3D Model and Structural-Kinematic Evolution of the Pre-Jurassic Crystalline Basement of the Western Georgia

Levan Basheleishvili[1], Giorgi Beridze[1*]

Abstract

The modern structure of Western Georgia is determined mainly by the meridional (sub-meridional) and latitudinal systems of faults covering different depths of the Earth's crust. The noted faults are often-sided boundaries of the blocks of the crystalline basement of the Earth's crust, creating a picture of its mosaic-block structure. The analysis of the lithofacies and thicknesses of the sedimentary cover developed within their limits, in several cases, indicating their autonomous and inversion nature of development. The comparison of geophysical and drilling data and applying the system analysis method of disjunctive structures made it possible to clarify some issues of the structural-kinematic evolution and morphogenetic of individual blocks and faults of the pre-Jurassic crystalline basement within the limits of the Southern Caucasus. A 3D physical model of the surface of the crystalline basement constructed by us within Western Georgia shows the spatial arrangement and the character of the inversion nature of individual blocks, indicating the manifestations of the Alpine and Late Alpine orogeneses. Analysis of the actual material, geophysical, and geological data for the intra-Caucasian intermountain area allows us to draw the following conclusions: the Georgian Block (a fragment of the Transcaucasian median massif, microplates, and terranes), with a pre-Jurassic crystalline basement exposed in its central part, is divided into the western and eastern subsidence zones, which in turn disintegrate into separate blocks. From the central zone of the uplift of the Georgian Block to the east and west, a gradual "stepwise" subsidence and tilting of the blocks of the crystalline basement is outlined. Similar structures are known in the literature as the so-called tilt blocks.

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

Introduction

Figure 1. Scheme of the fault tectonics of the crystalline basement of Western Georgia. Scale 1: 100 000.

[1] Al. Janelidze Institute of Geology, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia,
* Corresponding author: giorgi.beridzegeolinst@gmail.com

The modern structure of Western Georgia is primarily determined by the meridional (sub-meridional) and latitudinal systems of faults covering different depths of the Earth's crust. The noted faults are often the siding boundaries of the blocks of the crystalline basement of the Earth's crust, creating a picture of its mosaic-block structure [1-6]. The analysis of the lithofacies and thicknesses of the sedimentary cover developed within their limits, in several cases, indicating their autonomous and inversion nature of development. At the Early-Middle Jurassic stage, within the Colkheti depression, a clearly expressed Colkheti trough opened towards the eastern part of the Black Sea. At this time, two faults of the general Caucasian strike formed in the north. In the south of the basin, the northern Adjara-Trialeti fault also manifested a latitudinal strike. The only meridional structure at that time was the Tkibuli-Zestaphoni fault, from which the thickness of the Lower-Middle Jurassic formations sharply decreased to the east, apparently connected to the washout of the Dzirula land. At that time, the greatest sagging occurred in Samegrelo, where the thickness of the Lower-Middle Jurassic was 3000–3500 m (Fig. 1).

Results

The Samegrelo trough continued to develop in the Early Cretaceous. At the same time, the Rioni-Chaladidi trough was isolated distinctly for the first time. The entire western part of the Colkheti depression was cut off from the eastern one by the sub-meridional fault. Here, the eastern block is relatively elevated, where the thickness of the Lower Cretaceous is 2000 m. Thus, at that time, five uplifts and four troughs were isolated, and all these structures had a latitudinal and near latitudinal strike.

In the Late Cretaceous, the paleotectonic plan of the Colkheti depression changed. The central Samegrelo depression takes on a sub-meridional strike; to the west and north of the indicated trough, the meridionally spreading, narrow so-called Salkhino uplift and the sub-latitudinal Anaklia-Jvari fault were formed. In the Pliocene-Eocene time, the Central Samegrelo trough and the Salkhino-Kvaloni uplift acquire a distinctly meridional outline. At the same time, the Lessa and Dzirula uplifts of latitudinal strikes formed.

The Maikopian time (Oligocene–Early Miocene) in the Caucasus is characterised by the onset of the early orogenic stage of development, at which the Central Samegrelo trough retains its meridional strike with the accumulation of up to 1000 m of Maikop deposits. At the same time, two meridional Satanjo and Tsaishi uplifts that represent the area of erosion were isolated.

