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GEOLOGY

Mesozoic–Cenozoic Accretionary Complexes of the Greater Caucasus

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The present-day structure of the Caucasian segment of the Mediterranean mobile belt resulted from three stages of its evolution during the last 1 Ga of its geological history (older rocks are practically unknown in this region). The first of these stages (mainly, the Neoproterozoic) known as the Baikalian (in Russia) and Cadomian (in Europe) produced the consolidated basement in the southern (Gondwanan) part of the region extending up to the Transcaucasian Massif in the north. As for the Greater Caucasus and, probably, Ciscaucasia region, their structure resulted from subsequent Paleozoic (Hercynian or Variscan) and Meso–Cenozoic (Alpine or Cimmerian–Alpine) stages as is inferred from recent isotopic geochronological data [1]. It should be emphasized that the tectonomagmatic development of the study region was different at each of these stages.

At the Paleozoic stage (Ordovician–Permian), the Caucasian region belonged to the Paleo-Tethys and comprised basins underlain by the oceanic crust, relicts of which are represented by ophiolites. These basins were separated by microcontinents with volcanic arcs developing in response to subduction of the crust of these basins. Collision of microcontinents, which started in the mid-Early Carboniferous, and their subsequent accretion to the margin of the ancient East European continent were accompanied by strong deformations up to development of large-amplitude overthrusts in the future Greater Caucasus, regional metamorphism up to the amphibolite (locally, granulite) facies, and intense granite plutonism [2]. Judging from radiometric dating and the age of principal dislocations along the northern periphery of the orogen (the so-called Karpinsky Ridge), these processes terminated largely in the mid-Early Permian (i.e., during the Saalian phase of the West European orogenesis), resulting in the formation of the consolidated basement of the Greater Caucasus and Ciscaucasia and the transformation of the basement of the future Transcaucasian microcontinent.

A new geodynamic setting appeared in the Caucasian region since that time. The northern (Arkhyz) basin with the oceanic crust was closed. The Svanetia basin located between the Greater Caucasus and Transcaucasian microcontinent continued to exist or opened again (see below). The Central Lesser Caucasus basin, one of the two branches of the Tethys (or more exactly, Meso-Tethys), acquired the dominant role. Its existence in the Permian and Triassic is also evident from the following facts: (i) single finds of organic remains and dates obtained for rocks belonging probably to the ophiolitic association; (ii) distinct contrast between rocks constituting the basement of the Transcaucasian microcontinent with abundant Hercynian granitoids and the southern Transcaucasian region practically lacking signs of Hercynian orogeny and granitoid magmatism [3]. Meanwhile, the Svanetia basin accumulated terrigenous sediments of the Diz Group, which is usually considered the Devonian–Triassic formation. Since the Devonian and Carboniferous fossils are probably related to olistoliths and olistoplaques (according to Kaz'min and Sborshchikov [4]), this entire unit can be Permian–Triassic in age, like the Tauric Group that represents its analogue in the Mountainous Crimea. The lithology and dislocation patterns of the Diz Group imply its deposition on the continental slope and in its foothills, while the northern vergence is related to the northern margin of the Transcaucasian microcontinent. In fact, this is the oldest complex accreted to the post-Hercynian structure of the Greater Caucasus owing to subsequent processes. Its formation terminated at the Triassic–Jurassic transition during the early Cimmerian (or Indo-Sinian) orogeny, which affected to a variable extent the whole Caucasian region. These events marked the onset of the next, Alpine (late Cimmerian–Alpine), stage in the development of the study region.

The Central Lesser Caucasus basin remained a single "true" oceanic basin at this stage. The initial Jurassic (terminal Hettangian–initial Sinemurian) was marked by the appearance of the Greater Caucasus riftogenic basin between the Transcaucasian Massif,

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which bordered the basin in the south, and the southern margin of the Eurasian lithospheric plate represented by the young (epi-Hercynian) Scythian Platform. This basin (a marginal sea of the Tethys) extended west- and eastward to the Mountainous Crimea and Kopetdag, respectively. Lomize and Panov [5] examined the formation mechanism of the basin and demonstrated that it was developing as an asymmetrical rift in line with the model proposed by B. Wernicke. The basin accumulated a thick sequence of terrigenous sandy–clayey sediments largely derived from the northern East European Platform [6], in contrast to sediments of the Diz Group. The origin of the crust underlying this basin and the size of the basin are debatable issues. Based on the lack of ophiolites, most researchers believe that rifting provoked only partial breakup of the continental crust and not its replacement by the oceanic crust. However, some researchers noted compositional similarity of tholeiitic basalts to mid-oceanic (i.e., spreading) varieties. Sills and dikes of these basalts (dolerites) are abundant in the entire Liassic–Aalenian sequence, and more acid varieties appear in the Aalenian. The Jurassic marginal sea of the Greater Caucasus was most likely underlain by thinned and intensely transformed continental crust. The width of the deep axial part of the basin is estimated at 60–80 [7] or 200 [8, 9] km.

