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GEOLOGY OF THE CAUCASUS AND ADJACENT AREAS: 1:2 500 000 SCALE GEOLOGICAL MAP

Adamia Sh.^{1,2}, Chabukiani A.², Chkhotua T.³, Sadradze N.^{2,3}, Zakaraia D.², Zakariadze G.⁴

¹*Javakhishvili Tbilisi State University, 1 Chavchavadze av., 0128, Tbilisi, Georgia, sh_adamia@hotmail.com*

²*Nodia Institute of Geophysics, 1 M. Aleksidze str., 0195, Tbilisi, Georgia, sh_adamia@hotmail.com,*

³*Janelidze Institute of Geology, 9 M. Aleksidze str., 0195, Tbilisi, Georgia, ninosadradze@gmail.com*

⁴*Vernadsky Institute of Geochemistry and Analytical Chemistry RAS, Moscow, Russia, gurzak@geokhi.ru*

Abstract: The geological map of the Caucasus and adjacent areas of 1:2 500 000 scale, being presented on the 19th Congress of the CBGA includes on-shore and off-shore parts of the Black Sea-Caspian Sea region (Fig. 1). Small-scale thematic (geologic, tectonic, metallogenic etc) maps of the World and its large parts, such as Europe, Middle East etc., have been periodically compiled and published under umbrella of the Commission for Geological Map of the World (CGMW), for example: carte geologique de l'Europe, 1:10 000 000, 1970; carte tectonique de l'Europe et des regions avoisinantes, 1:10 000 000, 1975; carte tectonique internationale de l'Europe et des regions avoisinantes, 1:2 500 000, 1980; geological map of the Middle East, 1:5 000 000, 1986; 1:5 000 000 International geological map of Europe and adjacent areas, 2005, BGR Hannover; the international geological map of the Middle East, 1:5 000 000, second edition, 2009-2010. The Caucasian region, situated at the junction of the European and Asiatic segments of the Alpine-Himalayan orogenic belt and serving as a connecting link between these two branches, as a rule, is illustrated by maps of the both segments. The presented map demonstrates up-to-date level of knowledge on geological structure and evolution of the region.

Keywords: Caucasus, Eurasia, Tethys, Gondwana, pre-collisional, post-collisional.

1. Introduction

The tectonics and geological evolution of the Caucasus, or Black Sea-Caspian Sea region, in whole, are largely determined by its position between the still converging Eurasian and Africa-Arabian lithosphere plates, within the wide zone of a continent-continent collision. The region in the Late Proterozoic-Early Cenozoic belonged to the now-vanished Tethys Ocean and its Eurasian and Gondwanian/Africa-Arabian margins (Zakariadze et al., 1998, 2007). Within this convergence zones, there existed a system of island arcs, intra-arc rifts, back-arc basins etc. characteristic of pre-collisional stage (Late Proterozoic-Early Cenozoic) of evolution of the region. During syn-collisional (Oligocene-Middle Miocene) and post-collisional (Late Miocene-Quaternary) stages of the Late Alpine tectonic cycle, as a result of the continent-continent complete collision and inversion of the relief, at the place of back-arc basins were formed fold-thrust belts of the Great and Lesser Caucasus, and, in between, intermontane depression instead of Transcaucasian rigid blocks (microcontinents, island

arcs). Normal marine basins were replaced by hemi-closed basins of euxinic type (Paratethys) and later on (Late Miocene) – by continental ones with subaerial conditions of sedimentation. Deep basins of the Black Sea and Caspian Sea do not represent remains of the Tethys Ocean, however, they resulted from the Late Cretaceous-Early Paleogene rifting, northward of subduction zone that coincided with the North-Anatolian-Lesser Caucasian ophiolite suture (Adamia et al., 1981, 2007).

