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Main Features of Geological Structure and Geotourism Potential of Georgia, the Caucasus

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Abstract: The general overview of geology of the territory of Georgia as a component of Caucasian segment of the Mediterranean (Alpine-Himalayan) collisional orogenic belt is presented. Georgia is built up of Neoproterozoic-Paleozoic metamorphic complexes of supra-subduction zones, Mesozoic-Cenozoic sedimentary, submarine and subaerial volcanic rocks and intrusives of various ages and composition. The unique geological structure of Georgia's territory allows to be distinguished of several potential geoparks and geotourist routes. As the potential geoparks we could consider: 1) Kazbegi - Quaternary volcanoes and Pre-Jurassic Daryali massif; 2) Vardzia – Upper Miocene Megacaldera, its an ignimbrite flow (35 km length), explosion products of 1 km thickness and Vardzia rock-cut city; 3) Dmanisi - Dmanisi hominids site and the Mashavera gorge basaltic flow of 20 km length; 4) Sataplia - Dinosaur Footprints, together Sataplia and Prometheus caves. Geotourist route: 1) Tbilisi-Pasanauri-Kazbegi (155 km length) - crossing of the Eastern Greater Caucasus; 2) Tbilisi–Borjomi-Vardzia (240 km length) - crossing of the Lesser Caucasus: 3) Tbilisi-Kutaisi -Ushguli (450 km length) - Crossing of the transcaucasian massive and Western Greater Caucasus.

Key words: Caucasus, Georgia, geoparks, geotourist route

1. Introduction

The territory of Georgia is a component of the Caucasian segment of the Mediterranean (Alpine-Himalayan) collisional orogenic belt developing during the Neoproterozoic and Phanerozoic at the margins of Proto-Paleo-and –Neotethys oceanic basins [1]. Its territory covers all major structural units of the Caucasian Orogeny: the Greater and the Lesser Caucasus fold systems and intermountain depressions lying between them. This area represents a real "natural geological laboratory" exposing magmatic, sedimentary and metamorphic rocks, ranging wide on the geologic time scale (from the Neoproterozoic to the Quaternary inclusive), which are well studded. These rocks keep of the history of geological processes that have built numerous geological sites of important geological information observed in the present-day Georgia and are excellent destination for development of geotourism industry [3, 23, 28].

Nearly all geologic processes, that occur in the Earth's crust, can be observed and studied in Georgia in natural conditions. Furthermore, during Soviet period the country was actually restricted for foreign geologists, which fosters a special interest in geology of this country. Besides interesting natural geologic sides, various types of mineral resources are widespread on the territory of Georgia: mineral water

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(Borjomi, Sairme, Tskaltubo and others), manganese (Chiatura), and gold (Bolnisi) deposits among them.

The diversity of geologic objects is not the only reason to be fascinated by Georgia. It is also home to significant paleoarchaeological, archaeological and historic sites, that can be visited concurrently during the geological tour. Mtskheta, the capital of the early Georgian Kingdom of Iberia (during III B. C. –IV A. D.), and Dmanisi paleoanthropological site (1.8 Ma) are worthy of special mention. In addition to this, it should be noted that all potential geopark sites and geotourist routes contain important cultural heritage as well.

2. Main Features of Geological Structure of Georgia

The oldest, Precambrian and Lower-Middle Paleozoic rocks are exposed in all the structural units of Georgia. They are represented by gneisses, migmatites, crystalline schists and amphibolites within the Main Range zone of the fold system of the Greater Caucasus, Trans-Caucasus microplate (the Dzirula massif), and the fold system of the Lesser Caucasus (the Khrami and Loki massifs) (Fig.1) [4, 5].

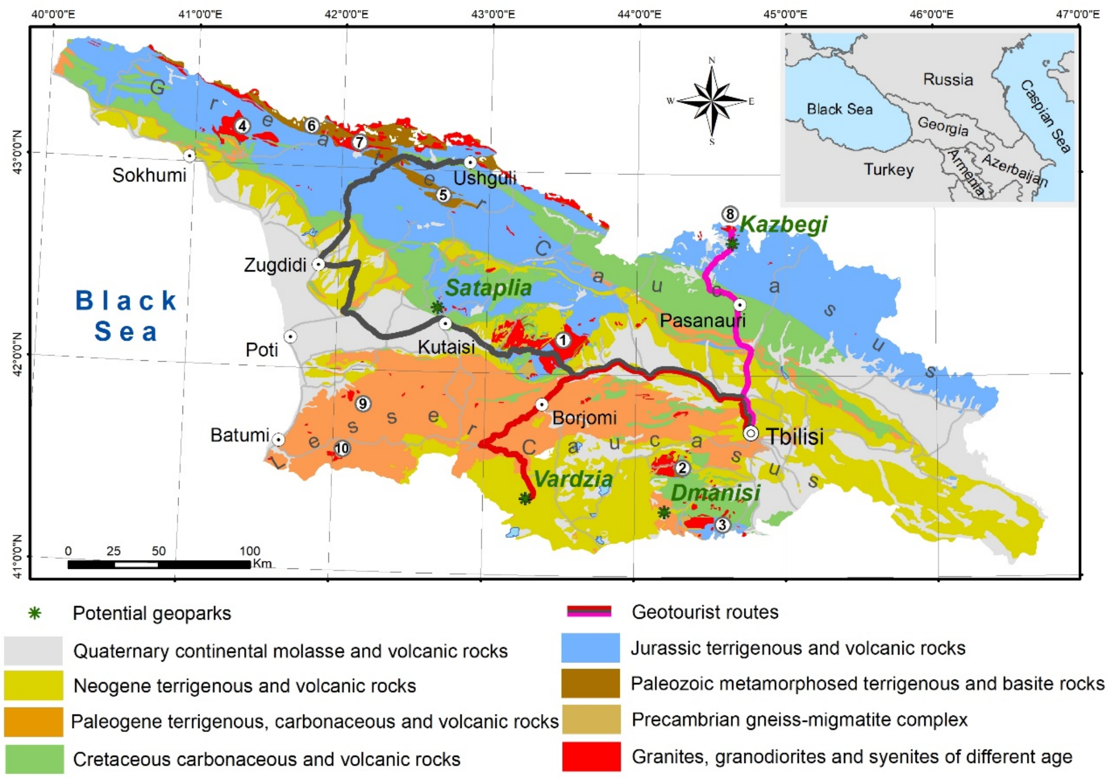

Fig. 1 Simplified Geological map of Georgia (adapted after [7] with Geotouristic routes and potential geoparks sites).
Geotouristic routes: 1. Tbilisi-Pasanauri-Kazbegi, 2. Tbilisi-Borjomi-Vardzia, 3. Tbilisi-Kutaisi-Ushguli.
Potential geoparks sites: Vardzia, Sataplia, Kazbegi and Dmanisi. Numbers in the circle: Exposures of Pre-Jiurassic crystalline basement and large intrusives: 1. Dzirula, 2. Khrami, 3. Loki, 7. Greater Caucasus and 8. Dariali; 4. Middle Jurassic Kelasuri granitoid massif; 5. Paleozoic Dizi metamorphic series; 6. Paleozoic Laba-Buulgeni metamorphic complexes; Middle Eocene syenite plutons: 9. Vakijvari and 10. Merisi.

Paleozoic rocks are exposed in the central part of the southern slope of the Greater Caucasus as well. They are represented mainly by black shales, sandstones, turbidites, olistostromes, lenses of marble and calc-alkaline andesite-dacitic volcanoclastics. Their visible thickness reaches 2000 m. This is the so-called Dizi series, in which faunally (by corals, foraminifera, and conodonts) the Devonian, Carboniferous, and

Permian are established. Comparatively weakly metamorphosed Paleozoic sediments are exposed in the Dzirula Massif as well. These are the allochthonous plates of the so-called ‘phyllitic suite’, which are in contact with Upper-Paleozoic granitoid and Precambrian gabbro-amphibolite and serpentinite (the metaophiolites) [6]. Precambrian and Paleozoic ophiolites within the crystalline core of the Greater Caucasus and in Lok-Karabakh zone (in the Loki massif) are present as well [4].

The Upper Paleozoic rocks are also developed in all tectonic units [1, 4]. In the Main Range zone of the Greater Caucasus, crystalline rocks are overlain by weakly metamorphosed sandstones, conglomerates, and argillites, which contain Upper Carboniferous-Lower Permian marine fauna. Continental and coastal calc-alkaline rhyolitic volcanic rocks and coal-bearing argillites with lenses of reef limestones are known in the Dzirula and Khrami massifs. Lower-Middle Carboniferous corals, brachiopods, foraminifers, and terrestrial flora have been found in this formation in the Khrami massif.

