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Geology

New Data on the Geological Structure of the Vardzia Cave City, Georgia

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ABSTRCT. The present paper is devoted to a unique historical Georgian cave city Vardzia of the 12th century. It is hewn into the volcanic tuff flow of the Pliocene andesitic-dacitic composition. Thorough geological survey of the Vardzia cave city was carried out. The results of the survey showed that the area has a complex geological structure. With the use of a differential GPS of high accuracy it was established that in comparison with the Erusheti block the Akhalkalaki block is 127 m lower. The Vardzia complex situated on the eastern slopes of the Erusheti ridge is hewn into the 900 m long tectonic block, which is detached from the main rocks of the Goderdzi suite and is gradually subsiding towards the Mtkvari (Kura) gorge. Exact measurements carried out with the GPS showed that the Vardzia block is lowered by 30.6 m in comparison with the southern borderer block. In addition, the Vardzia block is split into several microblocks by a joint set and thereby its stability lessens. The matter is made worse by the fact that the active deep fault runs along the Vardzia complex in the Mtkvari gorge and presents a potential earthquake source. If we take into consideration the rather strong erosion processes taking place along the Mtkvari gorge, it makes clear that the important monument of the Georgian cultural heritage is in danger of natural gradual destruction and earthquake hazards. The only factor contributing to relative stability of the Vardzia cave city is somewhat harder andesite stratum existing under it. *© 2016 Bull. Georg. Natl. Acad. Sci.*

Key words: Vardzia, volcanic flow, andesitic-dacitic tuffs.

The Cave city Vardzia, built in the 12th century, combines urban, defensive and monastic functions. It is one of the important monuments of Georgia, which became the world cultural heritage. It is hewn into the weakly cemented volcanic rocks, because of which it is weathered and broken. In addition, the Vardzia area is subject to active tectonic regime and at the same time the cliff itself, into which the fortress is hewn, passes along the Mtkvari river erosion bed. All these contributes to imminent gradual breaking of the Vardzia complex and leaves it under the threats of earthquakes. The factors mentioned above

Fig. 1. Panoramic view of the Vardzia region. In white color – volcanic flow of andesitic-dacitic composition. At the top of the flow–an upper part of the Goderdzi suit. In right – the Vardzia cave city.

prompted the government of Georgia and the National Agency for Preservation for Cultural Heritage to finance the project for saving the Vardzia historical fortress, and the rehabilitation works began. Within this project the collaborators of the faculty of Natural Sciences and Engineering of Ilia State University carried out thorough geological survey of the Vardzia complex. The present publication is a brief summary of the survey results.

Methods and Materials

The works were carried out with the application of classical geological methods and modern tools of high sensitivity. The final conclusions were made considering complex factors. During the field works more than 120 specimens were taken in the Vardzia area to conduct petrographic, geochemical and engineering surveys. All the specimens were attached to the topographic map using GPS. The complex study of the specimens was conducted in various laboratories of Georgia. To determine exact hypsometric location and vertical displacement of the differential high accuracy DGPS – Leica Viva GS15 was used. At the same time, monitoring of dynamics of the front part of Vardzia is being continuously carried out by stationary IBIS-FM radar.

General Geological Characterization of the Vardzia Region

The Vardzia region is situated in the Late Cenozoic volcanic province, which has been studied for long time [1-6]. According to the modern tectonic zoning it is a part of Erusheti block of the Javakheti subzone of the Adjara-Trialeti zone of the Lesser Caucasus [7]. Basically, the area is constructed by subaerial volcanogenic-sedimentary rocks – the so-called Goderdzi (Kisatibi) suite [2]. This suite is located discordantly on the mid-Eocene tuff-breccias, sandstones, argillites and marls, and is also discordantly covered with thick series of dolerites and basalts of the Quaternary age of the so-called Akhalkalaki suite [3].

Goderdzi suite is built by volcanic pyroclastic material of dacite-andesite composition and strata, which alternates with lake sediments. According to the data based on palaeonthology materials the age of the formation was determined as upper Miocene-Lower Pliocene [1,3] (the border to this period was considered as 11.1 Ma). In 1960th the suite was dated with the K-Ar method; the results obtained varied within the limits of 8.1 Ma [5].