At the Aalenian–Bajocian transition, subsidence of the Greater Caucasus basin was interrupted by the first strong compression phase. Panov [7] was first to indicate convincingly the importance of this and the next (pre-Callovian) phases. Previously, many researchers, including the author of the present paper [8], underestimated its significance. The onset of this compression phase corresponded with initiation of subduction of the oceanic crust of the Lesser Caucasus basin under the Transcaucasian microcontinent and the subsequent formation of the thick Pontian–Transcaucasian volcano-plutonic belt. Such a coincidence was naturally not incidental. It resulted in underthrusting of the Transcaucasian microcontinent and the crust of the central Greater Caucasus basin beneath the southern margin of the Eurasian Plate (Scythian Platform) that extended up to the present-day Main Caucasus Range. The underthrusting resembled pseudosubduction, which is observed now along the Apsheron Threshold of the Caspian Sea and, probably, the entire southern slope of the Greater Caucasus and eastern periphery of the Black Sea [11, 12].

This underthrusting and counterthrusting of the Scythian Platform were responsible for deformation of Liassic–Aalenian sediments constituting both the platform cover and, partly, the northern slope of the deep basin. According to Panov, the first uplift appeared in the central zone of the future orogen at the same time. All these events initiated the formation of an accretionary prism in that area (Panov [7] was first to compare the structure of the Lower–Middle Jurassic complex with the accretionary prism).

Subsidence of the axial trough of the Greater Caucasus basin was in progress at the Aalenian–Bajocian transition. This process resumed on its slopes in the Bajocian. Sedimentation patterns did not undergo principle changes, and accumulation of Bajocian–Bathonian terrigenous sediments terminated the formation of the Lower–Middle Jurassic dark shale complex. In structural terms, the sedimentation terminated with pre-Callovian deformations that resulted, according to Panov, in imbricate thrust dislocations. All these events were responsible for the formation of the second accretionary complex of the Greater Caucasus, in addition to the earlier Diz Group. The so-called Main Caucasian thrust served as its southern boundary by the initial Bajocian. The Bekishei–Malkamud (according to the tectonic scheme proposed by Doduev [12]) also served as the boundary by the initial Callovian. These boundaries can also be interpreted as surface manifestations of corresponding pseudosubduction zones.

In the Bathonian (i.e., during the pre-Callovian orogenic phase), granitoids intruded earlier central Caucasian uplifts in response to subduction of the suboceanic crust underlying the axial trough of the Greater Caucasus basin. By analogy with the present-day Caspian pseudosubduction zone, seismic sources located at a depth of 150 km were sufficient for magma formation.

In the Callovian, the situation in the Caucasian region became sharply different. This is particularly true of climatic conditions: the humid climate that favored accumulation of black shales and coal-bearing formations gave way to an arid one with deposition of carbonates and evaporites. In the Oxfordian, the barrier reef that isolated a saline lagoon from the main Caucasian basin started developing along the central Caucasian uplifts. A similar reef appeared on the volcanic arc that extended along the southern slope of the basin. Sedimentation in the Caucasian basin was also in progress at the Bathonian–Callovian transition, although carbonate flysch facies dominated at that time.