Mesozoic and Cenozoic formations are developed in all tectonic units of Georgia [1, 7]. Triassic sediments are observed in the Dizi series apart from the above-mentioned Upper Paleozoic deposits. To the Triassic also belong dacitic-rhyolitic volcanics, quartz sandstones, and siltstones with variable thickness (80-500 m), which crop out in the Dzirula massif and contain flora of Triassic age. Lower Jurassic-Aalenian sediments, that everywhere rest transgressively, are spread throughout all tectonic units of Georgia (Fig. 1). In the Foldsystem of the Greater Caucasus, these deposits are more than 5000 m in thickness and are represented by black shales, sandstone turbidites, rhyolitic (in the lower part) and tholeiite-basaltic (in the upper part) lavas and their pyroclastic. In the Georgian Block, Lower Jurassic sediments (80-90 m thick) crop out only along the edges of the Dzirula massif and are represented by arkosic sandstones, gravelstones. Conglomerates, clay, and red zoogenic limestones containing rich marine fauna (Ammonitico Rosso facies). In the southern parts of the Khrami and Loki massifs, the Lower Jurassic consists mainly of terrigenous deposits (120-600 m thick). In the central part of the Foldsystem of the Greater Caucasus, in Mestia-Tianrti zone the Bajocian stage is represented by clayey and clayey-sandstone schists and in Gagra-Djava zone by a thick (3500 m) volcanogenic series, which contains marine fauna and consist mainly of calc-alkaline basaltic,andesite-basaltic,and andesite-dacitic lavas and pyroclastics. Tephroturbidites sandstones, and conglomerates are rather scarce. The Bathonian stage in Mestia-Tianety zone is represented by clayey and clayey-sandstone schists and by regressive coal-bearing terrigenous deposits (65-200 m) in the Gagra-Java zone. In the central and eastern parts of the southern slope of the Greater Caucasus (Mestia-Tianeti zone), the Upper Jurassic sediments, which follow conformably the Middle Jurassic slate, consist mainly of clastic-limestone flysch (rhythmical alternation of clastic-limestone and pelagic marls) (1100-1500 m). On the rest of the territory, they lie transgressively and discordantly. In the western and eastern parts of the Gagra-Java zone, an Upper Jurassic marine facies is present. In the lower part, it is represented by sandstones and clays (120-200 m), and in its upper part — by reef limestones (400-900m). A rich marine fauna (ammonites, corals, etc.) is found in these sediments. To the south and within the Georgian Block, gypsum-bearing lagoonal-continental terrigenous (Kimmeridgian-Tithonian) deposits and to a lesser extent alkaline basalts, trachytes, and pyroclastic are present. Upper Jurassic shallow-water limestones and marls, alternating with calc-alkaline basalt-andesite-dacite volcanics are exposed at the western edge of the Khrami massif and in the Lok-Karabakh zone also.

There is a variety of Cretaceous deposits in Georgia. Within the Foldsystem of the Greater Caucasus (in the Mestia-Tianeti flysch zone), the Lower Cretaceous is developed in the form of clastic-limestone and sandstone- siltstone flysch (rhythmical alternation of sandstone and siltstone turbidite and clay shales) (750-1600 m), which conformably follows the Upper Jurassic flysch. In the south and within the Georgian Block, the old formation, including crystalline rocks of the Dzirula massif, is overlain transgressively by Lower Cretaceous rocks (300-550 m). In the main, limestones are developed within this area. Only in the middle of the section appear marls and clays (Albian stage) and glauconitic sandstones (Cenomanian stage). Reef limestones of Urgonian facies (Barremian stage) and ammonitic limestones (Aptian stage) are distinguished in the Lower Cretaceous.

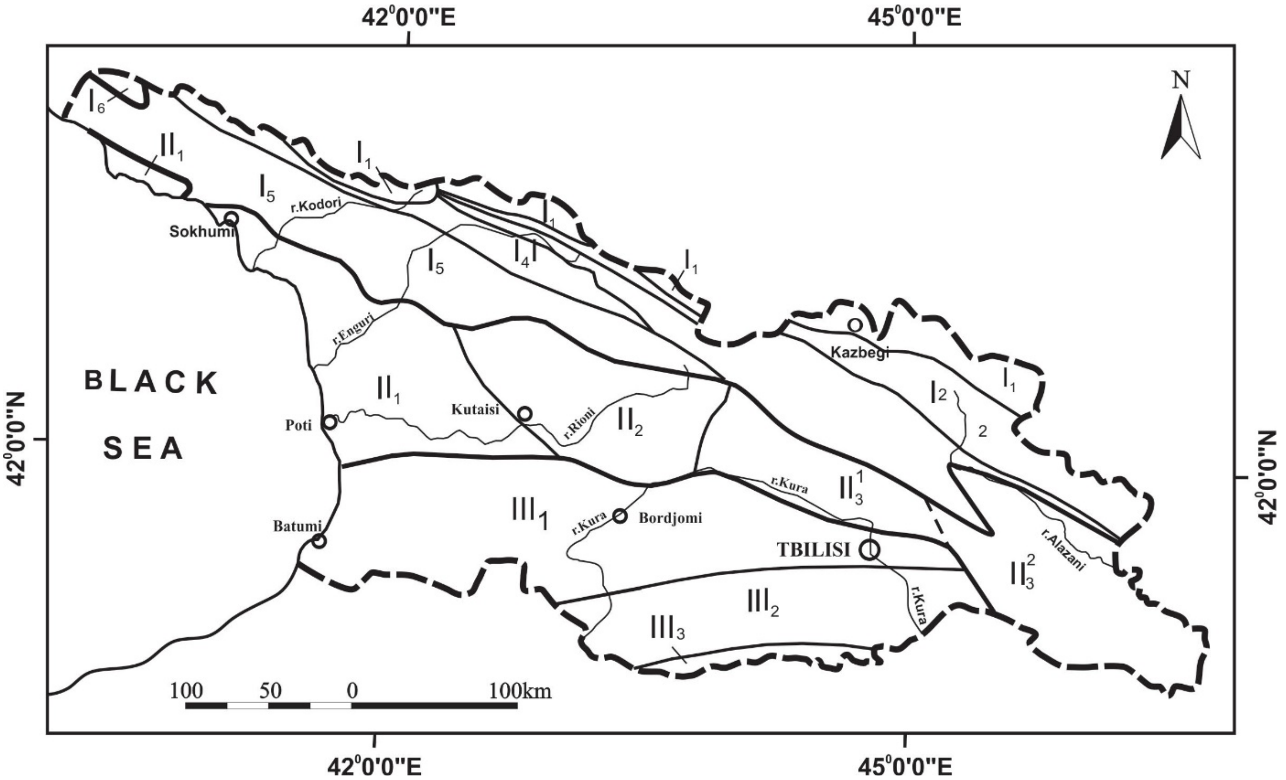

Fig. 2 Simplified tectonic subdivision of the territory of Georgia [8].

I-Fold system of the Greater Caucasus: I_1-Main Range zone; I_2-Kazbegi-Lagodekhi zone; I_3-Mestia-Tianeti zone; I_4-Chkhalta-Laila zone; I_5-Gagra-Djava zone; I_6-Novorosiisk-Lazarevskoe zone. II-Transcaucasian intermountain area: II_1-Western molasse zone of sinking; II_2-Central zone of uplift; II_3-Eastern zone of sinking. III-Fold system of the Lesser Caucasus: III_1-Adjara-Trialeti zone; III_2-Artvin-Bolnisi zone (block); III_3-Lock-Karabakh zone.

In the Upper Cretaceous sediments of the Mestia-Tianeti flysch zone, sandstone-siltstone (in the lower part) and clastic-limestone (in the upper part) flysch (500-900 m) prevail. Within the Gagra-Djava zone and Georgian Block, they are spread mainly as shallow-water limestones, marls, and glauconitic sandstones (250-1200 m), whereas to the west in the Dzirula massif, an alkali basalt-phonolitic series (70-300 m) occurs locally. In the Adjara-Trialeti zone, the Upper Cretaceousis represented by a volcanogenic suite with calc-alkaline basaltic composition, which in the lower part also contains the Albian stage. Stratigraphically higher, Upper Turonian-Senonian limestones and marls (300-1200 m) follow.

In the Arthvin-Bolsini Block and Lock-Karabach zone, transgressive Upper Cretaceous sediments are present, which subdivide into three parts. Cenomanian volcanogenic- carbonaceous series (900-1200 m) overlaps directly the Khrami and Loki massifs and Jurassic rocks. Ascending the section, there follows a basalt-andesite-dacite-rhyolite series (1100-3300 m) of Turonian-Santonian age. The uppermost part

(Campanian-Maastrichtian) is represented by shallow-water limestones and marls with interlayers of acidic tuffs (300-350 m).

Paleogene deposits are found in all tectonic units. In the southern slope of the Greater Caucasus, the Paleocene-Eocene is represented by sandstone-siltstone flysch (600-850 m). In the southern part, the Upper Eocene is built up of olistostromes (10-400 m) [2, 9].

In the Georgian Block, the Paleocene and Eocene consist of an alternation of limestones and marls (30-400 m). In the middle part of the Lirolepis horizon, a horizon of marls distinguished, which begins the Upper Eocene. In the Adjara-Trialeti zone, the Danian is built up of limestones and marls, whereas the transgressive Paleocene-Lower-Eocene consists of sandstone-siltstone and clastic-limestone flysch (Borjomi flysch), the thickness of which increases from west to east (1500-3000 m). These are followed by a very thick Middle Eocene volcanogenic suite, which in the western part of the zone is represented by tholeiitic and shoshonitic, mainly basaltic, submarine volcanics and tephro-turbidites, whereas in the eastern part there are calc-alkaline and tholeiitic, mainly andesitic rocks, olistostromes, and tephro- and sandstone-siltstone turbidites. Its thickness increases from east to west (1000-5000 m).

In the Artvin-Bolnisi zone and the Lok-Karabakh zone, a Middle Eocene volcanogenic suite is built up of calc- alkaline basalt-andesite-dacite-rhyolite volcanics (1200-2700 m) and transgressively overlaps Cretaceous and Jurassic rocks and the Loki Crystalline Massif.

In the Adjara-Trialeti zone, the Upper Eocene is distinctly transgressive and consists of marls, clays, sandstones and gravelstones (500-1500 m),whereas in the western part of the zone, it consists of andesitic-basaltic volcanoclastic (1000 m). Oligocene deposits (mainly the Maikop series) are generally represented by thin-bedded gypsiferous clays, which contain fish scales, and sandstones. This series continues in the lower part of the Miocene, too. It crops out in the Gagra-Djava zone, in the Georgian and Artwin-Bolnisi blocks, and in part of the Adjara-Trialeti zone. Its thickness is rather variable (250-3000 m).

