Geology

Geometry and Zircons U-Pb Geochronology of the Mtkvari Ignimbrites Flow, Samtske-Javakheti Volcanic Highland, Lesser Caucasus

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ABSTRACT. In the Samtskhe-Javakheti Volcanic highland (Lesser Caucasus), in the Mtkvari river canyon a large volcanic pyroclastic flow outcrops, which is represented by ignimbrites of andesitic-dacitic composition. Despite the fact, that one of the important monuments of Georgian cultural heritage cave-city Vardzia is hewn into this flow, the question of its geometry and geochronology is still unclear. Field works showed that the Mtkvari ignimbrites flow traced continuously from the Karzameti fortress to the Khertvisi fortress for more than 35 km. Thickness of the flow increases obviously from the magma centre (40 m on average) to the periphery (80 m on average), though its width is not still defined. The flow is inclined to the northern direction by 2-4^{o} angle. Perfectly straight surface of the flow and its bottom conforms to the relief, which confirms its magmatic formation. The flow is cut by a regional fault the Mtkvari canyon. At the same time, together with its enclosing rocks it is divided into smaller blocks by cutting local faults. In isotopic laboratory of the National Taiwan University the zircons of this pyroclastic flow were dated by U-Pb method, using LA-ICP–MS equipment. The samples were taken from three places: at the end of the flow, near the Khertvisi fortress (at 35 km; #13Geo4), in the central part of the flow, near the Vardzia cave-city (at 15 km; #13Geo5) and at the beginning of the flow, near the Karzameti fortress (#13Geo6). The results are practically identical within the margin of error and correspond to the Upper Miocene epoch: #13Geo4=7.50±0.42 Ma; #13Geo5=7.54±0.21 Ma; #13Geo6 =7.52±0.21 Ma. These almost identical results of the U-Pb geochronology from various sections of the Mtkvari volcanic flow indicate great credibility of this dating.

Key words: Samtskhe-Javakheti volcanic highland, Mtkvari ignimbrites flow, zircons U-Pb dating.

Powerful subaerial volcanic activity that happened in the N-W part of the Lesser Caucasus at Late Cenozoic formed a large volcanic highland stretching across the territories of Georgia, Armenia and Turkey. Its part, known as Samtskhe-Javakheti volcanic highland in Georgia occupies an area more than 4500 km^2. It has a long history of geological study [1-6].

The genesis of this volcanic highland is a disputable issue. Some modern researchers consider that its formation was conditioned by slab break off and its gradual subduction and melting in the mantle [7]. Some scholars believe that the formation of this volcanic highland was the result of decompression melting of the asthenosphere [8], or astenospheric upwelling, caused by the litospheric delamination [9]. Yet some others estimate that mantle plumes played an important role in formation of this volcanic province [10, 11].

In the present paper the so far unexplored subject of the geometry of Mtkvari powerful ignimbrites flow, which makes up a part of the Goderdzi formation in the Samtskhe-Javakheti volcanic highland and U-Pb geochronology of the flow zircons are discussed. We believe that this new information will contribute to the complex and interesting study of the Late Cenozoic volcanism in Samtskhe-Javakheti. At the same time, the powerful ignimbrite flow points to the existent of the large caldera structure [12], and, as it is known, caldera structures are quite often accompanied by the presence of significant ore mineralization. In addition, because the fortress-city Vardzia is hewn in the Mtkvari volcanic flow, its isotopic dating represents significant interest to the society.

Material and Methods

The geological field works were based on classical geological principles and physical volcanology. From three points of the Vardzia ignimbrites flow, 15 pieces of 3-4 kg were taken, of which, up to hundred zircon crystals were separated, from where 72 crystals were dated.

The zircon U-Pb dating was conducted at National Taiwan University, Taipei, Taiwan. After mouning the zircons on epoxy resin, cathodoluminescence (CL) images were taken for checking the internal textures of the zircon grains and selecting the suitable positions for in-situ U-Pb analyses. Measurement of zircon U-Pb isotopic analysis was performed by using Agilent 7500s ICP-MS coupled with a New Wave UP213 laser ablation system equipped at the Department of Geosciences, National Taiwan University following the analytical procedures by Chiu et al. [13].

Samtske-Javakheti Volcanic Highland

Samtskhe-Javakheti volcanic highland (Fig. 1) located discordantly on the Mid-Eocene tuff-breccias, sandstones and argillites. According to tectonic zonation it is divided into two blocks: Erusheti and Javakheti [5]. Three main magmatic activities should be marked in the formation of the highland: 1. Upper Miocene – Lower Pliocene, when huge 700-1000 m thick dacite-andesitic volcanic tuffs (the so-called Goderdzi suite) were formed; 2. Upper Pliocene-Lower Pleistocene, when 120-270 m thick continental flood basalts (the so-called Akhalkalaki suite) were formed and 3. Mid-Upper Pleistocene, when Abul-Samsari continental volcanic ridge was formed [3, 11].

