3D Model of Morphostructure of the Crystalline Basement of the Georgian Caucasus

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Abstract

Thus, for the first time for Georgia and the region, a plasticine model of the morphotectonics of the crystalline basement was created on a horizontal scale of 1:500 000 m and a vertical scale of 1: 200 000, which contributed to a clear visualization of the morphostructure of one of the main structural-tectonic elements of the upper part of the Caucasus crust within Georgia. The technique for reproducing the plasticine model of the morphology of the relief of a crystalline basement consists in removing the mass of plasticine that corresponded to a thick sedimentary cover below the zero mark, and above this mark, on the contrary, in building up to the required height. As a result, the obtained model clearly shows the modern picture of the relief morphology of the crystalline basement, and its mosaic-block structure.

Keywords: Georgia, crystalline basement, structural geology, 3D model

Introduction

In the structure of the upper part of the Earth's crust of the Caucasus, one of the main structural and tectonic elements is its crystalline basement, which was formed by the processes of pre-Alpine tectono-magmatic cycles and in the modern structure represents a rigid basement for the thick, mainly Mesozoic-Cenozoic sedimentary, volcanogenic, and volcanogenic-sedimentary deposits.

Georgia is a part of the Caucasus, which represents a complicated polycyclic geological structure involving mountain fold systems of the Greater and Lesser Caucasus and adjacent foredeeps and intermountain troughs. Paleomagnetic and paleo kinematic, as well as traditional geological data (character of sedimentation and magmatism, geology and age of ophiolites, paleoclimatic and paleogeographic data), indicate that with a typical oceanic crust, which separates the Afro-Arabian and Eurasian continental plates, in the geological past relatively small continental or subcontinental plates (terranes) were situated, having diverse geodynamic nature and characterized by specific lithologic-stratigraphic section and magmatic, metamorphic, and structural features (Gamkrelidze, 1997). During the Late Precambrian, Paleozoic, and Early Mesozoic times, these terranes experienced horizontal displacement in different directions within the oceanic area of Proto-Paleo- and Mesotethys (Neotethys) and underwent mutual accretion and ultimately joined the Eurasian continent. In the Caucasian segment of the Mediterranean mobile belt, the Greater Caucasian, Black Sea-Central Transcaucasian, Baibut-Sevanian, and Iran-Afghanian terranes, which in geological past represented island arcs or microcontinents, are identified. In terms of modern basis, they represent accretionary terranes of the first order separated by trustworthy or supposed ophiolite sutures of different ages. Terranes of the first order, in their turn, consist of a great number of subterranes delimited as a rule by deep faults (Gamkrelidze, 1997).

The territory of Georgia covers the southern part of the Greater Caucasian terrane, the Black Sea-Central Transcaucasian terrane, and the northern part of the Baiburt-Sevanian terrane (Somkhito-Karabakh subterrane). Each of these units is characterized by distinctive rocks that were formed under different geodynamic conditions (Gamkrelidze & Shengelia, 2005).

Recently, using U-Pb LA-ICP-MS dating of zircons, the ages of their constituent metamorphites and granitoids have been established. In particular, within the exposed part of the Greater Caucasian terrane (in the Main Range zone of the Greater Caucasus) based on the study of the in situ zircons from metamorphozed and granitoid rocks the following figures were obtained: 1) 626±2 and 627±19 million years, which corresponds to the earliest – Cadomian (Late Precambrian) stage of regional metamorphism, 2) 461±5.3 million years and 457±12 million years, which corresponds to the Caledonian (late Early Paleozoic - early Late Paleozoic) stage of regional metamophism, 3) figures 454±9, 468±5 and 471.7±4.6 million years obtained for granitoid rocks corresponds to Caledonian tectogenesis, 4) figures: 312.5±4 and 317.0±8.3 million years correspond to regressive regional associated with Late Variscan (Late Paleozoic) tectogenesi,s and 5) figures: 309±8, 310.9, 325±4 Ma, 311±5.9 and 357±5.9 Ma, corresponding to the formation of synmetamorphic Late Variscan granitoids. These data are in good agreement with geological and petrological data for the Greater Caucasus (Gamkrelidze et al., 2020).