Neogene formations are present only in molasse depressions. The Lower Miocene, as was mentioned, belongs to the Maikop series. Further up the section, the Miocene is represented in the lower part (Middle Miocene-Middle Sarmatian) by marine molasse (clays, sandstones, conglomerates, limestones, and marls), and in the upper part (Upper Sarmatian-Pliocene) by marine and continental molasse (conglomerates, sandstones, sands, and clays). There are very distinct unconformities at the bases of the Miocene, Meotian and Upper Pliocene. In the Artvin-Bolnisi block and Lok-Karabakh zone, and partially in the southern part of the Adjara-Trialeti zone, the Neogene is represented by subaerial calc-alkaline andesites, andesite-dacites and dolerites. Their upper part includes the Pleistocene and Quaternary, too. In the lower part (Upper Miocene-Lower Pliocene) subaerial volcanic contain a rich terrestrial flora, and in the Upper Pleistocene there are mammalian fauna.

Quaternary deposits are distributed very irregularly. These consist of river terraces, moraines of three glaciations periods, and a volcanic formation in the form of volcanic cones and lava flows (in the Greater Caucasus, to the south of Kazbegi and on the Trialeti Range in the Borjomi region). There are also vast accumulation plains in intermountain areas.

2.1 Tectonic Structure of Georgia

The territory of Georgia, as a part of the Caucasus, underwent a long and complicated tectonic evolution and contains structures of various types, scales and genesis [10]. Alpine structures have a different character in the various tectonic zones. The northeastern tectonic unit of Georgia — the Fold system of the Greater Caucasus (Fig. 2), is characterized by a distinctly expressed asymmetry in its structure: southward verging, often isoclinal folding on the southern slope and quiet, poorly folded, or monoclonal structure on the northern slope. Large southward-directed nappes are developed also on its southern slope [11]. The above-mentioned structures provide evidence of the leading role of late Alpine under thrusting of the comparatively rigid Georgian Block together with Gagra-Java zone under the Greater Caucasus during its deformation (intraplate subduction).

The northern boundary of the Georgian Block, in its western part is formed by a deep fault, which in the sedimentary cover manifests itself as a regional flexure. Study of the structural peculiarities of the Georgian Block has shown that its central and western parts are characterized by a mosaic-block structure of the basement and occurrence of typical above- fault folds in the sedimentary cover. In the eastern part of subsidence of the Georgian Block, its cover is detached and shifted towards the south together with the nappes of the southern slope of the Greater Caucasus [11].

The Adjara-Trialeti zone of the Lesser Caucasus, which is situated to the south of the Georgian Block is, on the whole, an anticlinorium and is characterized by block-fold and thrust-fold structures. To the west from the Dzirula Massif along the northern margin of this zone, an overthrust nappe is developed.

The Artvini-Bolnisi zone consists of two different tectonic units: the Javakheti zone (in the west) and the Bolnisi zone (in the east) (Fig. 2). In the young (Neogene-Pleistocene) volcanic cover of the Javakheti zone, sub-latitudinal gentle folds are observed. Two deep sub-meridional seismogenic faults are established, which served as conduit channels for young volcanics. The Bolnisi zone includes the horst-like Khrami inlier of pre-Alpine basement and the territory covered with Cretaceous and Paleogene volcanic rocks. Brachyanticlines and steep faults of various orientations are developed to the south in a sedimentary cover, which generally forms a gentle syncline.

The northeastern wedge of the Lok-Karabakh zone forms part of Georgia (Fig. 2) and is characterized by echelon-like disposition of internal anticlinoria. In the core of a sub-latitudinal Loki anticline, the pre-Jurassic crystalline basement is exposed. The axis of this structure plunges in both western and eastern directions and causes periclinal closure of the sedimentary cover.

The fold and fault systems of the Adjara-Trialeti, Lok-Karabach, and the Artvini-Bolnisi zones were formed mainly as a result of the manifestation of Late Alpine (Neogene) tectonic movements with the displacement of masses from south to north [11].

3. Geotourist Routes of Georgia

The unique geological structure of Georgia's territory allows us preparing several geotourist routes (see Fig. 1). In particular: 1) Tbilisi–Pasanauri- Kazbegi (along the Georgian military road -155 km); 2) Tbilisi-Kutaisi -Ushguli (450 km), Tbilisi–Borjomi-Vardzia (240 km). As an example geotourist route Tbilisi-Pasanauri-Kazbegi will be considered bellow in detail (Fig. 3). Other sites will be described but very briefly.

3.1 Tbilisi-Pasanauri-Kazbegi (Along the Georgian Miliraty Road)

3.1.1 First Day (Tbilisi-Pasanauri)

Acquaintance with the geological section begins in Tbilisi — capital of Georgia Tbilisi was founded in the 5th century A.D. by Vakhtang Gorgasali, King of Georgia. But archaeological finds suggest that 5-6 thousand years ago the territory and the vicinities of Tbilisi were already populated. Here influences of both East and West cultures mixed together. This gave the city unusually colorful, ornate and unique aspect.

The route longwise 155 km (Fig. 3) crosses eastern termination of the Adjara-Trialeti folded zone, Mtkvari intemontane depression and the Foldsystem of the Greater Caucasus [12-14]. In the vicinity of Tbilisi on the right bank of the Mtkvari river rather gentle folds of latitudinal strike are distinguished belonging to the eastern termination of the Adjara-Trialeti folded zone of the Lesser Caucasus.

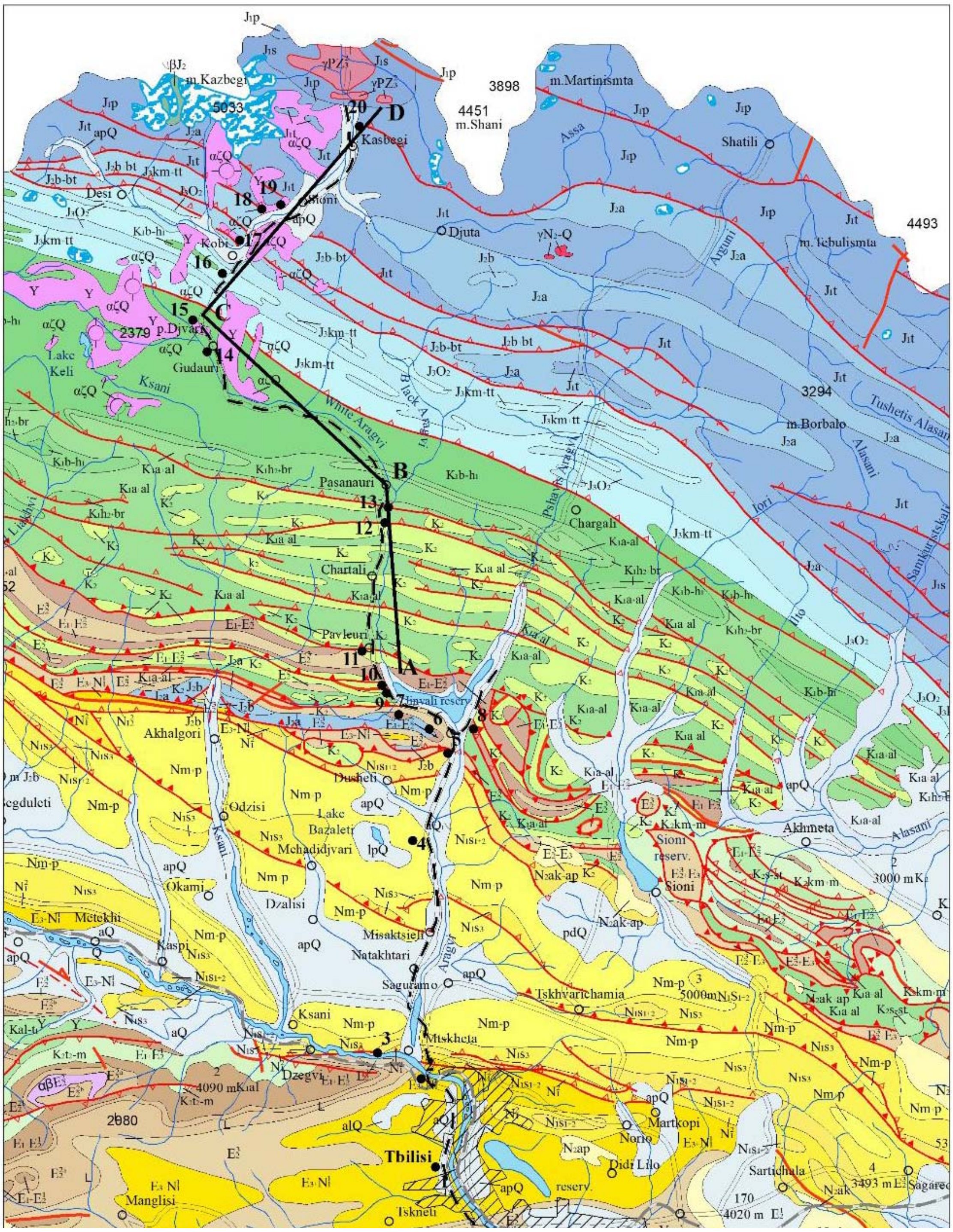

Fig. 3 Geotourist route: Tbilisi-Pasanauri-Kazbegi, along the Georgian Military Road. Clipping from the Geological map of Georgia (1:500 000) [7]. A-B-C-D – segmented line; 1, 2, 3 and so on - stop points.

Legend: Q - Quaternary, N_2ak+ap - Akchagilian and Apsheronian, Nm+p - Meotian and Pontian, N_1s_{1+2} - Lower and Middle Sarmatian, N_1s - Sarmatian, N_1^2 - Middle Miocene, $E_2^3+E_3$ - Upper Eocene-Oligocene, E_2^3 - Upper Eocene, E_2 - Middle Eocene, E_1+E_2 - Paleocene and Eocene, $E_1+E_2^1$ - Paleocene and Lower Eocene, K_2 - Upper Cretaceous, K_2km+m - Campanian-Maastrichtian, K_2t_2-m - Upper Turonian-Maastrchtian, K_2s-st - Cenomanian-Santonian, K_1al-K_2t_1 - Allbian and Lower Turonian, K_1a-al - Aptian and Albian, K_1h_2-br - Upper Hauterivian-Barremian, K_1b-br - Beriasian-Barremian, J_3 - Upper Jurassic, J_2bt - Batonian, J_2b - Bajocian, , J_1-J_2a - Lower Jurassic-Aalenian, J_2a - Aalenian, J_1t-Toarcian, J_{1P} - Plinsbachian, J_1s – Sinemurian, PZ_3^2 - Late Variscan granitoid intrusive (Dariali massif).