The volcanic pyroclastic flow of Mtkvari is spatially and genetically related to the first powerful magmatic formation of the Samtskhe-Javakheti volcanic province known in the geological literature as Goderdzi suite [3]. Goderdzi formation basically is built up of volcanic pyroclastic material of dacite-andesite composition and lava-flow, which alternates with lacustrine deposits. According to the data based on paleontology materials the age of the formation was determined as upper Miocene-Lower Pliocene [1,3] (the Mio-Pliocene border at that period was considered as 11.1 Ma).

Goderdzi formation is 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 two pyroxene andesitic and andesitic-dacitic composition prevail. Somewhere in this coarse tuff suite one can mark thin-layered gabbro-andesitic and pyroxene andesitic lava-flow. Above this part there is a 40-80 m thick whitish layer of the andesitic Mtkvari volcanic flow.

Above the Mtkvari ignimbrites flow, without

Fig. 1. Schematic Geological map of the Samtskhe-Javakheti volcanic highland.

any gaps, it is observed another thick effusive coarse pyroclastolithes of two pyroxenic andesites, pyroxenic-hornblende andesite-dacitic and hornblende-biotitic dacitic composition. This part of formation is significantly thicker (600-700 m), sizes of the pyroclastic material in this part are bigger, than in the first part, diameter of which is sometimes more than 1 meter. On the whole, thickness of the Goderdzi formation reaches 900-1000 m [3].

Mtkvari Ignimbrites Flow

Mtkvari ignimbrites pyroclastic flow is well observed in relief, along Mtkvari river canyon because of its whitish color (Fig. 2). Its thickness in the Vardzia section is 50-60 m and is different in the northern and southern directions. Up the river it lessens to 40 m and down to the north, near the village Saro it reaches 80 m. Such a thicknesses variation from the volcanic centre to the periphery is characteristic for the ignimbrite flows while the thickness of ash-fall tuffs decreases from the center to the of [14].

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 moving direction, in particular, to the north. It should be noted that the Mtkvari flow outcropping mainly on the left benches of the Mtkvari river, while they are marked fragmentarily on the right one, although, naturally the flow initially had single, straight surface. This fact was explained by active tectonic movement, according to which after the Mtkvari flow was formed (Late Miocene) a block of the Javakheti volcanic highland sank down by 130 m in comparison with Erusheti block, along the regional fault in the Mtkvari canyon [15]. Because of that above the Vardzia complex up-stream of the Mtkvari river, this volcanic flow is not observed anywhere along its right bank (the Akhalkalaki block), although below the complex it is exposed right along the highway and is wedged in 200 m below the Khertvisi fortress. As for the left bank of the Mtkvari river, Mtkvari volcanic flow is traced continuously for 35 km from the Khertvisi fortress to the Karzameti fortress.

Petrography of Mtkvari pyroclastic flow is described in details [4,15] and this is why we note only briefly that the flow is fine-grained andesitic-dacitic tuffs (content of SiO_2 is 58-61%), where turbulent

Fig. 2. The general view of the Goderdzi formation from the Niala valley (Mtkvari canyon). In white –Mtkvari ignimbrites flow. In the background of the picture, to the right, one can see the Vardzia cave-city.

motion is well-observed. E. Ustiev and D. Jigauri consider that the Mtkvari volcanic flow presents moderately weakly welded tuff [4]. In our opinion, this conclusion can be applied only to the central section of the flow, in particular, to the part of the Vardzia complex, which they studied because at the beginning of the flow, near the Karzameti fortress the degree of welded ignimbrites is higher, while they are actually non baked at the end of the flow near the Khertvisi fortress.

The conducted field works show that the volcanic flow of Mtkvari is traced continuously from the Karzameti fortress to the Khertvisi fortress more than 35 km in length (Fig.3). The thickness of the flow noticeably increases from the magma centre (40 m in average) to the periphery (80 m in average). The flow is inclined towards northern direction by the angle of 2-4^{o}. Its surface is perfectly straight and bottom is conformed to the relief, which points at its magmatic origin.

Zircons U-Pb Geochronology

In the isotopic laboratory of the National Taiwan University with the LA-ICP–MS facility we dated zircons of the Mtkvari ignimbrites flow by U-Pb method the very first time. Samples were taken from three segments of the flow (Fig.3): at the end, at the 35th km, at the Khertvisi fortress (#13Geo4); at the central part, at the 15th km, near the Vardzia cave-city (#13Geo5) and at the beginning, at the 2nd km, near the Karzameti fortress (#13Geo6).