Within the exposed part of the Black Sea-Central Transcaucasian terrane – in the Dzirula crystalline massif, five genetic and age-types of zircons are distinguished: 1) detrital zircon >1200 Ma; 2) zircon formed presumably at the Grenville stage of regional metamorphism - 1000- 800 Ma; 3) zircon developed during the crystallization of quartz-diorite orthogneisses - 650-540 Ma (Baikalian stage); zircon 4) formed presumably during the crystallization of tonalite-granitic series - 530-500 Ma (Late Baikalian stage of regional metamorphism) and 5) zircon formed during the crystallization of Late Variscan granitoids and also under the impact of high-temperature fluids over pre-Late Variscan rocks – 330-310 Ma (Gamkrelidze et.al., 2011).

In the Khrami crystalline massif of the same terrane, the results of age determination of 26 zircon crystals from the Late Variscan potassic granitoids by U-Pb LA-ICP MS dating show the mean age 325.6±2.3 Ma covering the interval 319-332±6 Ma. Only in one case, in the crystal core, the hereditary age 931±6 Ma is determined, which presumably corresponds to the Grenville stage of regional metamorphism of the Neoproterozoic gneiss-migmatite complex (Tediashvili, 2013).

In the Loki crystalline massif of the Baiburt-Sevanian terrane (in the Somkhito-Karabakh subterrane), U-Pb zircon age of gneissose quartzdiorites is 370±59-35 Ma (Bartnitsky et al., 1992; Vashakidze, 1999; Vashakidze, 2000), but K-Ar age of granitoids is 327±6 Ma (Vashakidze, 2000; Dudauri et. al., 1999). These data confirm without a doubt that quartz diorites are pre-Late Variscan (Late Devonian) and granites are Late Variscan formations.

On the surface, rocks of the crystalline basement are exposed in the form of salients at different hypsometric levels (the central zone of uplift of the crystalline core of the Greater Caucasus 3500-5000 m (Fig. 2), Dzirula-1000 m, Loki, and Khrami 1200-1300 m massifs). In the rest of the territory, the crystalline basement is buried under thick Meso-Cenozoic sediments. According to the available literature data (Gudzhabidze & Gamkrelidze, 2009; Gamkrelidze et al., 2013), the crystalline basement is dissected by latitudinal, meridional, and diagonal faults, which create a picture of its mosaic-block structure. Its individual sections are located at different hypsometric levels, where the surface of the basement is located above sea level at a maximum altitude of 5000 m, and below this level it is maximum at a depth of 12000-14000 m (Fig. 3).