Stop 1. The route of the excursion passes through the Saburtalo syncline consisting of clayey-sandy deposits of the Maikop series of the Oligocene. After leaving the city and covering a distance of 1.5 km the route crosses the Lisi anticline, formed by the lower part of the Oligocene, and then the wide syncline Digomi Valley. The syncline consists of the upper part of the Upper Eocene-Akhalsopeli suite (alternation of green sandstones and clays) and of the thick (up to 3000 m) clay-sandy Maikop series of the Oligocene-Lower Miocene.

Stop 2. The Maikop series is usually represented by thin bedded gypsiferous clays with fish scales, large septarian concretions and jarosite coatings. But in East Georgia a facies of coarse-grained quartz sandstones (Lower Miocene) is often related to the tops of the Maikop series. A thick (up to several hundred meters) suite of such sandstones outcrops in the northern limb of the Digomi syncline forming continuous scarp along the right bank of the Mtkvari. The appurtenance of these sandstones to the Sakaraulo horizon (Burdigalian) has been proved by means of microfauna. The upper clayey part of this series occurring in the core of the syncline is related to the Kotsakhuri horizon (Helvetian) while its lower clayey part, underlying the sandstones, is the Oligocene.

Near the Mtskheta town the lower part of the Upper Eocene is represented by foraminiferal marls of the Lirolepis horizon with sandstone interlayers dipping south. Mtskheta is one of the most ancient town in Georgia. Up to the 6th century A.D. it was the capital of the Georgian Kingdom. The town is extremely rich in monuments of ancient times. In the centre of the town stands a magnificent construction of the first quarter of the 11th century — the Svetitskhoveli cathedral. On the left bank of the Mtkvari, opposite the town of Mtskheta, the marvelous monument of the ancient Georgian architecture rises — the Djvari convent (convent of the cross). It was erected in 586-600 A.D.

Stop 3. Here at the confluence of the Mtkvari and Aragvi rivers two tectonic units collide: the Adjara-Trialeti folded zone and the Georgian block (Kartli depression). The former is represented by the Mtskheta anticline, whose northern limb is complicated by additional folding. In the core of the fold the Paleocene-Lower Eocene deposits outcrop (1000 m), while the limbs consist of the Middle Eocene volcanic formation (500 m) and the Upper Eocene clayey-sandy rocks (800 m). The fold axis, traced in the latitudinal direction along the Mtkvari, gradually rises westward, and at the village of Dzegvi in its core carbonaceous deposits of the Upper Cretaceous appear (500 m). In this part the Mtskheta anticline is thrust over the Georgian block. In their turn Miocene deposits eastward of the Georgian block are overthrust upon the Adjara-Trialeti zone.

Beyond Mtskheta overthrust on the left bank of the Mtkvari the monoclinal ridge Skhaltba is seen, which consists of the following deposits: Maikop clays and sandstones of the Oligocene-Middle Miocene (1400 m), Lower and Middle Sarmatian (50 m), continental sandstones and clays of the Upper Sarmatian (1500 m), continental Lower Pliocene (Meotian-Pontian) conglomerates (2000 m).

Stop 4. In the Mtkvari depression crop out Meotian-Pontian conglomerates, which completely composed by flysch rocks. Their age established on the basis of stratigrapic position and vertebrates of Meotian age. In the Mtkvari depression according to seismic reflection profiling and seismic tomography are developed many thrusts, which at the depth become subhorizontal. They arose under the influence of nappes of the southern slope of the Greater Caucasus.

Stop 5. Near the v. of Zhinvali the route enters the Zhinvali-Gombori subzone of the Mestia-Tianeti flysch zone, within which the Alisisgori-Chinchvelta, Sadzeguri-Shakhvetila and Zhinvali-Pkhoveli nappes and the Ksani-Arkala parautochthone are distinguished, representing in geological past independent structural-facies zones.

The present of the nappes is established on the basis of structural data. In particular of the existence of many tectonic windows and semiwindows, boring and geophysical data and paleogeographic reconstructions showing that above mentioned nappes completely overlap the Gagra-Java zone of the southern slope of the Greater Caucasus. It is general detachment of Miocene-Pliocene rocks of the Kartli molasse depression as well [2, 11, 13, 14].

Stop 6. To the north from Zhinvali depression the route crosses the Zhinvali-Pchaveli parautochthon, which is a comparatively thin plate torn off the autochthone (eastern continuation of the Gagra-Java zone) and thrust upon the Mtkvari depression (Fig. 3).

Near the Zhinvali reservoir begin outcrops of olistostromes of the southern slope of the Greater Caucasus. In the frontal part of the Zhinvali-Pkhoveli nappe olistostrome rocks of the Upper Eocene are widely developed (several hundred meters in thickness) formed due to intensive destruction of the cordillera band of the East part of the Gagra-Java zone [2, 9, 11].

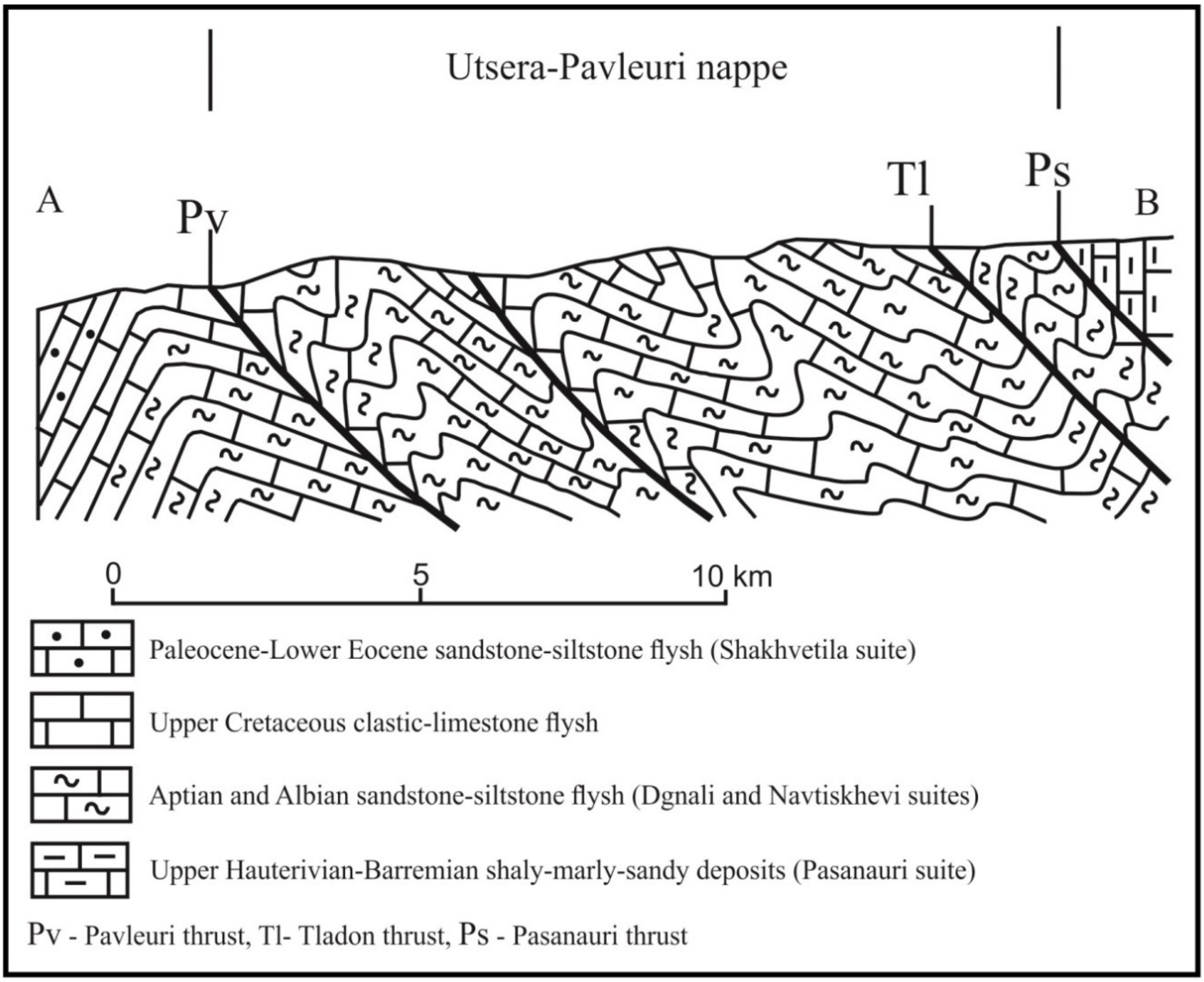

Fig. 4 Cross-section between Pavleuri and Pasanauri (A-B segment of profile).

The olistostromes consist of olistoliths of the Upper Jurassic reef limestones, volcanic rocks of the Bajocian, shales and sandstones of the Lias and various crystalline rocks of the Paleozoic, cemented by sandy-clayey deposits. That is source of these rocks was the Gagra-Djava zone of the Greater Caucasus (so-called Racha-Vanadam Cordillera), which at present is entirely overlapped by nappes of the Flysch zone in the eastern segment of the southern slope (east of the Rioni River). This cordillera was a major source of clastic material for Upper Cretaceous and especially abundant for Upper Eocene sediments.

From the South-West the strip of the Upper Eocene olistostromes outcropes is bounded by the large Zhinvali-Pkhoveli overthrust overlapping the Ksani-Arkala paraautochthone (Fig. 3).

The age of olistostromes of the Greater Caucasus southern slope was defined on the basis of their position in the section between the faunaly dated sediments of the Middle Eocene and Lower Oligocene, and according to findings of nummulitic fauna in the matrix of block breccias, specifying their Upper Eocene age [2].