Near the Khertvisi fortress, the samples were taken right at the bottom of the fortress where 51 zircons were selected, and the age of only 25 of them was determined. In the central part, near the Vardzia complex, the samples were taken from two places: one from the exposed ignimbrite near the parking (sp. 13Geo5P) and the second right at the entrance to the complex. From the 1st group of samples 50 zircon grains were selected and only 14 of them were dated; from the 2nd group 46 grains were taken and 15 dated. At the starting point of the flow samples were taken from the pink ignimbrite exposure near the Karzameti fortress. Among 48 grains 22 ones were dated.

The zircons in all three groups of the samples from the Mtkvari volcanic flow have similar morphology, namely, similar prismatic forms; their length does not exceed 150 μm and the width is about 70-80

Fig. 3. The outcrop part of the Mtkvari volcanic piroklastic flow (pink colored).

µm. Most zircons are euhedral with long prismatic pyramidal forms and show oscillatory zoning, indicating magmatic origins. Zircons with separated core and rim are rarely observed and their zonality is quite simple and only 2-3 zones are noted (Fig.4). Some zircon grains are crumbled, presumably as a result of a powerful explosion of magma chamber. It should be noted that none of the zircon grain contain any fragments of old zircons, which means that these zircons are formed in the magma chamber that stimulated the flow. Due to the limited volume of the paper

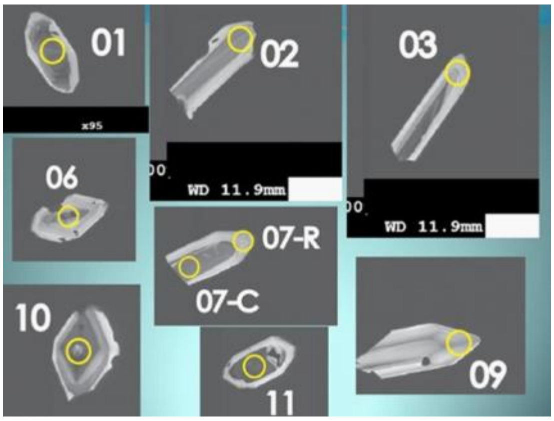

Fig. 4. Part of CL pictures of the zircons grains of the Mtkvari ignimbrites flow. A-the samples #13Geo4;

and because the nature of the analyzed zircons is identical, we give below only the samples #13Geo4 CL pictures (Fig.4), chemical analyses (Tab. 1), U-Pb concordia plot (Fig. 5) and U-Pb weigh mean (Fig. 6).

As we see from table (Tab.1) U and Th concentrations in zircons in the sample #13Geo4 vary within the limits 83-166 ppm and 56-277 ppm, respectively; in the sample #13Geo5 - within the limits 175-1678 ppm and 79-1799 ppm respectively; in the sample #13Geo6 – 131-1385 ppm and 79-2609 ppm, respectively. It should be noted that Th and U concentrations in all zircons of the Mtkvari flow are in direct proportionality and Th/U index is always > 0.4, which manifests the typical magmatic formation of the zircons [16].

With regard to the results of the zircons U-Pb geochronology, the Fig. 5 shows the U-Pb concordant plot age of the sample#13Geo4, where the U/Pb curves are concentrated closely, which demonstrates that the U-Pb isotopic system was closed soon after crystallization. The weight mean U-Pb age of this sample (Fig. 6) is 7.50±0.42 Ma (MSWD=0.74), which reflect its crystallization ages. In general in the all three sections of the Mtkvari ignimbrites flow, the

Table 1. Chemical analyses and U-Pb isotope data of the Mtkvari ignimbrites flow zircons (sample #13Geo4)