Goderdzi suite is strictly divided in two big parts: the lower part with the thickness of 200-250 m is built up of pyroclastic formations, in which mainly dark, weakly cemented coarse material of hyperstenic and 2-pyroxene andesitic and andesitic-dacitic composition prevails. Somewhere in this coarse tuff suite one can mark cenotypal thin-layered pyroxene andesitic rare strata, the composition of which is the same as that of tuff-breccia, above this part there is a 20-80 m thickness whitish layer. It is slightly sintered fine-grained andesitic-dacitic tuff flow (Vardzia horizon) [5]. It was the segment of the volcanogenic rocks where the Vardzia complex was hewn in the 12th century (Fig.1).

Above the Vardzia horizon, without any gap, another thick fully effusive coarse-grained pyroclastolithes of hyperstenic and 2-pyroxenic

andesites, pyroxenic- hornblende andesite-dacites and hornblende-biotitic dacites composition is observed . This part of the suit is significantly thicker (600-700 m), in addition, sizes of the pyroclastic material in this part are bigger than in the first part. On the whole, thickness of the Goderdzi suit reaches 900-1000 m [8]. Erusheti ridge, a part of which is prolonged to the South, on the territory of modern Turkey, is built up of these rocks.

Characterization of the Vardzia Horizon

Vardzia horizon presents fine-grained andesitic-dacitic slightly sintered tuffs. It is well observed in relief because of its whitish color. Its thickness in the Vardzia section is 40-60 m and is different in the northern and southern directions. It should be noted that the horizon outcropping mainly on the left benches of the Mtkvari river, while they are marked fragmentarily on the right ones (Fig.2).

The supposition that this horizon was formed as a result of cooling of a volcanic flow is confirmed by the irregular form of its foot, which suits the relief, as well as ideally smooth surface, which is less inclined towards move direction, in particular, to the north (Fig.1).

The upper border of the Vardzia horizon is a fine-grained white layer of 25-35 cm thickness (Fig.3), which continuously traces along it and presents very good bench mark zone.

As for the layers underlying the Vardzia horizon, unfortunately, they are hardly exposed as they are covered by deluvial formation. Although, these rocks outcropping straight under the central part of the Vardzia complex for about 120 m section, and presents intensively broken and brecciated pyroxene andesitic lava-flow (Fig.4). Thickness of which cannot be measured at this outcrop. In our opinion, such a structure of the Vardzia foundation is the significant factor for reserving its stability. Apparently, the volcanic flow kept its relatively stable state at the Vardzia section due to such foundation.

The thickness of the Vardzia horizon tuffs greatly varies beyond the complex borders. Up the river it lessens to 30-40 m, and down, to the north, near the village Saro, it reaches 70-80 m. Such a thicknesses variation from the volcano centre to the periphery is characteristic for the ignimbrite flows while the thickness of fall tuffs decreases from the centre to the periphery [9].

In general, the gradation of the material in the Vardzia flow is not observed. It seems turbulent movement caused mix and homogenization of pyroclastic material in the entire flow, although single areas can be denoted which are built up of only ash material and small sizes of volcanic breccias (2-3 cm in diameter). But, generally, tuffs of the Vardzia horizon must be defined as massive, homogenous layer.

As it is known, vertical jointing is considered as one of the important parameters of welded tuffs, although this jointing is intensive in the high temperature, high quality sintered tuffs. As for mid-temperature tuffs, they are slightly jointed, and in uncemented tuffs the vertical jointing is not observed practically [9]. The Vardzia tuff flow is speckled with ideal vertical cracks with a distance of 50-60 m between them. Along the cracks intensive weathering processes are developed. Probably, those are cracks of volcanic flow cooling, which later, like mountain glacier flows, began enlarging under the effect of gravitation forces.

Petrography of the Vardzia Flow

Tuffs of the Vardzia flow are rather soft rocks. They make fingers dirty although it is impossible to crash them by hand. Their color changes from lateritious-pink to light grey-white. In the petrographic sense these tuffs can be divided into three parts: lithoclastic, porphiroclastic and cementing materials.