In the Middle-Late Miocene, the meridional Central Samegrelo trough continues to develop, where the thickness of the Miocene reaches 2000 m. At the same time, the axial line of the trough migrates to the northeast compared to the Maikopian.

The Paleocene stage of the development of the Colkheti depression, compared with the previous one, was characterised by a change in the paleotectonic plan, and the inversion stage of development started. This is visible in the Central Samegrelo trough; after the accumulation of 200–300 m (Pontian) deposits, uplifting took place, transforming the area into the erosion area. At that time, the submeridional trough turned into a latitudinal one.

In the Quaternary period, the final relief from the Colkheti Depression takes place. First, the broad Central Samegrelo uplift reappears and again acquires a meridional direction. The thickness of the deposits reaches 200 m.

The meridional Saberio-Tsaishi uplift also formed, where Quaternary deposits are missing. This narrow uplift in the east takes a northeasterly direction and thus almost entirely isolates the Central Samegrelo trough from the rest of the Colkheti depression.

Thus, the initiation and development of meridional structures in the Colkheti depression show that the structural plan was rearranged at least twice, and this was associated with the region's main tectonic phases of deformation. Such data analysis makes it possible to comprehend the mechanism of the formation of meridional (anti-Caucasian) structures within Western Georgia. Recent studies show that in the Colchis depression, according to seismic data, the crystalline basement subsided from east to west from 0 to 8–9 km (in the coastal part of the Black Sea). However, with general subsidence to the west (in some places in the basement), local uplifts are noted, which are quite clearly recorded on seismic profiles. In addition, these uplifts in the eastern part were exposed by boreholes. Here, Lower Cretaceous deposits directly overlie the basement rocks, and the thickness of the Mio-Pliocene deposits is 400–450 m. To the west, between the villages of Akhali Sviri and Vartsikhe, a trough is noted, where the thickness of the Mio-Pliocene remains unchanged but the thickness of the Upper Cretaceous deposits doubles. The basement uplift was recorded in the village of Vartsikhe, well No. 18, at a depth of 720 m. On a five-kilometre stretch of uplift, the thickness of the Mesozoic-Cenozoic cover is reduced to a minimum (700–750 m). To the west, in well No. 66 (Sakuliya), the thickness of the Miocene-Pliocene deposits doubles, and Chokrakian deposits directly overlie the Upper Cretaceous deposits. To the west of the village of Sakuliya, the basement submerges again. No. 1 (Samtredia) in 2800–3045 m exposed the Middle Jurassic deposits. Here, deposits of the Meotian stage rest on the Upper Cretaceous deposits. Thus, along the latitudinal profile of Zestaphoni-Samtredia (Fig. 2), the thickness of the Upper Cretaceous deposits does not exceed 250–200 m, except for the Akhali Sviri-Rodinauli area, where their thickness is 800 m, and the thickness of the Lower Cretaceous and Mio-Pliocene deposits does not change compared to neighbouring areas. To the west of the mentioned trough, geological and geophysical data record the uplifted Vartsikhe Block, which, as the drilling data show, is limited by faults penetrating at least to the bottom of the earth's crust from the west and east. From them, the western one within the Georgian Block caused a halving of the thickness of the Mio-Pliocene deposits. According to M. I. Ioseliani et al. [7], igneous bodies that are not exposed on the surface are confined to this fault within Ajara-Trialeti. The Vartsikhe fault, the eastern limit of the Vartsikhe uplift within the Georgian Block, is well recorded on satellite images as a profound fault. It may also have a right-shear component. Another fault of sub meridional strike is outlined along the Ozurgeti-Amtkheli line, which, in addition to the data of the seismic profiles of Anaklia-Zestaphoni and Sabazho-Simoneti, is also confirmed by the analysis of geological materials. In particular, within the Ajara-Trialeti zone, it corresponds to a meridional fault-slip, along which the Upper Cretaceous and Middle Eocene deposits of the Guria Range come into contact with the Mio-Pliocene deposits. The vertical amplitude of this fault slip is more than 3000 m. Jurassic deposits are missing east of the Sakuliya village to the Dzirula massif (along the Samtredia-Zestaphoni profile). West of Samtredia, according to seismic data, the basement is submerged to a depth of 8 km [7]. In the vicinity of the village of Lessa (Lanchkhuti district), deep wells (No. 2, 21) exposed a thick complex of Sarmatian and post-Sarmatian deposits. The Upper Cretaceous deposits gradually wedge out from north to south, and the Lower Sarmatian sandstones and conglomerates directly overlie the Albian-Cenomanian volcanogenic deposits. According to the data from well No. 1, the sole of the Albian-Cenomanian volcanogenic sequence is recorded at a depth of 3450 m. According to seismic data, the marked area is within the Rioni-Supsa trough [9] or the Paliastomi graben [1, 8].