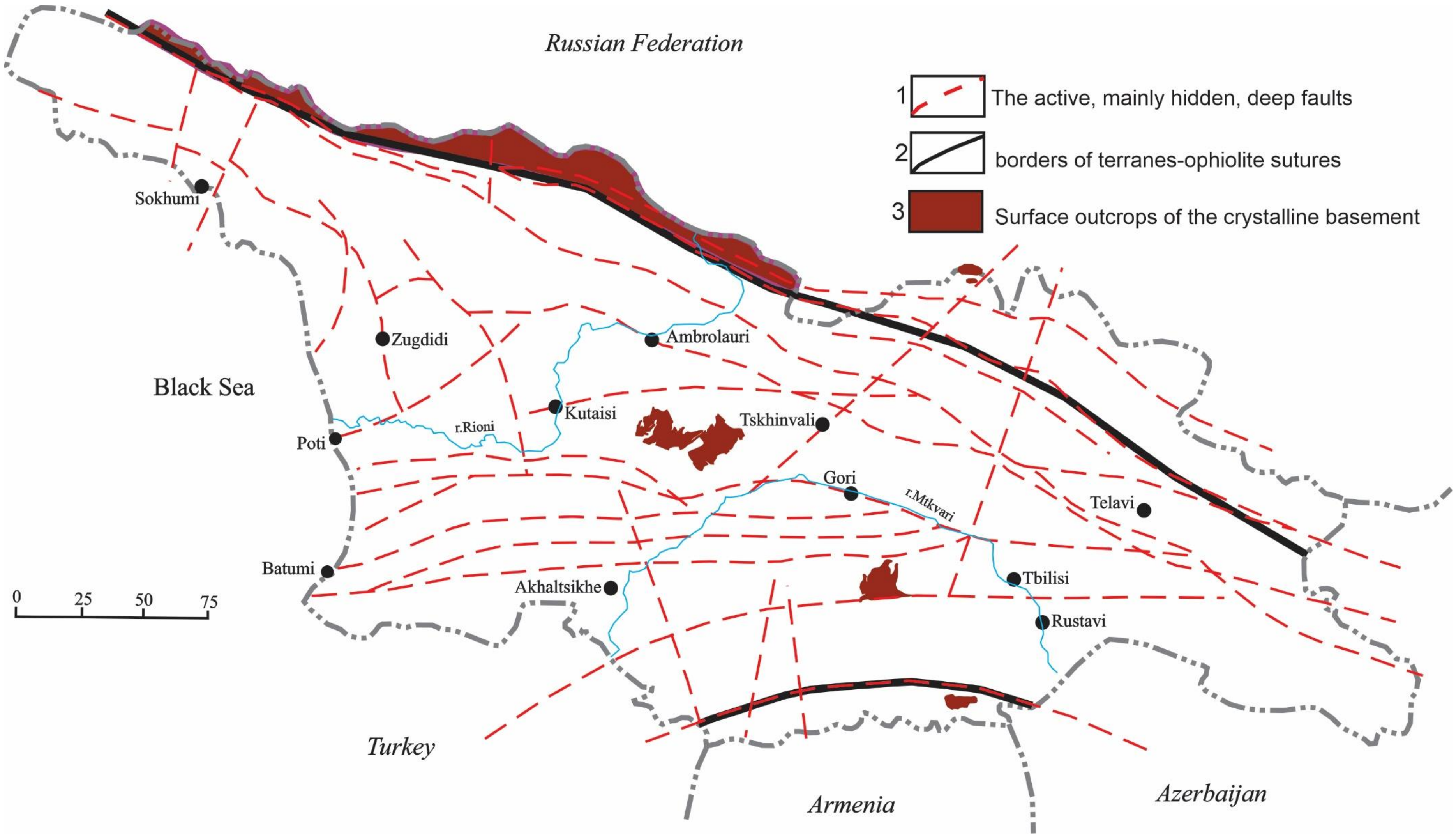

Figure.1. Active seismic faults of the territory of Georgia

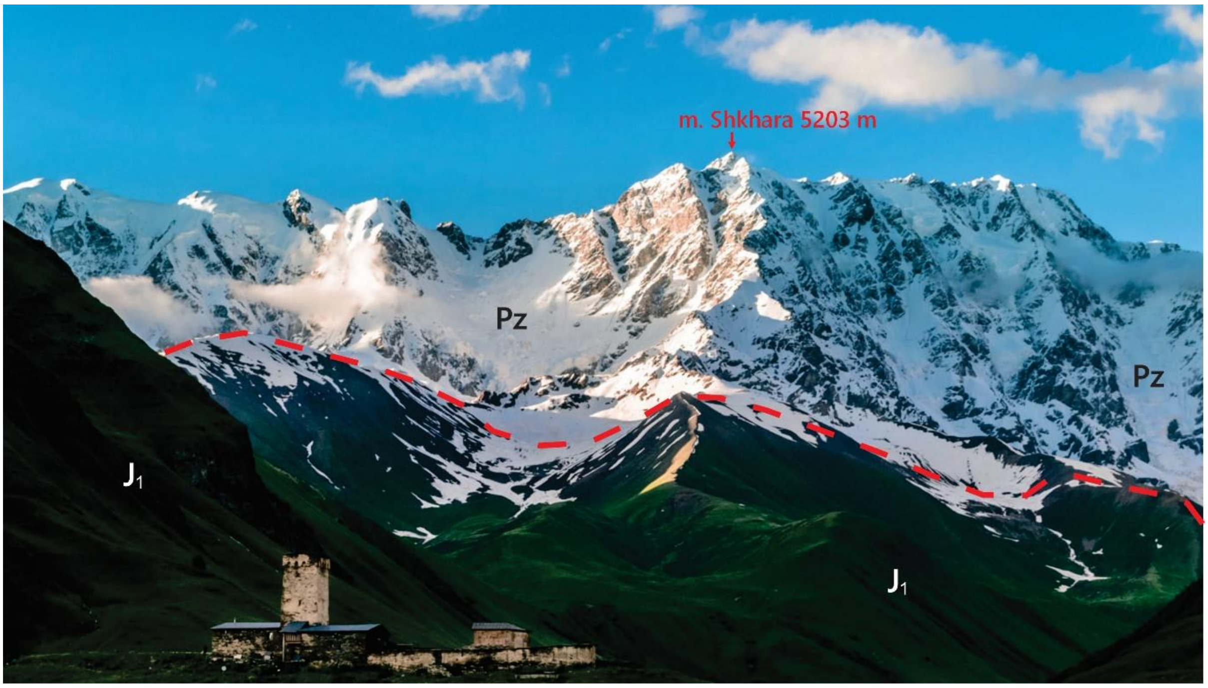

Figure.2. Pass subzone of the Greater Caucasus Main range zone - maximum uplift mark