Spot #13	U (ppm)	Th (ppm)	Th/ U	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{206}Pb/^{238}U$	1σ	Age (Ma)	1σ
Geo4-02	88	75	0.86	0.04455	0.10809	0.0092	0.23	0.0015	2	10	2
Geo4-03	83	56	0.68	0.0451	0.12707	0.00901	0.02705	0.00145	2	9	2
Geo4-04	132	143	1.08	0.04443	0.0767	0.00745	0.01368	0.00122	1	7.9	1
Geo4-05	83	61	0.74	0.04907	0.12368	0.00756	0.02038	0.00112	1	7	1
Geo4-06	115	76	0.67	0.04663	0.08098	0.00819	0.01525	0.00127	1	8	1
Geo4-07	118	104	0.89	0.04561	0.10426	0.00693	0.01691	0.0011	1	7	1
Geo4-08	119	73	0.61	0.04478	0.09766	0.00791	0.01841	0.00128	1	8	1
Geo4-09	114	72	0.63	0.005381	0.10154	0.0117	0.02399	0.00158	2	10	2
Geo4-10	114	73	0.64	0.05059	0.18127	0.00564	0.0217	0.00081	2	5	2
Geo4-11	86	66	0.76	0.04575	0.12554	0.00708	0.02067	0.00112	1	7	1
Geo4-12	138	106	0.77	0.03989	0.07526	0.0063	0.01262	0.00115	1	7.4	1
Geo4-13	187	241	1.29	0.0476	0.07657	0.00682	0.01179	0.00104	0.9	6.7	0.9

weight mean U-Pb age are practically identical and corresponds to Upper Miocene epoch, in particular: #13Geo4=7.50±0.42 Ma; #13Geo5 = 7.54±0.21 Ma; #13Geo6=7.52±0.21Ma.

Discussion

The study presented important results but raised a new problem concerning the width of the Mtkvari volcanic pyroclastic flow. As it was noted above, it is assumed that the volcanic flow is traced along the Mtkvari canyon [4], although it is unknown whether this canyon existed about 7.5 million years ago. As it is known intense exhumation processes at the Lesser Caucasus began about 9-8 million years ago [17] and naturally during the period of 1.5 Ma years a river could not dug such a powerful

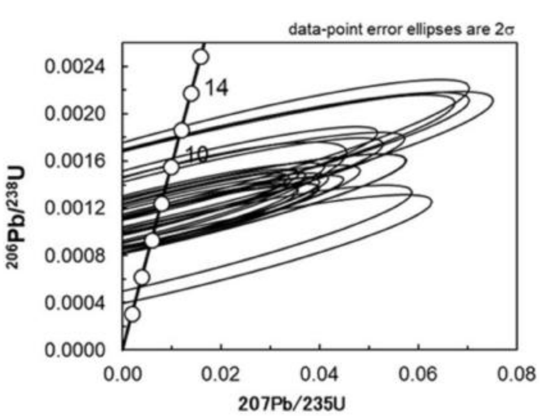

Fig. 5. Concordia plot U-Pb age of the of the Mtkvari ignimbrites flow zircons. Sample #13Geo4.

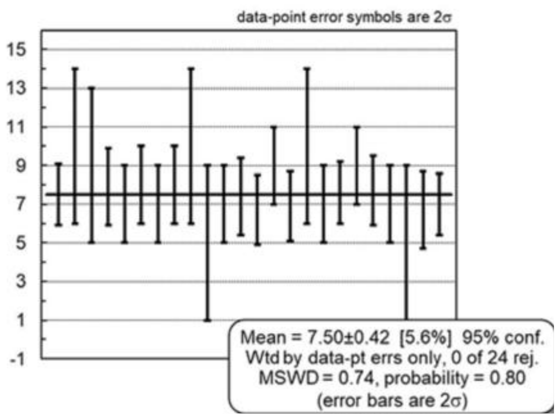

Fig. 6. Weight mean U-Pb age of the #13Geo4 sample of the of the Mtkvari ignimbrites flow.

canyon as it is meant in [4]. In addition, geological arguments suggest that the flow was broad. Specifically, in the Chachkari gorge that cuts through the Mtkvari river,the entire section of the Mtkvari volcanic flow is exposed and it traced along the gorge for about 1.8 km with unvarying thickness (50 m in average). Besides to the river Mtkvari flow analogous formation is also exposed in the Uraveli river canyon where its thickness is within 30-40 m. Some ignimbrite flows are also detected in the upper part of the Goderdzi formation at the ridge between the rivers Uraveli and Mtkvari. These facts allow us to assume the Vardzia volcanic flow could has been of a sheet nature erupting at the northern slope of caldera, and the ignimbrite flow was later dissected by river gorges, among them by the river Mtkvari, the canyon of which was probably formed along the regional fault. The zircons U-Pb geochronology showed that the Mtkvari flow erupted in Late Miocene epoch approximately 7.5 million years ago and a large part of the Goderdzi formation could have been formed during that time.

Conclusion

As a result of our field works it was determined that the Mtkvari volcanic flow is traced continuously from the Karzameti fortress to the Khertvisi fortress for more than 35 km in length. The thickness of the flow noticeably increases from the magma centre (40 m in average) to the periphery (80 m in average) however, the size of its width is disputable. The flow is inclined to the northern direction by 3-5^o angle. Its surface is perfectly straight and the bottom conforms to the relief, which confirms its magmatic formation. The flow is cut by regional fault along in the Mtkvari canyon and in addition, it is fragmented together with enclosing rocks and it is dissected into smaller blocks by cutting local faults.