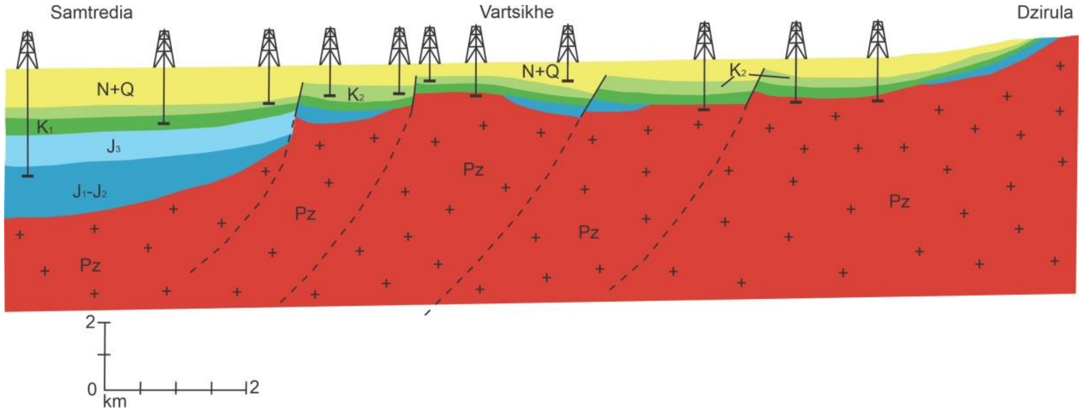

Figure 2.Latitudinal geological profile (Samtredia-Dzirula) according to drilling data.

The Rioni-Supsa trough is the most submerged part of the Colkheti depression, where the basement surface from east to west subsides to 6–8 km along seismic profiles. From the south, the noted trough is limited by the Guria depression, the deep structure of which is due to faults of latitudinal and also meridional and diagonal strikes. In the east of the depression (east of Chokhatauri), the basement is uplifted, and the absolute depth of its attitude is 3–4 km. The foundation is significantly higher in the south of this strip compared to its northern part. Thus, the noted Kobuleti-Zekari band is, according to all geological and geophysical features, a fault zone, which is also fixed on the map of the depths of the upper mantle surface compiled by M.A. Ioseliani et al. [7]. A diagonal (northeast strike) fault is outlined along the southeastern margin of the Guria depression. Both gravimetric and seismic studies argue for the fault. Seismic and seismic-geological sections compiled and interpreted by M.S. Ioseliani et al. [7] for various profiles of the Colkheti depression (Sukhumi-Batumi, Chaladidi-Jgali, Didi Kukhi-Zestaphoni, Vani-Besiauri, and Dzirula massif-Anaklia) lead to the conclusion about the confinement of marginal velocities to the surface of the crystalline basement. For the Colkheti depression, the regularity derived for most parts of the Kura depression, where the surface is confined to the volcanogenic Middle Jurassic, is generally not revealed. This difference is probably due to the fact that the processes of continental rifting were rather intensive in the Colkheti Depression during the Late Jurassic and Late Cretaceous (the latter formations include rocks of the Mtavari Suite). This process led to deconsolidation, fragmentation, and, in connection with this, a decrease in density and velocity in the underlying formations of the volcanogenic Middle Jurassic (Bajocian), as a result of which the rocks of the pre-Jurassic basement turned out to have higher density and velocity, which leads to the fact that the marginal velocities established for the basement rocks, in this case, correspond precisely to these rocks. The Odisha Block, structurally the most distinct unit, covers the Samegrelo syncline. In the Late Cretaceous, it experienced a change in the tectonic plan with the formation of the sub-meridional Central Samegrelo foredeep and the accumulation of deposits up to 500 m thick. To the west and north of the trough, meridionally elongated, narrow uplifts are outlined, in which Upper Cretaceous deposits were not accumulated. At the same time, the accumulation of the Mtavari volcanic suite indicates the activation of the process of continental rifting, with a more or less meridional strike of this structure. In Paleocene-Eocene time, its meridional trough is outlined to the west (Odishi depression), where sediments with a thickness of more than 1000 m accumulate. According to estimations, the crystalline basement is located at a depth of 7000m.