2. Main Tectonic and Tectonostratigraphic Units

There are distinguished rigid (platform, sub-platform, quasi-platform) and fold-thrust units (Fig. 2): the Scythian (pre-Caucasus) young platform; fold-thrust mountain belt of the Great Caucasus including zones of the Northern Slope, Fore Range, Main Range and Southern Slope; the Transcaucasian and Aras intermountain depressions superimposed mainly on the rigid platform zones; Achara-Trialeti and Talysh fold-thrust mountain belts; Artvin-Bolnisi rigid sub-platform zone; Bayburt-Garabagh fold-thrust mountain belt; Lesser Cauca-



Fig.1. Physical map of the Caucasus and adjacent areas of the Black Sea-Caspian Sea region.

sus ophiolite suture; Lesser Caucasian part of the Taurus-Anatolian-Iranian platform. The youngest structural unit includes Neogene-Quaternary continental volcanic formations and extinct volcanoes. The Eastern Black Sea and Caspian Sea basins unconformably overlie different structural units of the Caucasus, eastern Pontides, Iranian Talysh and Garadagh (Adamia et al., 1981; 2007).

Within the region, there are developed sedimentary, magmatic and metamorphic rocks, dated as Late Proterozoic-Phanerozoic. Their formation occurred under various paleogeographic (facial) and geodynamic environments: oceanic and small oceanic basins, intercontinental areas, active and passive continental margins. Late Proterozoic-Phanerozoic interval of development is divided into two stages: pre-collisional (Late Proterozoic – Early Cenozoic) and syn-post-collisional (Late Cenozoic).

3. Geological Provinces

The region is divided into the Southern and Northern Tethyan geological provinces. During the Late Proterozoic, the Southern Province distinctly demonstrated Pan-African tectonic events, throughout the Paleozoic it represented platformal area, which

accumulated mainly shallow-marine sediments. In the Paleozoic, the Northern Province is featured by strong manifestation of tectonic events: supra-subduction volcanism, granite-formation, deep regional metamorphism and orogenesis. Throughout the Mesozoic and Early Cenozoic, the Southern and Northern provinces distinctly differ each from the other, too. The boundary between the above-said provinces runs along North Anatolian-Lesser Caucasian ophiolitic suture belts (Zakariadze et al., 2007; Adamia et al., 2007).

3.1. Pre-Collisional Stage. Late Proterozoic-Paleozoic: Basement Rocks

Basement rocks are represented by regionally metamorphosed sedimentary, volcanic and plutonic rocks. Magmatites are represented by two main rock complexes of (1) hyperbasite-basite-diorite and (2) granite-migmatite composition. The former is the carrier of information on oceanic basins of Prototethys-Paleotethys, and is represented by relatively small, dismembered, strongly deformed and metamorphosed fragments of basites and hyperbasites.