Lithoclastic material presents residuals of crystallic rocks, which broke up in debris of various sizes during the volcano eruption. Usually, in the Vardzia tuff flow they are of angulated form and their sizes in cross-section vary in the range of 0.1-3.5 cm, although sometimes lithoclasts of larger dimensions

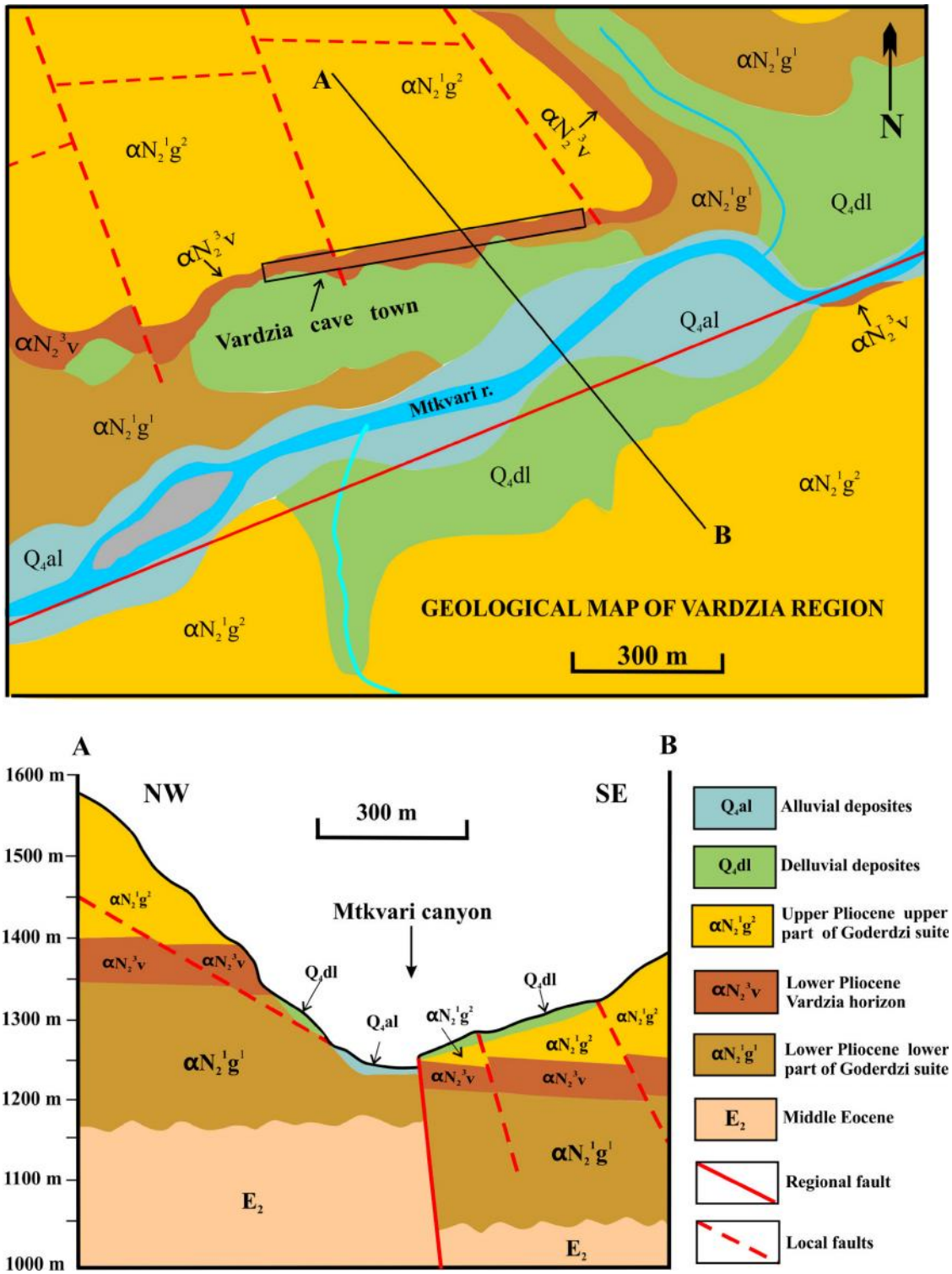

Fig. 2. The geological map of Vardzia region, adapted from [8] and cross section (A-B).

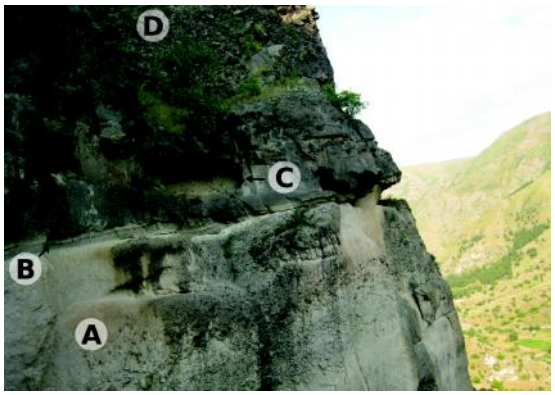

Fig. 3. The upper part of the Vardzia horizon (A) at the southern of Vardzia complex. A fine-grained white layer (B); remains of the tunnel (C) that was used to supply the Vardzia fortress with water. The bottom of the upper part of the Goderdzi suit (D) continues the ascending part of the section.