of crystalline substrate from the sea level. Dashed line indicates the Main Thrust zone.

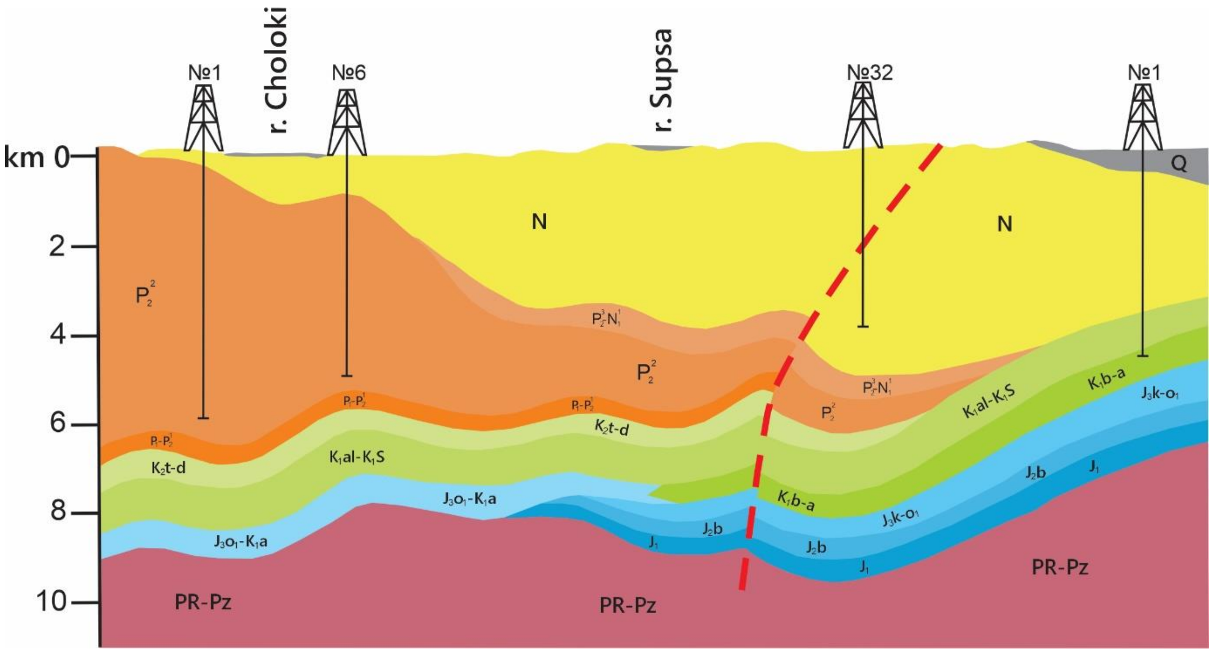

Figure. 3. Guria trough – one of the most subsided areas of the crystalline substrate – 9000 m [22]