By the end of the Late Eocene, at the maximum of the Pyrenean tectonic phase, landslide events were abundant due to the beginning of horizontal displacements and catastrophic earthquakes.

The Pyrenean movements in that period were related to displacement of the Transcaucasian block to the north and its underthrusting beneath the fold system of the Greater Caucasus, which was most evidently expressed in the major (pre –Late Pliocene - Rodanian) phase of the nappe emplacement [11].

Stop 7. Along the road one can see Middle and Upper Eocene terrigenous deposits of this unit, which transgressively overlap Aalenian sandstones and shales (Sori suite).

Different nappes crop out well to the east of the Georgian Military Road, along the river Pshavis-Aragvi (left tributary of the river Aragvi) [2, 13].

Stop 8. Along the river Pshavis-Aragvi, in the frontal part of the Sadzeguri-Shakhvetila nappe, one can observe a thin scale consisting of intensively dislocated Paleogene deposits which form a heavily compressed syncline overturned to the West-South-West. Along the highway dark-grey, greenish-grey, sometimes carbonaceous argillites and schistose clays crop out with interlayers of carbonaceous sandstones and schistose marls of the Paleocene Shakhvetila suite, as well as greenish-grey and green schistose marls, carbonaceous argillites, and sandstones of the Kvakevriskhevi suite of the Lower-Middle Eocene.

To the North-East the Alisisgori-Chinchvelta nappe is observed, whose lower part consists of the terrigenous Navtiskhevi (Albian), Ukughmarti (Lower Cenomanian), Ananuri (Upper Cenomanian- Lower Turonian) and carbonaceous Margalitisklde (Upper Turonian) and Eshmakiskhevi (Coniacian-Santonian) suites. Along the highway is observed an overthrusting of flat-lying dark-grey, greenish, thin-bedded argillites and medium and thin bedded grey-rusty grey sandstones of the Lower Cenomanian (Ukughmarti suite) and sometimes sillicites of the Upper Cenomanian-Lower Turonian (Ananuri suite) of the Alisisgori-Chinvhvelta nappe upon the heterochronous rocks of the Sadzeguri-Shakhvetila nappe dipping at high-angles (Fig. 3). Both nappes are ruptured by young sublatitudinal reverse faults seen along the route of the excursion.

Stop 9. Returning to the gorge of the river Aragvi near the Ananuri fortress one can see that the Zhinvali-Pkhoveli nappe is represented here by one large Ananuri antikline (Fig. 3). The core of the fold is built up Aptian shales and sandstones (Tetrakhevi suite) and of variegated marls and sandstones of Albian age (Navtiskhevi suite). On vertical southern limb of Ananuri anticline one of the best monument of architecture of late feudalism Ananuri fortress is raised. Limbs of the fold are composed of sandstones and thin-laminated marls of Lower Cenomanian (Ukughmarti suite), Upper Cenomanian-Lower Turonian silicified thin laminated marls and brown silicates (Ananuri suite), red marls, lithographic limestones of the Upper Turonian-Santonian (Margalitisklde and Eshmakiskhevi suites) Maastrichtian deposits are represented by orbitoid thin-laminated marls and limestones with interlayers of microconglomerates, gradually continuing by marls of Danian age. Rather to the east of this locality in the vicinity of the village Zhinvali Maastrichtian deposits

(Orbitoide suite) are almost completely composed of olistostromes.

Stop 10. From here begins the Sadzeguri-Shakhvetila nappe where Paleogene deposits in sandstone-siltstone flysch facies and often interruptions in sedimentation (before the Albian, Cenomanian, Maastrichtian and Paleocene) are wide developed [2, 11].

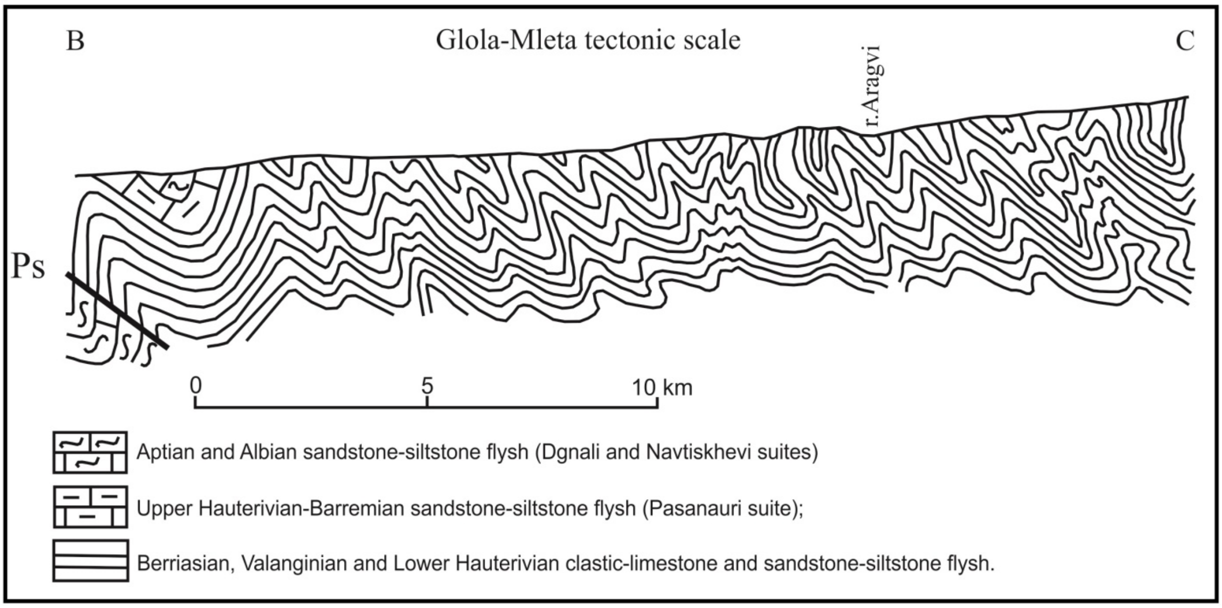

Fig. 5 Cross-section between Passanauri and Cross (Djvari) Pass (B-C segment of profile).

Stop 11. From the v. of Pavleuri begins Utsera-Pavleuri nappe, in which from North to south smaller imbricated scales are distinguished built up of clays and sandstones of the Lower Cretaceous (Aptian-Albian), siliceous-sandy deposits (Cenomanian) and limestones of the Turonian-Lower Santonian. Owing to the imbricate structure of the Utsera-Pavleuri nappe these deposits are repeated several times in the section between overthrusts [13, 14] (Fig. 4).

Stop 12. Clay shales of the Aptian (Dgnali suite) near the v. of Bibliaani overthrust various horizons of the Upper Cretaceouss clastic-limestone flysch deposits on the so-called Tladon thrust. This fault bounds the Glola-Mleta scale from the South (Fig. 4 and 5).

3.1.2 Second Day (Pasanauri-Kazbegi)

Stop 13. The area of the v. of Pasanauri is characterized by scenery, climatic and balneological conditions of mountain health-resort. A mineral spring of the, Yessentuki,, type is known here since antiquity. The waters are of small discharge (700 l/per day). It is connected with the core of the Pasanauri anticline, built up of Hauterivian-Barremian shaly-marly-sandy deposits (Bakhani and Pasanauri suites).

Between Pasanauri and Gudauri thrusts exists a large Glola-Mleta tectonic scale. It is mainly formed of Lower Cretaceous deposits with intensively minor folding (Fig. 5).

Beyond the Gudauri tunnel-passageway the road descends along the andesite-basalt Gudauri lava flow of the Sakokhe-Sadzele volcano to the v. of Kvesheti. This lava fills the paleoriver channels of the White Aragvi and its lefts tributaries.

Stop 14. The Cross (Djvari) Pass affords a panorama of the mountain-and-valley topography of the Aragvi river headwaters. To the west of the Pass the Keli volcanic upland can be seen built up of a group of extinct Pleistocene-Holocene volcanoes termed, Seven Brothers. Fragments of lava flows from these volcanoes are preserved in the area of the Cross Pass (Fig. 3). At present they are separated from their sources by a deep canyon (400-500 m) of the White Aragvi river. Small remnants of flows occur in the vicinity of the v. Khatissopeli, on right bank of the Aragvi.

The band of Upper Jurassic clastic-limestone flysch deposits, between the Gudauri and Truso thrusts, represents a large Kolosan-Pakhvidji tectonic scale, which overlaps a series of folds of the Lower Cretaceous carbonaceous rocks (Fig. 6).