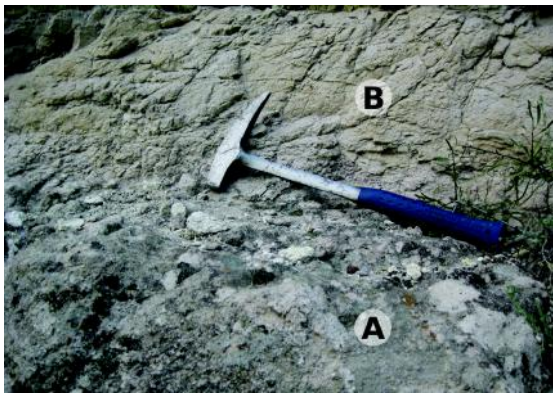

Fig. 4. One of the sections of the lower border of the Vardzia horizon. A- a fragment of the andesitic lava-flow, B- tuffs of dacite composition of the Vardzia horizon.

(5-15 cm) are met (Fig.5). Lithoclasts are mainly hypersten- hornblende andesite-dacites with rare biotite inclusions, in which SiO_2 content is 58-61% in average.

Porphiroclastic material. Porphiroclastic component in the Vardzia volcanic flow is 40-50% of the entire mass and presents broken or idiomorphic plagioclase (0.5-1 mm). Hornblende, biotite, hyperstene and augite are met in subordinate quantity. Magnetite, apatite and zircon are marked as separate grains.

Cementing material consists mainly of glass particles presenting finely grained ash material (volcanic ash). In the cementing mass it is denoted both wall gluing and gradual change of contours. This effect is obvious a sintering process [9]. Taking into consideration this fact one can believe that the Vardzia volcanic flow presents moderately welded tuff that is noted by some researchers [5]. Such supposition is confirmed by the fact that wall paintings of the 12th century on these tuffs are well kept.

Tectonic Structure of the Vardzia Region

Tectonic structure of the Vardzia region is rather complex (Fig.2). There tectonic faults of two types are distinguished: 1) faults provoked by regional geological processes and 2) those conditioned by local gravitation phenomena. The basic tectonic structure of the area is a deep fault, which traces towards SW-NE and actually goes along the Mtkvari river gorge. Along the fault the Vardzia area is divided in two large geoblocks: a western block – Vardzia (Erusheti) and an eastern – Javakheti [7]. Along it, after the Vardzia horizon was formed (beginning of the Pliocene), a significant vertical displacement was detected. Apparently, the centre of Vardzia destructive earthquake in 1283 was located right along this fault.

As a result of field works conducted it was found

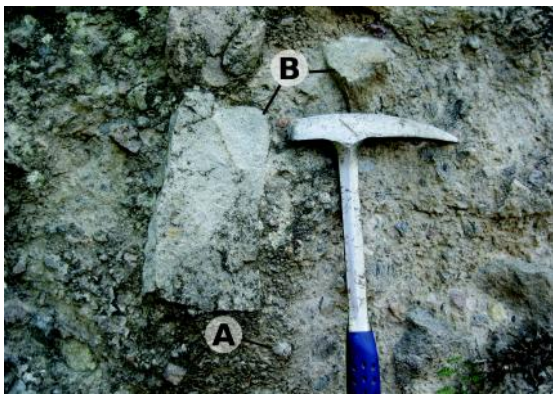

Fig. 5. Exposure of tuffs of the Vardzia horizon on the right of the path exiting the Vardzia complex. A – lithoclasts characterizing the horizon (0.2-3.5 cm); B – rare rudaceous lithoclasts (10-15 cm).