Methodology for creating a model

To implement the 3D model, plasticine bars were taken as the main material, and after melting it into a pre-prepared container, a volumetric plasticine briquette with parameters 60 cm - 10 cm - 110 cm was obtained, where the upper horizontal surface corresponded to zero isohypsum, i.e., sea level. A tectonic map of Georgia was drawn on this surface at a scale of 1:500,000 (Gamkrelidze et al., 2013). Then, because of the analysis of numerous geological and geophysical profiles of the territory of Georgia, the modern morphology of the crystalline basement was reconstructed where below the zero isohypsum, part of the material that corresponded to the sedimentary cover was removed. Further, in some areas where the substrate rises above the zero isohypsum, it was necessary to complete the construction according to the existing geological and tectonic maps (Gudzhabidze & Gamkrelidze, 2009; Gamkrelidze et al., 2013) on which surface outcrops of crystalline rocks are recorded in the area of the Central uplift of the Main Range of the Greater Caucasus, Dzirula, Khrami, Loki, and Gveleti massifs. As a result, a picture of the modern morphology of the surface of the crystalline basement was obtained, the vertical scale of which corresponds to 1:200,000. Analyzing numerous literary data on geological and geophysical structure in the form of many profiles, unfortunately, we have to note significant discrepancies between some authors in the interpretation of data on the deep structure, which raises doubts about the choice of an optimally objective profile (Gamkrelidze et al., 2013a; Krasnopevtsova, 1966; Gamkrelidze, 1976; Terekhov, 1979; Basentsyan et al., 1981; Gamkrelidze, 1984; Yusupkhodzaev et al., 1986; Basheleishvili, 1987; Ioseliani et al., 1989; Philip et al., 1989; Banks et al., 1997; Nadareishvili, 2002; Pangani et al., 2003; Basheleishili & Kloshvili 2004; Kundadze et al., 2005; Gamkrelidze et al., 2013b, JMauvilly et al., 2016; Gusmeo et al., 2021; Mosar et. al., 2022; Gamkrelidze et. al., 2024; Cavazza, et al., 2024) We gave preference to those profiles that were compiled based on geological data. Lithological-sedimentary, stratigraphic, and thickness data

Morphostructure of the crystalline basement

The formation of the modern morphostructure of the crystalline basement within Georgia is largely determined by a fault network of latitudinal, meridional, and diagonal strike, covering different depths of the Earth's crust. Analysis of the lithofacies and thickness of the sedimentary cover developed within their boundaries indicates their autonomous and inversional nature of development. Subsequently, when constructing a model of the surface of the crystalline substrate, we removed the entire mass of the sedimentary cover (Fig. 4).

As is known, faults in the Earth's crust often change their character with depth and become gentler, representing thrusts and nappes. The model we constructed reflects the modern hypsometric position of the basement surface. The most elevated area is the area of the Main Range of the Greater Caucasus, from 2000 m to 5000 m. From the south, the marked structure is limited mainly by the Main Caucasian Thrust, the plane of which dips at an angle of 50-60. The total vertical amplitude of this thrust is more than 16 km and can be traced throughout the entire stretch. Only to the west of the city of Sokhumi does the amplitude decrease to 8-10 km. This thrust is the southern border of the Greater Caucasus terrane and the northern border of the Black Sea-Central Transcaucasian terrane. This kind of subsidence also appears further south, in the zone of the Gebi-Lagodekhi fault, where the depth of the basement subsidence is 10-12 km.

Within the Georgian block, the crystalline basement is also located at different hypsometric levels, but within its limits, meridional and submeridional faults predominate (Gudzhabidze & Gamkrelidze, 2009). Five blocks are distinguished in the western Colchis subsidence zone. Of these, the most submerged part (10-12 km) is in the Ochamchire-Kulevi block. In the eastern direction, the basement rises stepwise, and around the Dzirula salient, it reaches the surface at around +1000 m. Following to the east, within the Kura depression, the basement again sinks stepwise through listric faults (Basheleishvili 1993; Basheleishvili, 1999), and around the Middle Kura depression (in the Dedoplistskaro area) it plunges to a maximum depth of 12-14 km.

Within the Adjara-Trialeti zone, the basement is quite dissected. This is especially clearly expressed in the latitudinal structures, but at the same time, a meridional zonality emerges (Gamkrelidze, 1976). Its western and eastern parts are immersed at the lowest levels (12-14 km), and the central part rises to zero value, and above this area within the Adjara-Trialeti corresponds to the Transcaucasian transverse elevation of the northwestern strike. This refers to the Trialeti Cordillera or the Peli–Uriuli uplift.

The crystalline basement within the Javakheti highlands is located higher, where, in addition to the surface outcrops of the Loki and Khrami massifs, at an altitude of 1200-1300 m above sea level, a dive of up to 3000-4000 m is noted.