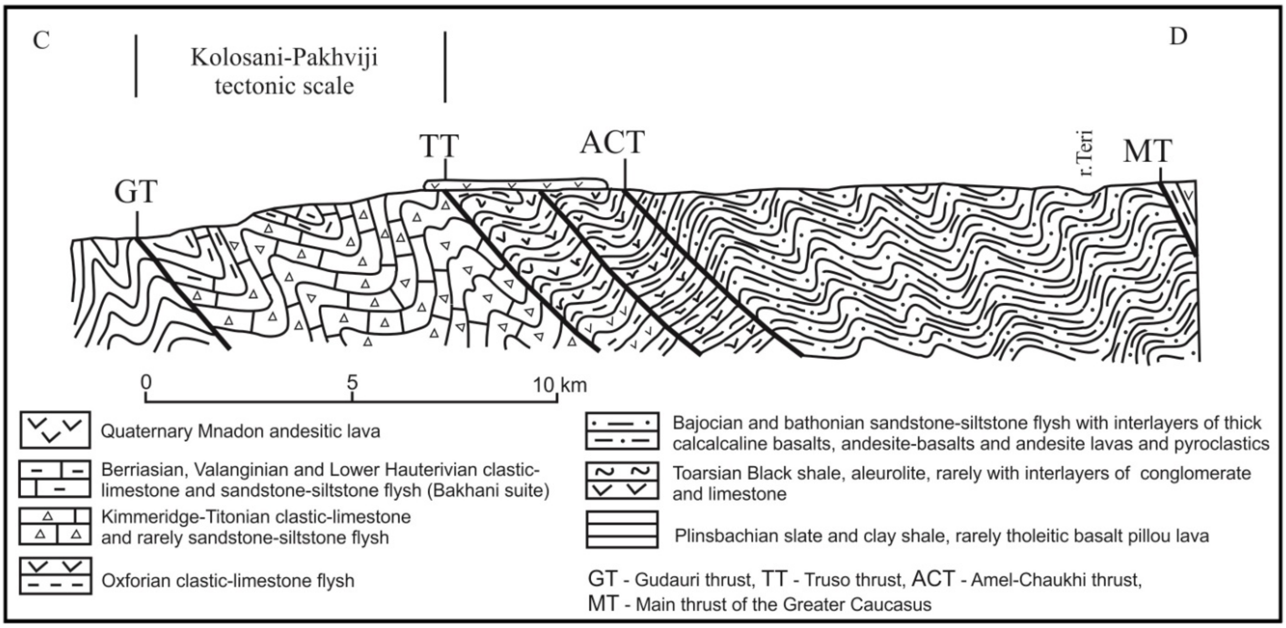

Fig. 6 Cross-section between Cross (Djvari) Pass and Kazbegi (C-D segment of profile).

Stop 15. In the middle course of the Bidara gorge (right tributary of the r. Tergi), on the slope of the gorge some fragments of Quaternary andesitic agglomerate tuffs and lava breccias of the Sakokhe-Sadzele volcano are presented. Numerous ferrous-carbonate mineral springs of the “Narzan” type flow out from fissures of carbonaceous rocks. Sometimes large accumulation of red and yellow-brown carbonaceous tuffs (travertines) are observed around the springs.

Stop 16. South of the v. Kobi — along the Bidara gorge one can see the Upper Jurassic rocks consisting of clastic-limestone flysch deposits. They without interruption crop out up to the Cross Pass and form numerous small narrow folds overturned southward.

Stop 17. Near the v. Kobi on the left bank of the Tergi under the Mnadon andesite lava clay-shales, quartz and polymictic sandstones and rarely sandy-limestone Shevardeni suite of the Bathonian age (250-300 m) are exposed. The suite is thrust southwards onto various horizons of the Upper Jurassic clastic-limestone flysch. From this thrust begins the Kazbeg-Lagodekhi zone of the Greater *Caucasus* (Fig. 6).

Stop 18. Between Kobi and Sioni a large volcanic edifice of the mount Kabardjina (3121 m) occupies the left bank of the Tergi. This is a polygenetic stratovolcano, built up of heterogeneous volcanic facies produced by several eruptive phases. At the base of the volcano a thick series of andesite-dacitic agglomerated tuffs and lahar breccias occur; they are overlain by lava of similar composition cut through by dacitic extrusions. The volcanic edifice is dated Middle-Late Pleistocene (Fig. 3). Further for a distance of 6 km along the left slope of Tergi crop out strongly dislocated, broken by imbricated overthrust faults, Upper Aalenian clay shales, aleurolites and sandy limestones of the Upper Ukanapshavi suite (300 m) and Bajocian clay slate of the Mnadon suite.

Stop 19. In the vicinity of Sioni the Toarcian shaly-sandy deposits are thrust upon the Bajocian clay

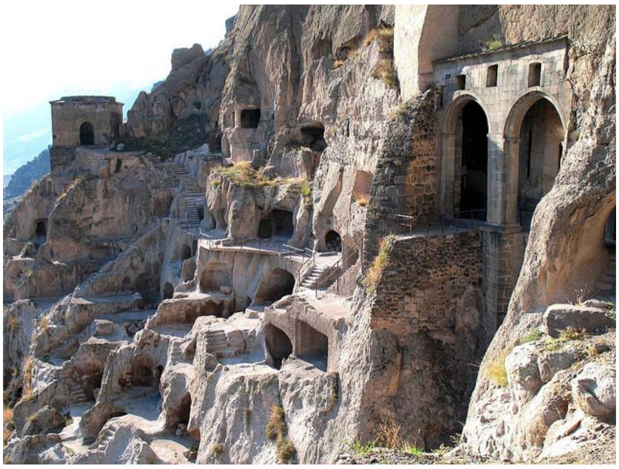

Fig. 7 Front view of Vardzia rock-cut city- is hewn into Mtkvari ignimbrites flow.

slates and argillites of the Mnadon suite along the large Amel-Chaukhi thrust (Fig. 6). This zone comprises several eruptive centres of the Quaternary andesite-dacite lava flows filling the beds of the left tributaries of the Tergi.

Further to Kazbegi the route crosses the band of complexly dislocated Toarcian rocks. They are complicated by three parallel thrusts, which comprise numerous carbonaceous springs of the "Kazbeki" type [12-14].

Stop 20. To the north from Kazbegi along the road between the Plinsbachian and Toarcian shaly-sandy deposits one can see the steeply dipping northward Main thrust of the Greater Caucasus limited from south the Main Range zone of the Greater Caucasus (Fig. 6).

3.2 Tbilisi- -Kutaisi-Ushguli

The route longwise 450 km at the beginning crosses the eastern termination of the Adjara-Trialeti zone and further, along the Mtkvari (Kura) river – Neogene and Quaternary molasse deposits of Kartli intermountain depression (see Fig. 1). Near v. Surami the route enters into the Dzirula crystalline massif – the largest inlier of the pre-Alpine crystalline basement in the Transcaucasus (see Fig. 1). It is composed of Precambrian gneiss-migmatite complex, three generation of metabasites, quartz-diorite orthogneisses and of Variscan granite-gneisses and granites. In the south-eastern part of the massif, in so-called Chorchana-Utslevi strip, faunally dated Lower and Middle Paleozoic metaophiolites (serpentinites and amphibolites) are preserved [4, 6].

Near the v. of Shorapani crop out Lower Jurassic-Aalenian and then Neogene trerrigenous rocks belonging to the sedimentary cover of the Dzirula crystalline massif. Further, near the town Kutaisi the route crosses alkaline volcanics of so-called Mtavari suite of Upper Cretaceous age. After that at a great distance the route passes through the Quaternary deposits of the Western (Rioni) molasse depression). Beginning from the v. of Senaki the route crosses Paleocene-Eocene, Oligocene and Miocene terrigenous deposits, forming large and wide so-called Odishi syncline.

Near the v. of Djvari one can see big flexure built up of Upper Jurassic terrigenous, Cretaceous carbonaceous and Paleogene terrigenous rocks. The flexure reflects on the surface a hidden deep fault at a depth, which represents the boundary between Georgian block and the Gagra-Djava zone of the Fold system of the Greater Caucasus (see Fig. 1 and Fig. 2). To the north, within the Gagra-Djava zone along the river Enguri the route crosses relatively gentle folds, composing of Lower Jurassic terrigenous rocks and Bajocian calc-alkaline basalts, andesites, lava breccias, volcanic tuffs and, in places, tephroturbidites.

After that the route crosses weakly metamorphosed mainly terrigenous deposits of so-called Dizi series, in which faunally (the corals, foraminifera, conodonts and flora) the Devonian, Carboniferous, Permian and Triassic are established. Dizi series belong to the Chkhalta-Laila zone of the Greater Caucasus (see Fig. 1 and Fig. 2). Then follow Sinemurian, Plinsbachian and Toarcian slates and shaly-sandy deposits. In the vicinity of v. of Ienashi crop out Middle Jurassic clayey and clayey-sandy schist, sandstones and siltstones.

To the north-east from the v. of Mestia along the rivers Mulkha (eastern tributary of the r. Enguri) and Mestia-Chala crop out Berriacian-Hauterivian and

Upper Jurassic clastic-limestone and rarely sandstone-siltstone turbidites, marls and clay shales belonging to Mestia-Tianeti (Flisch) zone of the Greater Caucasus (Figs. 1 and 2). Settlement Mestia — the district centre of the Upper Svaneti is one of the Alpine ethnographic regions of Georgia. Upper Svaneti (Suania in ancient sources), a historic province of the ancient Georgian Kingdom of Colchis, is lies on the southern slopes of the central Greater Caucasus. Village Ushguli (2300 m a.s.l.), which is located in the r. Enguri sources (Fig. 8), being one of the highest continuously inhabited settlements in Europe. The 9th-12th centuries famous 30 towers of village have been included in the UNESCO's World Heritage list.

Ushguli is overlooked by magnificent 5100-5200 meters high and 15 km length Upper Palezoic Shkara granitoid massif covered with perpetual snow and glaciers. Near the Enguri river source, between the Shkhara Paleozoic massif and the Lower Jurassic shales crops out the Main Thrust zone of the Greater Caucasus, which is easily accessible on foot (Fig. 8). Here we can observe how this grandiose crystalline massif thrusts over sedimentary rocks and how it rolls up them. This quite interesting route ends with this unique outcrop.

Fig. 8 The upper reaches of the river Enguri, village Ushguli and the granitoid massif Shkhara.
The highest point is 5201 m. The age is 320 Ma (dated by U-Pb single zircons method).
Dashed line indicates the main thrust zone.

3.3 Tbilisi-Borjomi-Vardzia

The route longwise 240 km at the beginning, from Tbilisi to Khashuri, crosses Neogene and Quaternary molasse deposits of the Kartli intermountain depression (see Fig. 1 and Fig. 2). To the south-west from Khashuri, near the v. Akhaldaba the route enters into the western part of the Central segment of the Adjara-Trialeti folded zone. The oldest Upper Cretaceous deposits of the zone are built up of carbonaceous rocks. The Paleocene-Lower Eocene is represented by two facies: by sandstone-siltstone flysch (so-called Borjomi flysch), in axial part of the zone, and shallow water clayey-marl facies (so-called multicolored suite) on its peripheries. Middle Eocene volcanogenic formation follows conformable in axial part of the zone and discordantly (up to the Upper Cretaceous) on its peripheries. It is subdivided into three suites: Likani — of volcanic tuff of subalkaline basalts, Kvabiskhevi — of lava flows of differentiated series and Dviri — of rudaceous and massive tuff breccias and lava sheets of low-titanium basalt. Upper Eocene deposits are represented by terrigenous rocks.