In isotopic laboraory of the National Taiwan University was dating the zircons of this ignimbrites flow, by U-Pb method, using LA-ICP–MS equipment. The samples were taken from three main parts of the flow: in the end of the flow, near the Khertvisi fortress (at 35 km; #13Geo4), in the central part of the flow, near the cave-city Vardzia (at 15 km; #13Geo5) and at the beginning of the flow, near the Karzameti fortress (13Geo6). The results are practically identical within the margin of error and corresponds to Upper Miocene epoch: #13Geo4=7.50±0.42 Ma; #13Geo5=7.54±0.21 Ma; #13Geo6 = 7.52±0.21 Ma. It should be noted, that almost identical results of the U-Pb geochronology, from various sections of the Mtkvari ignimbrites flow, indicate a great credibility of this dating.

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გეოლოგია

მტკვრის იგნიმბრიტული ნაკადის გეომეტრია და ცირკონების U-Pb გეოქრონოლოგია, სამცხე-ჯავახეთის ვულკანური ზეგანი, მცირე კავკასიონი

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(წარმოდგენილია აკადემიის წევრის ე. გამყრელიძის მიერ)

მცირე კავკასიონის გვიან კაინოზოურ სამცხე-ჯავახეთის ვულკანურ ზეგანზე, მდ. მტკვრის ხეობაში, შიშვლდება მძლავრი, ვულკანური პიროკლასტური ნაკადი, რომელიც წარმოადგენს ანდეზიტურ-დაციტური შედგენილობის იგნიმბრიტებს. მიუხედავად იმისა, რომ ამ ნაკადში მე-12 საუკუნის ბოლოს გამოკვეთილ იქნა ქართული კულტურული მემკვიდრეობის უნიკალური ძეგლი ციხე-ქალაქი ვარძია, დღემდე გაურკვეველი იყო მისი გეომეტრია და იზოტოპური ასაკი.

ჩატარებული საველე სამუშაოების შედეგად დადგინდა, რომ მდ. მტკვრის ხეობის იგნიმბრიტული ნაკადი უწყვეტად გაიდევნება ქარზამეთის ციხე-სიმაგრიდან, ხერთვისის ციხე-სიმაგრემდე 36 კმ-ზე. მისი სიმძლავრე მაგმური ცენტრიდან (40 მ) პერიფერიისკენ აშკარად იზრდება (80 მ), თუმცა, ჯერ კიდევ გაურკვეველი დარჩა მისი სიგანე. ეს ნაკადი დაქანებულია ჩრდილოეთისკენ 2-4°-იანი კუთხით, ზედაპირი იდეალურად სწორია, ხოლო ძირი მორგებულია რელიეფზე, რაც აშკარად მის მაგმურ გენეზისზე მეტყველებს. იგი მიმართულების გასწვრივ იკვეთება მდ. მტკვრის ხეობაში გამავალი რეგიონული რღვევით, ხოლო მიმართულების გამკვეთი ლოკალური რღვევებით დანაწევრებულია მცირე ბლოკებად.

ტაივანის ნაციონალური უნივერსიტეტის იზოტოპურ ლაბორატორიაში, LA-ICP–MS დანადგარზე, პირველად განხორციელდა მტკვრის იგნიმბრიტული ნაკადის ცირკონების U-Pb მეთოდით დათარიღება. ნიმუშები აღებულ იქნა ნაკადის სამი მონაკვეთიდან: ნაკადის ბოლოდან (ხერთვისის ციხე-სიმაგრესთან, ნიმ.#13Geo4), ნაკადის ცენტრალური ნაწილიდან, (ვარძიის ციხე-ქალაქთან, ნიმ. #13Geo5) და ნაკადის დასაწყისიდან (ქარზამეთის ციხე-სიმაგრესთნ ნიმ. #13Geo6). მიღებული შედეგები თითქმის იდენტურია (7,5 მლნ. წ.) და პასუხობენ ზედამიოცენურ ეპოქას, კონკრეტულად: #13Geo4=7,50±0,42 მლნ.წ., #13Geo5=7,54±0,21 მლნ.წ. და #13Geo6=7,52±0,21 მლნ.წ. ვარძიის იგნიმბრიტული ნაკადის სამივე მონაკვეთზე ცირკონების U-Pb მეთოდით დათარიღების იდენტური შედეგები მოცემული დათარიღების დიდ სიზუსტეზე მეტყველებს.

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