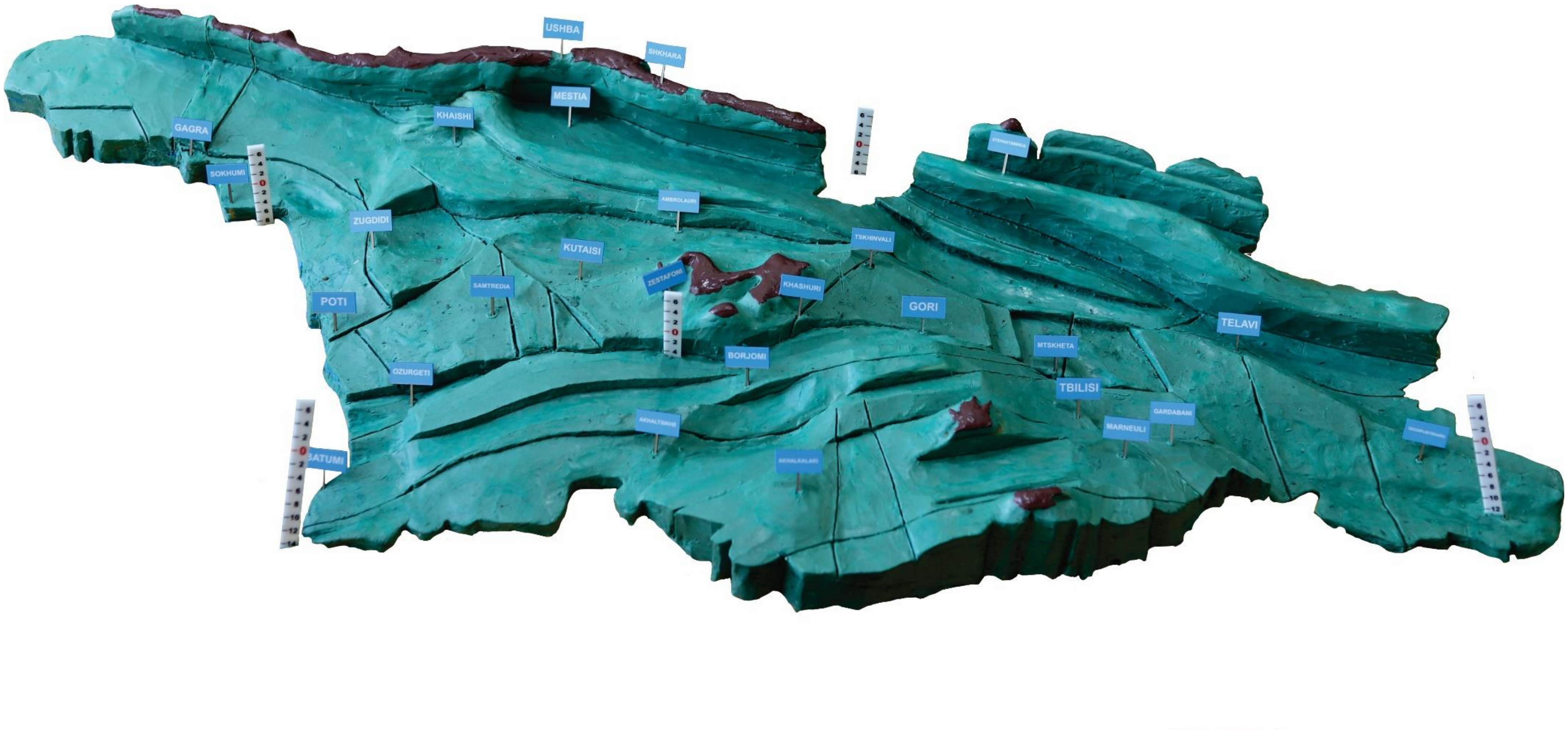

Figure. 4. 3D Model of Morphostructure of the Crystalline Basement within Georgia (plasticine); Scale: horizontal 1: 500000, vertical 1:200 000 (https://obsidian4d.nira.app/a/ca9QqJCcTx22s4Js-1cknQ/1)