Meanwhile, the Lower–Middle Jurassic accretionary prism between the axial trough and barrier reef was transformed into the northern slope of this trough, which accumulated detrital material from the eroded barrier reef in the Late Jurassic and Neocomian–early Aptian to form thick olistostromes, which are particularly widespread in the northwestern and southeastern subsided parts of the Greater Caucasus. In the Late Aptian, carbonate massifs of the barrier reef in the eastern area (Azerbaijan) were detached from their Middle Jurassic base and thrust southward over Lower Cretaceous (largely clayey) sediments of the continental slope, which is particularly characteristic of the Shaghdag Massif [13]. Similar processes took place also at the opposite, northwestern flank of the orogen, where Fisht and Oshten reef massifs were displaced during this orogenic phase. Later on, they continued to deliver olistoliths to the continental slope and its foothill at least up to the Maestrichtian in the southeast. In the axial part of the Greater Caucasus basin, flysch continued to accumulate until the late Eocene. By that time, the flysch sequence in the northern half of the basin acquired a relatively complicated (imbricate) thrust fault structure, resulting in the formation of the third accretionary complex, which adjoined the first two complexes in the south, and expansion of the southern margin of the Eurasian Plate. It would be incorrect to think that the formation of its structure was a one-stage process that predated the Oligocene episode, despite the fact that the pre-Oligocene unconformity is documented well in both the northwestern (Kuban) and southeastern (Dagestan, Azerbaijan, offshore areas north of the Apsheron Peninsula) subsided parts of the Greater Caucasus. Geostructural drilling in the coastal areas of northern Azerbaijan revealed that folding commenced there at least in the Valanginian and that upper Paleocene sediments unconformably overlie the older strata [14]. Of principal significance were, however, pre-Oligocene deformations, which were not incidentally synchronous to even more intense compression in the Lesser Caucasus. These events mark the onset of the orogenic development stage with the formation of thick olistostromes on the northern and southern slopes facing the Kura and Araks rivers, respectively. The intense subduction of the oceanic crust along the northern periphery of the Neo-Tethys (not Meso-Tethys) was responsible for such events practically through the entire Caucasus.

The major thrust (known as the Krasnaya Polyana Fault in the northwest and the Gainar–Gozluchai Fault in the southeast) serves as the southern boundary of the accretionary complex [13]. The fault corresponds probably to the frontal part of the pre-Oligocene subduction. Beginning from upper reaches of the Geichai River in Azerbaijan, the fault separates the pre-Oligocene accretionary complex from the late Miocene (more exactly, pre-Pontian) complex known as the Govdag–Sumgait Complex [13]. In addition to the Cretaceous and Lower Paleogene flysch, the Oligocene–Miocene sediments (including the Maikop and Diatom groups) are also present in the latter complex. Transgressive and unconformable overlapping of all these strata by shallow marine sediments of the Pontian regional stage (an equivalent of the Mediterranean Messinian Stage), which crown the Miocene section, marks termination of the Govdag–Sumgait Complex formation.

This complex is discretely exposed in Azerbaijan and eastern Georgia. Its structure is characterized by the most complicated pattern (numerous sheets and nappes) in the whole Greater Caucasus. The nappes are displaced southward over tens of kilometers. In the southeast, they nearly completely overlap the Oligocene–early Miocene Lagich (Lakhydz) deep trough and are thrust over the northern slope of the Vandam marginal uplift of the Transcaucasian Massif. On the Caspian coast, the complex appears to be overridden by the northwestern slope of the South Caspian Basin composed of Pliocene–Eopleistocene sediments. Anomalous interstitial pressure in the thick Oligocene–Miocene sequence, which was tectonically overlapped by this complex, was responsible for wide development of clay diapirism and, particularly, mud volcanism in the region. In this respect, the accretionary complex under consideration resembles present-day accretionary complexes of Barbados, Makran, the Columbian margin of the Caribbean Sea, and Cadiz Bay of the Atlantic Ocean.

Dotduev [12] identified a less developed Chvezhipse Complex in the northwestern Greater Caucasus as an analogue of the Govdag–Sumgait Complex. Like the latter complex, it is also thrust over the marginal Gagra–Dzhava Uplift of the Transcaucasian Massif to form the Vorontsovka tectonic–gravitational nappe, an analogue of the Basgal nappe in Azerbaijan. This marginal uplift, which incorporates the Gagra–Dzhava, Mountainous Kakhetia, and Vandam blocks, was separated from the Transcaucasian microplate in the course of its collision with the southern margin of the Eurasian Plate and closure of the Greater Caucasus marginal basin in the terminal Eocene, when the margin was uplifted and thrust over the basin. This is evident from the composition of olistostromes in the southern part of the basin in eastern Georgia and Azerbaijan that include characteristic Upper Jurassic reefal limestones, Bajocian porphyrites, and even granodiorites. On the western and eastern flanks of the Greater Caucasus (northwest of Tuapse and east of Shemakha, respectively), the marginal uplift of the Transcaucasian microplate dips under Oligocene and younger sediments.

Marginal uplifts of the Transcaucasian Massif are bordered by the Abkhazia–Lechkhum (Orkhevi in eastern Georgia) and Adzhichai–Alyat thrusts on the southwest and extreme southeast, respectively. The relatively strong Racha earthquake that occurred along the former structure in 1991 showed that the fault represents a gentle overthrust in the upper crust that reflects general thrusting of the Greater Caucasus (including the Gagra–Dzhava zone) over the Transcaucasian Massif [15].

