of ascending tectonic movements must have been at least 3 or 4.

16. Lithostratigraphic analysis of the cave subterranean sediments conducted by us and the available archaeological materials allow us to prove that the formation of caves in the platform karst region of Zemo Imereti ended mainly in the Middle-Upper Pleistocene, and on the southern slope of the adjacent Racha Range and Ertso-Tsona area (southern slope of the Caucasus) - in the Lower Pleistocene.

Based on the complex study of karst cave sediments, it seems that in the near future, also in Zemo Imereti will be revealed climatogenic layers of autochthonous cave deposits, cult caves and other such monuments, study of which will precise the contentious questions of paleography of anthropogene, which once was elucidated on the example of Tsutskhvati caves (Maruashvili, 1978).

17. Low temperature cave streams and vaucluse springs have dominant position in the water supply of Chiatura and its environs. In some valleys there are good conditions for arranging a pond-trout farming on the basis of karst waters. In addition, the caves can be used for tourism purposes, greenhouses, refrigeration, etc.

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