This part of the Adjara-Trialeti zone are characterized by block-folded structure. In the axial strip Central block elevation is distinguished, which is represented by large Borjomi and Lomismta anticlines and separated them gentle Baratkhevi syncline built up mainly of Paleocene-Lower Eocene Borjomi flysch. To the north and south of the elevation Khashuri and Akhaltsikhe-Dviri synclinoriums and Tarson anticlinorium are traced. These units by deep seated faults are separated. From the north and south Surami-Gokishuri, Northern and Southern axial and Akhaltsikhe-Tedzami deep faults are distinguished.

From Borjomi the route continues towards the Akhaltsikhe depression and runs along left ledges of the river Mtkvari, where the Middle Eocene volcanogenic rocks crop out continuously. Given outcrops are quite interesting, since it comprises of classic basaltic pillow lavas with characteristic joints. At the Khertvisi fortress these rocks are covered by Late Miocene subaerial volcanogenic rocks. From here to the Vardzia rock-cut city outcrops go along the Mtkvari ignimbrites flow and end at this place.

4. Potential Geoparks of Georgia

As the potential geoparks we could consider: 1) Vardzia – Upper Miocene Megacaldera, its explosion products of 1 km thickness and an ignimbrite flow (35 km length); 2) Kazbegi - Quaternary volcanoes and Pre-Jurassic Daryali massif; 3) Sataplia — Dinosaur Footprints, together Sataplia and Prometheus caves; 4) Dmanisi — Dmanisi hominids site and the Mashavera gorge basaltic flow of 20 km length. As an example geopark — Vardzia Middle Miocene megacaldera, an ignimbrite flow and ancient Vardzia cave town will be considered bellow in detail. Other sites will be described very briefly.

4.1 Vardzia Potential Geopark

Vardzia and its surroundings are one of the most promising region of Georgia in terms of geoparks development. Here crop out unique subaerial volcanic formations, in particular: 1) Late Miocene megacaldera and remnants of its margins; 2) Volcanogenic material, almost one kilometer in thickness, where it is easy to observe repeated activity of megavolcano; 3) Ignimbrite deposits of 35 km length produces by this caldera; 4) Andesitic ash layers of 3 m thickness; 5) Sulfide mineralization zones under andesitic-basaltic lava sheets and other significant geotouristic objects.

It should be noted, that Vardzia area is an old historical region, where numerous medieval ritual and household buildings are cut out into volcanic ash and ignimbrite layers. These buildings and geological objects represent remarkable synthesis of natural and cultural monuments. The most important and magnificent of these, is 12th century Vardzia rock-cut city (Fig. 9 and Fig. 10), which is dug out into the Upper Miocene ignimbrites. Such synthesis of natural and cultural monuments, significantly strengthens economic, environmental and educational potential. Based on the abovementioned, we believe that Vardzia area is one of the most promising geopark.

The Vardzia area is located in southern Georgia, near the Georgia-Turkey border within the Lesser Caucasus volcanic highland. Geologically, this region represents part of the Late Cenozoic thick subaerial volcanic province, which also covers large portions of Turkey and Armenia. In Turkey these volcanics comprise so called Erzurum-Kars plateau, in Armenia — Armenian plateau and in Georgia — Samtskhe-Javakheti plateau. These volcanics occupy about 30,000 km^2 and overlap unconformably Middle Eocene volcanogenic rocks. These formations contain invaluable information about the geological evolution of the region and therefore they have been objects of intensive geological study [15-21].

The Samtskhe-Javakheti volcanic highland occupies more than 4500 km^2 in Georgia and discordantly covers

Mid-Eocene tuff-breccias, sandstones and argillites. According to the tectonic zonation of Georgia, it is divided into two blocks: Erusheti and Javakheti [1, 8]. The mean elevation of the highland is about 1500-2000 m above the sea level; individual volcanic edifices, however, reach up to 3000 m (Gumbati dome – 2996 m, Didi Abuli volcano – 3305 m). The highland contains a complex geological structure and has been studied extensively.

In medieval Georgia and the Byzantine Empire, both ritual and residential types of buildings have been carved out into fine-grained tuffs of these volcanic formations. Nowadays, their preserved parts represent important historical-cultural heritage, which are under the influence of natural destructive processes and present serious geotechnical problems [19].

The complex consists of 13 floors with a total area of over 5000 m^2 and includes 542 dwellings, among them 28 special storage facilities for wine (Marani), 3 pharmacies, and 5 Christian churches. In 1283, after a strong earthquake, the cave complex was severely damaged, but it did not cease its operation. In 1553, the Persian army destroyed it, after which the complex was abandoned. In 2007, Vardzia, together with Khertvisi medieval fortress, which is located at 14 km from it, was designated by UNESCO as a World Heritage Site.

Three main stages of magmatic activity have contributed to the formation of the highland: 1. Upper Miocene-Lower Pliocene, when huge, 700-1000 m thick dacite-andesitic volcanic tuffs and basaltic-andesitic lava flows were formed; 2. Upper Pliocene-Lower Pleistocene, when 120-270 m thick continental flood basalts were formed and 3. Mid-Upper Pleistocene, when the Abul-Samsari intraplate volcanic ridge was shaped [20].

Vardzia region is mostly built up of Upper Miocene-Lower Pliocene 700-1000 m thick dacite-andesitic volcanic tuffs and basaltic-andesitic lava flows s. c. Goderdzi formation [15]. In the Goderdzi formation SiO_2 content changes from 58% to 65%, however, there is no europium anomaly in rare earth element distribution patterns, which points to the lack feldspar of fractional crystallization in the magma chamber. Isotopic studies of this formation show that εNd values are is positive and vary between +2 and +4, and$^{87}Sr/^{88}Sr$ ratios vary between 0,7034 and 0.7045. Based on these data we assume that the rocks have a mantle source. U-Pb ages of zircons from the Goderdzi formation varies between 8 and 7 Ma [20].

On the basis of field work, using physical volcanology techniques, we suppose that the magmatic center which produced the Goderdzi formation was a megavolcano, located on the Georgia-Turkey border. Modern Niala fields (12 ×18 km) are possibly the site of caldera subsidence, which could be the source of the Mtkvari pyroclastic density currents. At present, it is injected by post-volcanic andesitic domes, such as Gumbati mountain (2996 m). The Niala fields are covered with Quaternary sediments and the eastern part of the caldera is eroded by the Mtkvari river canyon. Despite the fact, that this territory undergoes erosion for about 7-7.5 Ma, the identification of large caldera circular structures is still possible here.

Large amounts of eruptive material, rhythmic alternation of the different types of volcanics, noticeable sizes of lithic breccias (sometimes > 1 m), thick volcanic ash layers (3 m) (Fig. 9), vast distribution of pyroclastic flow deposits and other factors make it apparent that the Goderdzi suite is the result of caldera-forming eruptions. One of those eruptions, we believe, was responsible for the formation of the Mtkvari ignimbrites flow [19].

The Mtkvari pyroclastic flow is well-observed in relief along Mtkvari river canyon because of its whitish color and is traced continuously from the Karzameti fortress to the Khertvisi fortress, more than 35 km in length. The thickness of the flow increases noticeably from the supposed magma center (40 m in average) to the periphery (80 m in average). The flow is inclined towards the north by the angle of 2-4^o. Its surface is perfectly straight and the bottom is conformed to the relief, which points to its magmatic origins (Fig. 10).

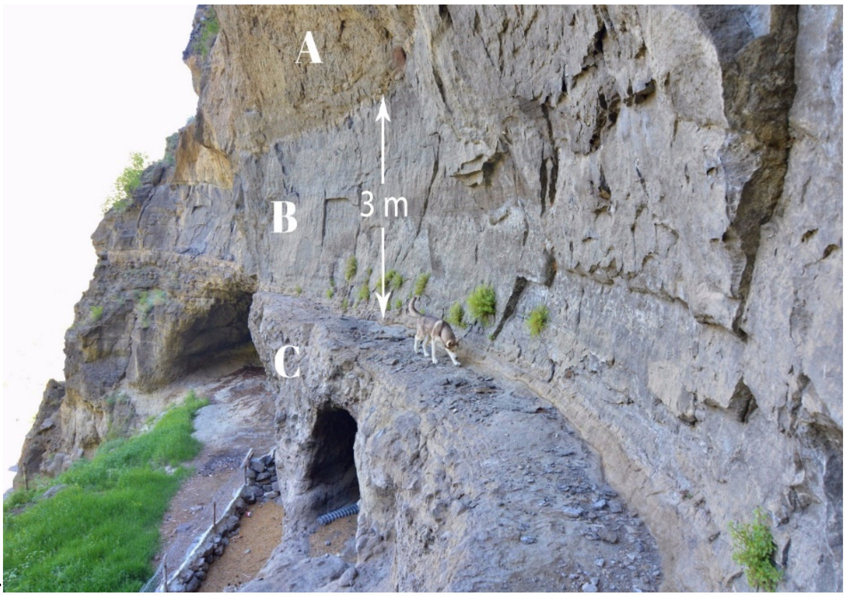

Fig. 9 The exposure of thick layer of volcanic ash of Vani kettles. A: medium-grained tuffs, B: grey volcanic ash, C: coarse-grained tuffs.

Fig. 10 Panoramic view of the Mtkvari pyroclastic flow. In right – Vardzia rock-cut city. A: The Goderdzi pyroclastic formation, B: the Mtkvari ignimbrites flow. The dashed line indicates a detachment of Vardzia block.