Conclusion

The comparison of geophysical and drilling data and applying the system analysis method of disjunctive structures made it possible to clarify some issues of the structural-kinematic evolution and morpho-genetics of individual blocks and faults of the pre-Jurassic crystalline basement within the limits of the Southern Caucasus. A 3D plasticine model of the surface of the crystalline basement constructed by us within Western Georgia shows the spatial arrangement and the character of the inversion nature of individual blocks, indicating the manifestations of the Alpine and Late Alpine phases of ectogenesis (Fig. 3).

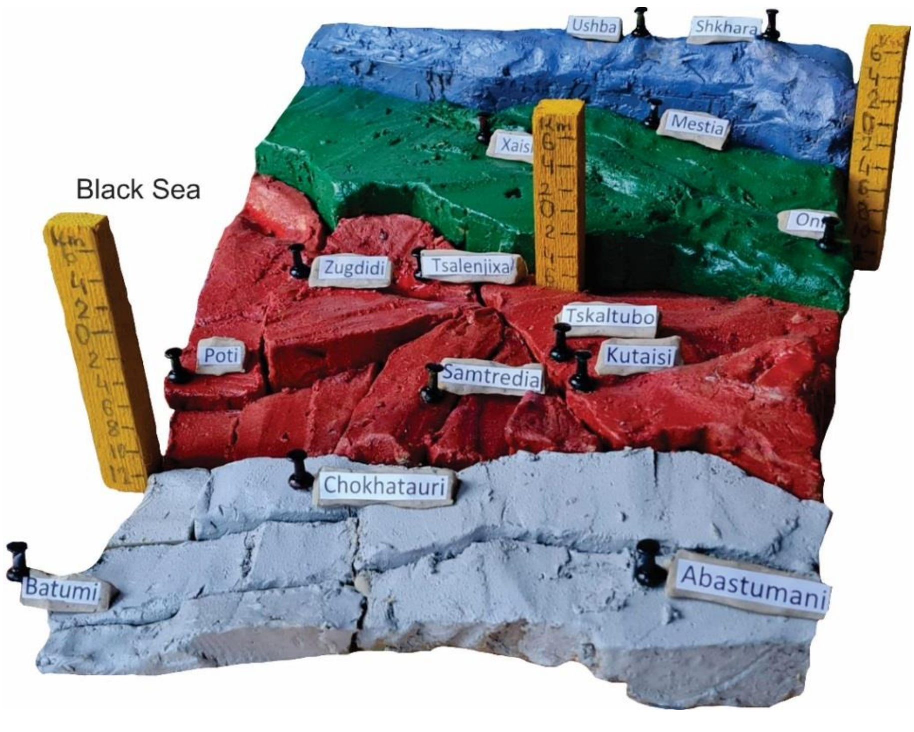

Figure 3. 3D plasticine model of the pre-Jurassic crystalline basement of Western Georgia Scale – Horizontal 1:500 000; vertical 1:200 000

Thus, the Odisha Block, located approximately in the central part of the depression from the western and eastern sides, is bounded by faults of a strike-slip nature, above which in the sedimentary cover, supra-fault echelon folds are developed, indicating the right-lateral component of the faults. In general, the kinematics of the Odisha Block indicate its shift in the southwest direction; the Block is slightly inclined in the eastern part concerning the Askhi and Okriba Blocks. From the south, it is bounded by the Abasha Block, one of the most subsided structures of the Colkhida depression. Analysis of the actual material, geophysical, and geological data for the intra-Caucasian intermountain area allows us to draw the following conclusions: the Georgian Block (a fragment of the Transcaucasian Median Massif, microplates, terranes), with a pre-Jurassic crystalline basement (Dzirula uplift) exposed in its central part, is divided into the western and eastern subsidence zones, which in turn disintegrate into separate blocks.