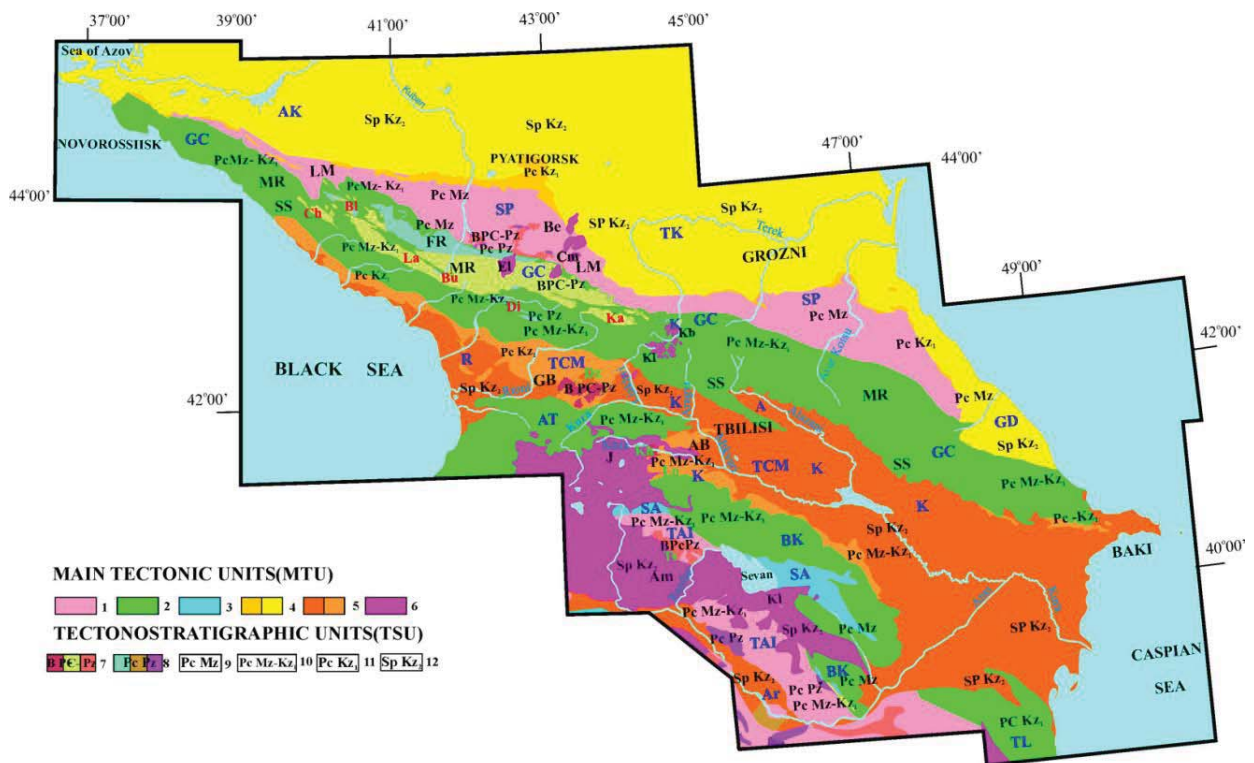


Fig. 2. Tectonic map of the Caucasus. MTU-Main tectonic units; TSU-Tectonostratigraphic units. MTU: 1. Platforms: SP -Scythian; TAI - Taurus-Anatolia-Iranian. 2. Fold-thrust mountain belts: Great Caucasus (GC); Achara-Trialeti (AT); Talysh (TL); Baiburt-Garabagh-Kaphan (B). 3. Ophiolite suture belt: Sevan-Akera (SA). 4. Foredeeps: Azov-Kuban (AK), Stavropol high (ST), Terek-Caspian (TK), Gussar-Devichi (GD). 5. Transcaucasian massif (TCM) and forelands: Rioni (R), Kura (K), Alazani (A), Aras (Ar). 6. Neogene-Quaternary subaerial volcanic formations. TSU: 7. BPE-Pz, Pre-Cambrian-Paleozoic basement; 8. PCPz, precollisional Paleozoic. 9. PcMz, precollisional Mesozoic. 10. PcMz-Kz1, precollisional Mesozoic-Early Cenozoic. 11. PcKz2, precollisional Early Cenozoic. 12. Spkz2, syn-postcollisional Late Cenozoic. Tectonic zones: Bechasin (Be), Laba-Malka (LM), Fore Range (FR), Main Range (MR), Southern Slope (SS), Georgian Block (GB), Artvin-Bolnisi Block (AB). Salients of the basement complexes: Dzirula (Dz), Khrami (Kh), Loki (Lo), Tsakuniats (Ts). Metamorphic complexes: Blib (Bl), Chugush (Ch), Laba (La), Buulgen (Bu), Kassar (Ka), Dizi (Di). Volcanic highlands, plateaus and extinct volcanoes: Elbrus (El), Chegem (Cm), Kazbegi (Kb), Keli (Ke), Javakheti (J), Kelbajar (K), Armenia (Am). Pc, Precollisional, SP, Syn-postcollisional.

The rocks of pre-Mesozoic oceanic basins of the region, generally, are closely associated with granite-gneiss-magmatite complexes of pre-Cambrian-Paleozoic basement, and represent rock associations belonging to both continental and transitional types of the crust. The rocks are strongly deformed: tectonic nappes, slices, tectonic melange, accretional prisms etc are frequent.

Southern Province

The Pan-African (Neo-Proterozoic) oldest basement of the Anatolia-Central Iranian platform in the region crops out northward of Erevan (Armenia, the Tsakhkuniats massif). It consists of two pre-Cambrian terrains: 1. Arzacan (ensialic) and 2. Hancavan (ensimatic) unites. The Arzacan metamorphic complex is intruded by granites whose Rb/Sr isochron age is 620 Ma and the Hancavan complex is intruded by trondhjemite whose Rb/Sr

isochron age is 685 ± 77 Ma (Agamalyan, 2004).