The upper boundary of the Mtkvari ignimbrites layers a 25-35 cm thick, fine-grained white tuff layer. As for the layers under ignimbrites, unfortunately, they are barely exposed as they are covered by colluvium. However, these rocks crop out straight under the central part of the Vardzia rock-cut city section of about 120 m length and present intensively broken and brecciated andesitic lava flow. In our opinion, this structure of the Vardzia foundation is a significant factor for preserving its stability. Apparently, the pyroclastic flow kept its relatively stable state at the Vardzia section due to this foundation.

The Mtkvari pyroclastic flow particles is not well graded which should be the result of the turbulence of pyroclastic density currents. We believe that these turbulent movements were responsible for mixing of ash and other pyroclastics. Nevertheless, exceptions can be noted, since at some places the flow is represented only by ash or relatively small-size breccias (15-25 cm).

The Mtkvari pyroclastic flow is andesitic-dacitic welded, weakly welded and non-welded ignimbrites, with SiO_2 content varying between 58% and 66%. Its color changes with respect to the degrees of welding. In particular, southern parts of ignimbrites near the Karzameti fortress are highly welded and pink in color; to the north, near the Vardzia rock-cut city these ignimbrites are weakly welded and their color changes to whitish-pink, and even further to the north, near the Khertvisi fortress ignimbrites are white, non-welded, rocks. In general, these rocks can be easily excavated, for which reason in the Byzantine Empire and in medieval Georgia numerous ritual and residential types of buildings have been hewn into them.

At the isotopic laboratory of National Taiwan University, are dated zircons from the Mtkavri ignimbrites using the U-Pb method with an LA-ICP–MS [20]. Samples were taken from three segments of the flow: at the Khertvisi fortress (#13Ge-04); at the central part near the Vardzia rock-cut city (#13Ge-05) and at the beginning of the flow near the Karzameti fortress (#13Ge-06). It should be noted that Th and U concentrations in all zircons of the Mtkvari pyroclastic flow are proportional and Th/U index is always > 0.4, which manifests the typical magmatic formation of the zircons [22]. With regard to the results of the zircons U-Pb geochronology, in all three sections of the Mtkvari ignimbrites flow, the weighted mean U-Pb ages are practically identical and correspond to the Upper Miocene epoch, in particular: #13Ge-04 = 7.5±0.4 Ma; #13Ge-05 = 7.5±0.2 Ma and #13Ge-06 = 7.5±0.2Ma. Almost identical dating results of these zircons from the pyroclastic flow, indicate to high precision of the measurement.

So, as we have seen from this short review, one of the oldest historical regions of Georgia - the Vardzia area is so interesting in terms of geology and cultural heritage. Because of the above mentioned, also due to pleasant climate, easy-to-access terrain and well-developed infrastructure, the site satisfies all the criteria to aspiring a geopark.

4.2 Sataplia Potential Geopark

Sataplia mountainous area is located in Tskaltubo district, Near the city of Kutaisi (5 km), on 250 km from Tbilisi. In Georgian Sataplia means “place of honey” and this name gained from the wind honey, which is a lot in the local forest. In this area there is a rare combination of the important geological sites: karst cave and dinosaur footprints imprinted into the Lower Cretaceous limestones (Fig. 11). These imprints are unique because there are two stratigraphic levels: lower imprinting of the predatory dinosaurs and 1.5-1.7 m above — of herbivorous dinosaurs. Today 96 footprints of dinosaurs are preserved in Sataplia. From Sataplia dinosaur footprints on 400 m distance is located Sataplia karst of 600 m in length. From the entrance of the cave, on 100 m distance, is located a cupola-shaped hall (maximum height - 6 m), where the beauty of stalactites and stalagmites astonishes visitors.

Fig. 11 Sataplia herbivorous dinosaurs footprint imprinted into the Lower Cretaceous limestones.

It should be noted that from Sataplia park on the 15 km distance is located Kumistavi (Prometheus) cave. Kumistavi Cave is one of Georgias’s natural wonder monument with breathtaking example of stalagmites, stalactites, underground rivers, lakes and “petrified waterfalls”. Today, surrounded by a 3 km long specifically designed landscape area, Kumistavi cave is one of the most visited spots of Georgia. Total length of Kumistavi karst cave is more than 11 km and has 16 halls, with their maximum height of 21 meters. 1060 m route is prepared for tourists, from which 280 m is a karst lake. Air temperature is 15-17°C and water temperature — 13-14°C.

Abovementioned remarkable geological monuments and region’s well-developed infrastructure are good preconditions for Sataplia geopark establishment. Also, there are unique medieval orthodox cathedral churches – Bagrati and Gelati near Sataplia, which are good opportunities for tourists to get familiar with Georgian cultural heritage.

4.3 Kazbegi Potential Geopark

Kazbegi is the northernmost region of Georgia, which is located on the Main Ridge of the Greater Caucasus, at 130 km from Tbilisi [23]. Region is built up basically by Paleozoic granitoids (Dariali massif) and Meso-Cenozoic sedimentary rocks. During the Pleistocene subaerial volcanic centers and lava flows of basalt-andesite-dacite composition have developed in the region. Kazbegi volcano (5033 a.s.l.) is the central structure of the region, which is covered by everlasting snow and glacier and with reference to its beauty is named 'bride' of the Greater Caucasus. Its greatest eruption by carbon method was dated as 6 ka, but historical sources indicate that the last eruption took place 700 BC. It should be noted, that near the geological site are many ancient historical monuments as well, among them is distinguished the 14th century magnificent Christian church of Sameba, constructed on andesite volcanic flow (Fig. 12).

Fig. 12 "Bride" of the Greater Caucasus Kazbegi Pleistocene volcano and orthodox church of Sameba.

The second important geological object of the Kazbegi region is the Late Paleozoic granitoid massif of Dariali. It is protrusively emplaced into the Lower Jurassic sediments. It mostly consists of diorites and granodiorites of mantle-crustal genesis and their zircons ages are determined as 314 Ma, by using U-Pb dating methodology (La-ICP-MS study). Since the massif is cut by the deep gorge of river Dariali, impressive outcrops of these granitoids are exposed for 7 km along the gorge.

4.4 Dmanisi Potential Geopark

Dmanisi is a town which is located at 85 km southwest of Tbilisi on the Quaternary Javakheti basalt volcanic plateau. Where there are two important geosites: Dmanisi hominid site and Mahavera river Quaternary basalt flow. Dmanisi hominid site discovered in 1991, is situated on a promontory, elevated 80 m above the confluence of the Mashsavera and Pinezauri rivers. It takes over 300 m^2 and it is built up by Mashavera river Quaternary basalt flow. Five skulls, four mandibles and many other bones of Homo Georgicus have been discovered in this basalt flow [24].

The hominids and faunal remains are placed above basalt flow, which by the $^{40}Ar/^{39}Ar$ method are dated as 1.85±0.01 Ma. All the remains are covered with 1 m thick andesitic pyroclastics (tephra), which are eroded and overlying fluvial sediments. Volcanics by the $^{40}Ar/^{39}Ar$ method are dated as 1.81±0.05 Ma [25]. As a result of the data analysis, it is clear that Dmanisi hominid died between these ages. Among the remains

5 hominids, 4 are between 13-40 years old, whereas one hominid is older because it does not have teeth. Such age variations of Dmanisi hominids and geological conditions of fossilization suggests that they died during volcanic eruption from toxic volcanic gases and later were covered with pyroclastic material [25].

The Dmanisi hominid specimens are the most primitive and small-brained humans found outside the Africa continent, and they were attributed to Homo erectus sensu lato. Lately, they were identified as a subspecies *Homo Erectus Georgicus* or even *Homo Georgicus* representing transitional stage between *Homo Habiles* and *Homo Erectus* [24]. It is widely recognized that the Dmanisi discoveries have changed the knowledge concerning the migration of Homo from Africa to the European continent.

Mashavera river Quaternary basalt flow comes from Dmanisi volcanic plateau and occupies Mashavera river gorge for 20 km. Its thickness varies between 15-17 m and overlies alluvial deposits of the river gorge. The basalt flow builds left bank of the river and makes excellent geologic outcrop, where contact of high temperature lava and underlying alluvium can be observed. It should be noted that, lots of faunistic material are found along the surface of the flow, as teeth bones of elephant, wolf, deer, ox and horse.

Near modern Dmanisi are ruins of Dmanisi castle-city from 6th-15th century, where old houses, streets, wine cellars and other medieval buildings are well preserved. Described unique geological objects, closeness with Tbilisi and developed infrastructure are good preconditions for global geopark establishment.

5. Conclusion

Thus, as we have seen from this article, small territory that Georgia occupies (70 000 km^2), hosts totally different types of geological formations, representing huge range of time (from Precambrian to Quaternary). Additionally, because of the small area it is possible to become familiar with the whole spectrum of rocks during several days. For example, only one day is enough to see both Precambrian gneisses of Dzirula massif and Quaternary volcanoes of Abul-Samsari Range. Also, during a day one can get to know the whole cross-section of collision zone starting from the Fold System of the Lesser Caucasus and ending with megastructure of the Greater Caucasus.

Georgia provides an opportunity to see Paleozoic and Mesozoic intrusive bodies of the Greater Caucasus which form glacier covered gorgeous summits; footprints of Cretaceous dinosaurs at Sataplia; relicts of the Late Miocene megavolcano in the southern part of Georgia and its pyroclastic flows in which amazing medieval rocks cut city Vardzia of 12th century; glacier-capped fascinating Quaternary volcano Kazbek and many other interesting geological sites.

Finally, according to modern multidisciplinary research, it is highly probable that Argonauts' journey to the ancient kingdom of Colchis (present-day territory of western Georgia) in quest of the fabled "Golden Fleece" really occurred [26, 27]. In this case, we can assume that Georgia was one of the first countries where the geotourists traveled. Over and above that, those first geotourists were Argonauts. So, participating in these tours means following in these Greek heroes footprints and actually being a "Modern Argonaut" [28]. Dear geotourists welcome to the country of "Golden Fleece"!

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