West of the Tuapse meridian, the Chvezhipse zone loses its individuality. The Krasnaya Polyana Thrust, branches of which bordered the Chvezhipse zone, dips under Black Sea waters, probably continues along the shelf edge, and separates the Novorossiisk flysch complex from sediments of the so-called Tuapse Trough. The trough, which occupies the continental slope and its rise, represents in fact a typical accretionary prism composed of Oligocene–Neogene terrigenous sediments. It is a homologue rather than analogue of the Govdag–Sumgait Complex. This is evident from manifestations of clay diapirism and mud volcanism.

At the rise of the continental slope, the Tuapse Trough contacts with the underwater Shatsky Swell that continues southward to the Abkhazia shelf and adjoins the main body of the Transcaucasian Massif. This suture marks in fact the present-day pseudosubduction zone at the bottom. In the north, the Tuapse Trough adjoins the similar Sorokin Trough that fringes the structures of the Mountainous Crimea and is confined to a similar pseudosubduction zone with the seismofocal zone of Crimean earthquakes.

In the southeastern subsided part of the Greater Caucasus, the accretionary complex of the Govdag–Sumgait zone is bordered by the Zangi Thrust. According to Dotduev and Kengerli, the latter thrust is a continuation of the Krasnaya Polyana Fault. At upper reaches of the Geichai River, where the Govdag–Sumgait Complex pinches out, the Zangi Thrust adjoins the Gainar–Gozluchai Thrust that continues northward from the Krasnaya Polyana Fault and separates Oligocene and pre-late Miocene accretionary complexes. Based on geophysical data, Kengerli [13] assumed that the Zangi Thrust is a fracture, which becomes gradually gentler downward and reaches the mantle beneath the Main Caucasus Range. It can be interpreted as a pseudosubduction zone that was active in the late Miocene, when the Greater Caucasus started to experience pressure of the Arabian Plate via the Transcaucasian microplate. It can be assumed that the present-day pseudosubduction zone extending along the southern periphery of the Apsheron Threshold in the Caspian Sea represents an "active" continuation of that pseudosubduction zone between the South Caspian microplate and the Eurasian Plate. Young magmatism of the Greater Caucasus could presumably be related to the activity of this zone.

In a small area between upper courses of the Geichai and Shemakha, the Govdag–Sumgait Complex is thrust along the Zangi Fault over a narrow trough that separates the complex from the Vandam Uplift. The trough, filled with clayey sediments of the Maikop Group, probably represented a deep-sea trench at the beginning. To the east, it is partly overlapped by tectonic sheets of the Govdag–Sumgait Complex and partly widens to be additionally filled with relatively deepwater Miocene sediments (diatom oozes and others). According to Kengerli, the thickness of this Shemakha–Gobustan Complex increases up to 18–20 km near the Caspian shore. It is conceivable that the deposition center of Caspian Sea with Pliocene–Quaternary sediments (more than 20–22 km thick) is located precisely at its continuation. This area of the Baku Archipelago is located south of the Apsheron Peninsula with particularly powerful mud volcanism.

Thus, folds of the Shemakha–Gobustan zone include the youngest Pliocene–Quaternary sediments as well. They take part also in the structure of the above-mentioned Adzhichai–Alyat thrust zone, which borders simultaneously the Shemakha–Gobustan zone and the buried Vandam Uplift. Rocks of the uplift are found in mud volcano breccia in the Alyat Ridge and southern islands of the Baku Archipelago in the Caspian Sea.

Thus, the Meso–Cenozoic development of the marginal riftogenic basin of the Greater Caucasus in response to pseudosubduction of its suboceanic crust and lithosphere under the margin of the Eurasian Plate, which is a consequence of the "true" subduction zone in the Meso- and Neo-Tethys periods, was accompanied by successive accretion of sedimentary complexes to the southern margin (Scythian Platform) of the Eurasian Plate. Along with uplifting of the southern Scythian Platform margin, the basement of which is now exposed in the Main and Frontal ranges of the Central Caucasus, this process was responsible for the formation of the Greater Caucasus orogen.

Naturally, pseudosubduction is not completely identical to subduction. Correspondingly, the accretionary complexes mentioned above are not true counterparts at least in their internal structure. Nevertheless, they are significant and probably typical not only of the Greater Caucasus, but also of the Pyrenean Mountains and some other similar orogens.

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