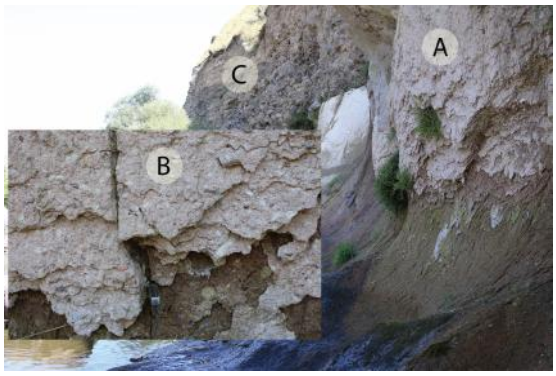

Fig. 6. Exposure of the Vardzia horizon (A), its fragment (B) and the bottom of the upper part of the Goderdzi suite (C) at the left side of the Mtkvari River across the Chachkari village.

out that the Vardzia horizon at the right side of Mtkvari river right across the Vardzia complex and further towards the upper reaches is submerged below the river level and covered by talus and alluvial deposits although across the village Chachkari a small part of andesitic-dacitic tuffs of Vardzia is exposed. The thorough analysis of this exposure showed that it is analogous with tuffs constructing the Vardzia horizon (Fig.6). This exposure traces for 50 m along Mtkvari Riverand then is covered by deluvium. Although at about 500 m towards Tmogvi fortress these rocks are exposed again in some places along the main road although it undergoes intensive weathering and alteration. Up the river Mtkvari at its right benches the Vardzia horizon submerges and does not expose anywhere while at the left benches it traces continuously.

We detected exact heights a.s.l. of the upper border of the Vardzia horizon in the exposures at both sides of the Mtkvari river using a high accuracy differential GPS. It was found that the horizon at the right riverside is at 1253 m a.s.l. but its upper border is at 1380 m a.s.l., straight along the exposure at the same side, i.e. the Vardzia horizon in the Vardzia complex is situated upper in comparison with the right riverside by 127 m. Taking into consideration the facts that the Vardzia horizon at the right side of Mtkvari is lowered to the depth and while forming the Vardzia horizon had a straight surface, one can suppose that the right blok of the Mtkvari – Javakheti block is lowered by 127 m.

Besides the considered deep fault, the local faults are also denoted in Vardzia region, which take an important place in the tectonic structure of the area. As the works conducted showed, the 900 m long Vardzia block is formed in the Vardzia horizon; it is cut off with tectonic faults from the southern and northern sides. The faults themselves by the own nature are the result of gravitational subsidence of the segment towards the Mtkvari river bed provoked by the erosion influence of the river. Analogous segmentation of the horizon reveals in the entire longitudinal section of the horizon but with different intensities at different sections. These processes are observed in the Tmogvi area with special intensity.

The sliding of Vardzia block is especially well detected along the tectonic fault existing to the south from it (Fig.7). There is an ideal geological picture of gravitational subsidence here. Moreover, a gruss surface is well seen, the analysis of which shows that the block moves downstream with the inclination of 32-35°. At the same time, because of the gruss surface is unchanged, we believe this displacement is active. In addition, a thorough analysis of the fault helped to establish a scale of the vertical displacement of the Vardzia block. In this section the Vardzia horizon ends with white fine-grained layer of

Fig. 7. A general view of the southern tectonic contact of Vardzia segment. It is well seen a fault zone and Vardzia block sliding downwards. A - Upper part of the Goderdzi suite, B - Vardzia horizon, dotted line shows a fault zone.

25-35 cm thickness (Fig.3). We detected absolute heights a.s.l. of this reference layers at both sides of the fault with a high accuracy differential GPS. The lowered reference layer of the Vardzia block is located at1393.574 m a.s.l. and that of the block bordered from the southern side - at 1423.764 m. Taking into consideration these data, it turns out that the Akhalkalaki block is located lower than the Vardzia block by 30.19 m.

Besides, it is well seen along the southern fault that the Vardzia flow in the creeping block is not located horizontally but is inclined towards southern-west in the opposite direction of the river bed with the inclination 5-7^{o} (Fig.3).The Figure shows remnants of the tunnel that used to supply the Vardzia fortress with water. The plane of a rock fall divides the tunnel almost in half. This fact allows to assume that water percolation caused the formation of the crack system, along which almost a third part of the Vardzia complex was destroyed by the disastrous earthquake in 1283.

The Vardzia block is bordered from the North by fault system as well (Fig.2), although in difference with the southern border tectonic dislocation is relatively intensive here. In the fault zone rocks are mixed, they undergo crushing and argillization, so it is difficult to determine the scale of the block displacement but it is undoubtedly that it moves towards the gorge.

The western border of the Vardzia block, which presents tearing area, detachment of the eastern slopes of Erusheti ridge, it is not well expressed in the relief because it is mostly covered by talus deposits (Fig.1). Although prolonged depressions are nevertheless observed, which is geomorphologic expression of the detachment area.