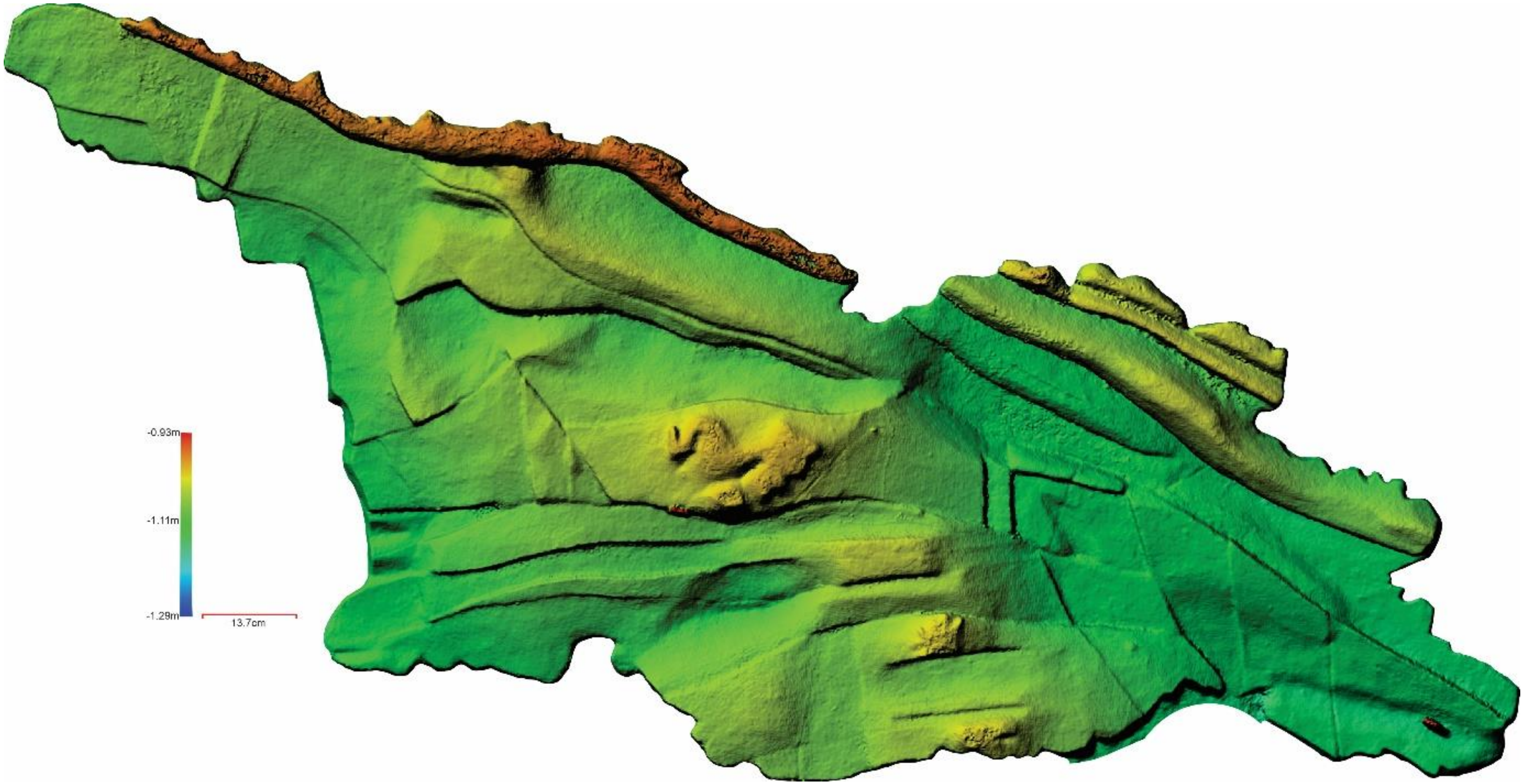

Figure. 5. 3D Model of Morphostructure of the Crystalline Basement within Georgia

Conclusion

Thus, for the first time for Georgia and the region, a plasticine model of the morphotectonics of the crystalline basement was created on a horizontal scale of 1:500,000 and a vertical scale of 1:200,000, which contributed to a clear visualization of the morphostructure of one of the main structural-tectonic elements of the upper part of the Caucasus crust within Georgia. The technique for reproducing the plasticine model of the morphology of the relief of a crystalline basement consists of removing the mass of plasticine that corresponded to a thick sedimentary cover below the zero mark and, above this mark, on the contrary, building up to the required height. As a result, the resulting model clearly shows the modern picture of the morphology of the relief of the crystalline basement and its mosaic-block structure.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

L.B., G. B., and B.G. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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