From the central zone of the uplift of the Georgian Block to the east and west, a gradual "stepwise" subsidence and tilting of the blocks of the crystalline basement is outlined. Similar structures are known in the literature as the so-called tilt blocks [3, 5, 10]. They are quite distinctly recorded on different geophysical profiles. In some cases, the transverse uplifts of the crystalline basement are recorded by drilling data. Several transverse faults are associated with earthquakes, which are characterised by tensile stress and, therefore, can have a fault character with the inclination of the shear planes towards the centres of maximum tension. As a result of gravitational modelling, it is established that the M-boundary within this profile is indicated by a local uplifting under the Central Black Sea and a comparative subsidence under the Dzirula uplifts. The above outlines two plans of structural symmetry in the modern structure of the pre-Alpine consolidated crust of the South Caucasus Median Massif. The first (latitudinal profile) is characterised by extensional structures, mainly stepwise tilting blocks, which transform into listric faults. The second (meridional) is characterised by tangential, sub-meridional compression of the region caused by the advancement of the Arabian inlier to the north with the formation of the Transcaucasian transverse uplift and other collision structures.

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

All authors provided critical feedback and helped shape the research, analysis and manuscript.

References

1. Basentsyan, Sh., Pilipenko, A., Svistunov, Yu. et al. (1981). *Struktura osadochnogo chehla jugo-vostochnoj chasti Chernogo morja po sejsmicheskim materialam* [Structure of the sedimentary cover of the south-eastern part of the Black Sea by seismic data]. Izv. AN SSSR. Ser. Geol., USSR, Moscow, 10, 5-18 (in Russian).
2. Basheleishvili, L. (1987). *Kinematika al'pijskoj deformacii Adzharo-Trialetskoj skladchatoj zony i Gruzinskoj glyby Zakavkazskogo sredinnogo massiva* [Kinematics of the Alpine deformation of the Ajara-Trialeti folded zone and the Georgian Block of the Transcaucasian median massif]. Proc. of the Second National Junior School in Geology. Sofia, Bulgaria, 215-222 (in Russian).
3. Basheleishvili, L. (1993). *Extension Structures of the Transcaucasian Intermontane Depression (Latitude Profile).* Annals Geophysical. European Geophysical Society. Germany, 56.
4. Basheleishvili, L. (1999). *Structure Associations of the Basement and Sedimentary Cover of the Georgian Part of the Caucasus.* Basement Tectonics-13, Blacksburg, Virginia, U.S.A, 25-32.
5. Basheleishvili, L., Kuloshvili, S. (2004). *Morfokinematika sdvigovyh deformacij gruzinskoj chasti Kavkaza* [Morphokinematics of shear deformations in the Georgian part of the Caucasus]. Proceedings of the Institute of Geology of the Georgian Academy of Sciences. Tbilisi, Georgia, № 119, 90-97 (in Russian).
6. Gamkrelidze, I. (1984). *Tektonicheskoe stroenie i al'pijskaja geodinamika Kavkaza* [Tectonic structure and Alpine geodynamics of the Caucasus]. Proceedings of Geological Institute of the Acad. Sci. of the GSSR. Tbilisi, 86. 105-184 (in Russian).

7. Ioseliani, M., Chichinadze, Sh. et al. (1989). *Stroenie litosfery territorii Gruzii po sejsmicheskim dannym* [Structure of the lithosphere of the territory of Georgia according to seismic data]. Tbilisi: Metsniereba.
8. Krasnopevtsova, G. (1966). *Rezul'taty issledovanija glubinnogo stroenija zemnoj kory na zapade Kavkaza po linii profilja Anaklija–Zestafoni* [Results of the study of the deep structure of the Earth's crust in the west of the Caucasus along the line of the Anaklia-Zestaphoni profile]. Deep structure of the Caucasus. GSSR. Tbilisi, 97-102.
9. Terekhov, A. (1979). *Osobennosti stroenija mezozojsko-kajnozojskih otlozhenij v vostochnoj chasti Chernogo morja (po sejsmicheskim issledovanijam MOV)* [Features of the structure of the Mesozoic-Cenozoic deposits in the eastern part of the Black Sea (according to seismic studies)]. Geotectonics, USSR, Moscow, 2, 5-18 (in Russian).
10. Yusupkhodzhaev, Kh., Mindeli, P., Kartvelishvili, K. et al. (1986). Model' litosfery Krymsko-Kavkazsko-Sredneaziatskogo regiona (vdol' geotraversa Varna-Tbilisi-Chardzhou-Tashkent.) [Model of the lithosphere of the Crimean-Caucasian-Central Asian region (along the Varna-Tbilisi-Chardzhou-Tashkent geotraverse)]. USSR, Moscow, Nauka.