Conclusion

Thus, Vardzia, a unique monument of the 12th century Georgia, is hewn into the weakly cemented volcanic tuff flow of the andesitic-dacitic composition, therefore it suffers constant weathering and destruction. It should be noted that these rocks can be cut even with a simple iron knife and this very factor must have been the reason of building the Vardzia complex into these rocks.

As the survey showed, the Vardzia area has a complex geological structure. With the use of a differencial GPS of high accuracy it was established that in comparison with the Erusheti block the Akhalkalaki block is lower by 127 m. One part of the Vardzia complex situated on the eastern slopes of the Erusheti ridge is hewn into the 900 m long tectonic block, which is detached from the main rocks of the Goderdzi suite and is gradually subsiding towards the Mtkvari gorge. Exact measurements carried out with the GPS showed that the Vardzia block is lowered by 30.6 m in comparison with the southern borderer block. In addition, the Vardzia block is split into several microblocks by a joint set and thereby its stability lessens. The matter is made worse by the fact that the active deep fault runs along the Vardzia complex in the Mtkvari gorge and presents a potential earthquake source. If we take into consideration the rather strong erosion processes taking place along the Mtkvari gorge, it makes clear that the important monument of the Georgian cultural heritage is in danger of natural gradual destruction and earthquake hazards. The only factor contributing to relative stability of the Vardzia cave city is somewhat harder andesite lava-flow existing under it.

გეოლოგია

ახალი მონაცემები ვარძიის კლდეში ნაკვეთი ქალაქის გეოლოგიური აგებულების შესახებ

ა. ოქროსცვარიძე, მ. ელაშვილი, ნ. ფოფხაძე, გ. კირკიტაძე

** ილიას სახელმწიფო უნივერსიტეტის საბუნებისმეტყველო მეცნიერებათა და საინჟინრო ფაკულტეტი, თბილისი, საქართველო*
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საქართველოს კულტურული მემკვიდრეობის სააგენტოს შეკვეთით განხორციელდა მე-12 საუკუნის უნიკალური ქართული ისტორიული ძეგლის, ანდეზიტურ-დაციტური შედგენილობის ვულკანურ ტუფურ ნაკადში გამოკვეთილი, კომპლექსური დანიშნულების ქალაქის (ურბანული, თავდაცვითი და სამონასტრო) ვარძიის დეტალური გეოლოგიური შესწავლა. კვლევამ გვიჩვენა, რომ რაიონი ხასიათდება რთული გეოლოგიური აგებულებით. მაღალი სიზუსტის დიფერენციალური GPS-ით, გამოყენებით დადგინდა, რომ ერუშეთის ბლოკთან შედარებით ახალქალაქის ბლოკი 127 მეტრით ქვემოთაა დაწეული. ერუშეთის ქედის აღმოსავლეთ კალთებზე მდებარე ვარძიის კომპლექსი, რომელიც გამოკვეთილია 900 მ სიგრძის ტექტონიკურ ბლოკში, მოწვეტილია გოდერძის წყების ძირითადი ქანებისგან და ნელ-ნელა მოძრაობს მდ. მტკვრის ხეობისკენ. GPS-ით ზუსტმა გაზომვებმა აჩვენა, რომ სამხრეთის მომიჯნავე ბლოკთან შედარებით, ვარძიის ბლოკი დაწეულია 30,6 მ-ით ქვემოთ. ამასთან ერთად, ვარძიის ბლოკი ნაპრალთა სისტემით დაყოფილია ცალკეულ მიკრობლოკებად, რაც მნიშვნელოვნად ამცირებს მის მდგრადობას. აღნიშნულს ემატება ის აქტიური სიღრმული რღვევაც, რომელიც ვარძიის კომპლექსის გასწვრივ, მდ. მტკვრის ხეობაში გადის და რომელიც მიწისძვრის მუდმივ პოტენციურ კერას წარმოადგენს. თუ იმ გარემოებასაც გავითვალისწინებთ, რომ მდ. მტკვრის ხეობაში საკმაოდ ძლიერია ეროზიული პროცესები, მაშინ ქართული კულტურული მემკვიდრეობის უმნიშვნელოვანესი ძეგლი ბუნებრივი თანდათანობითი დაშლის და მიწისძვრის საფრთხის რეჟიმში იმყოფება. ერთადერთი ფაქტორი რომელიც ვარძიის კომპლექსის შედარებით სტაბილურობას განაპირობებს ესაა მის ქვეშ არსებული შედარებით მყარი ანდეზიტური განფენი.

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