Boundary between Northern and Southern Provinces

The Sevan (Lesser Caucasian) ophiolite melange contains inclusions of different basic-ultrabasic olistolites. Metamorphic exotic blocks are represented by granate-amphibolites, amphibolites and micaschists. Sm-Nd mineral isochrones for two gabbro-norites have shown Late Triassic age: 226 ± 13 and 224 ± 83 Ma (Bogdanovsky et al., 1992)

Northern province

Transcaucasian massif. The basement of the TCM is composed mainly of Variscian granitoides. Relatively small outcrops of differently tectonized and metamorphosed basite-hyperbasite rocks are generally associated with pre-Cambrian – Early Paleozoic gneissose diorites and plagiogranites (“grey

granite” complex), and they are also present within the tectonic melange zone. The tectonic melange consists of a number of allochthonous tectonic slices of different age and facies: phyllites, schists, Paleozoic high-silica volcanics, sheared Late Carboniferous microcline granites, metabasites and serpentinites.

Whole-rock Sm-Nd isotopic data for amphibolites from different tectonic slices defined a regression line corresponding to the age of 810 ± 100 Ma (Zakariadze et al., 1998, 2007).

Data on Neoproterozoic-Cambrian (~750-500 Ma) age limits of dioritic intrusions of the Grey Granite Basement Complex were received from U-Pb zircon studies of gneissose granodiorite and quartz diorite-plagiogranite migmatite of the Dzirula salient (Bartnitsky et al., 1989). Middle-Late Carboniferous age of emplacement of the Potassium Granite Basement Complex (“red granites”) is reliably constrained by biostratigraphy and various K-Ar, Rb/Sr and U-Pb data for micas and zircons (Geology of the USSR, 1964).

Great Caucasus, Main Range Zone, basite-ultrabasite complexes. Within the MRZ, pre-Mesozoic basites and ultrabasites crop out along: the southern margin of the MRZ, its western submergence zone, the Fore Range zone and the Bechasin zone of the Scythian platform.

The southernmost stripe of the MRZ is represented by thrust slices of ultrabasites, gabbro-amphibolites, amphibolites and mica-schists, plagiogneisses, marbles (the Laba, Buulgen, Chugush and Kassar groups). Detailed geochemical studies showed that composition of the metabasite series of the Paleozoic metabasite complexes correspond to the types of oceanic spreading centres (T-type MORB) and suprasubduction zones (immature arc-back arc association).

Age identification of the basite-hyperbasite complexes of the MRZ was made according to stratigraphic, paleontologic and geochronologic data. On the basis of the stratigraphic position they are dated as pre-Middle-Carboniferous. According to paleontologic finds (crinoidea) the upper part of Laba series is attributed to post-Middle-Ordovician time. Results of identification of absolute age of basites of the Laba and Buulgen complexes, in whole, well agree with stratigraphic and paleontologic data (Somin, 2007).

Great Caucasus: basites and ultrabasites of the Fore Range Zone. Within the FRZ, outcrops of ophiolites are traced as strongly deformed allochthonous tectonic sheets and slices. They are underlain by Upper Devonian-Lower Carboniferous volcanogenic-sedimentary island-arc type deposits and overlain by Middle-Upper Carboniferous molasse.

According to rare finds of fossil fauna (corals) age of volcanogenic-sedimentary series is identified as Middle Devonian. Zircon SHRIMP age of gabbro of the Maruch nappe is 416 ± 8 Ma, that is in a good agreement with the data on Lower-Middle Paleozoic age of ophiolites of the FRZ (Somin, 2007).

An isolated outcrop of metabasites and ultrabasites (the Blibi complex) tectonically underlies Middle Paleozoic sediments of the extreme western part of the FRZ. Sm/Nd age is 311 ± 22 Ma, and Lu-Hf garnet chronometer confirmed age of 322 ± 14 and 316 ± 5 and 296 ± 11 Ma (Phillipot et al., 2001). U/Pb age of the gabbro-amphibolites is 357-400 Ma (Somin, 2007).

Great Caucasus: granite complex. The rocks of Granite Complex (granites, granito-gneisses, migmatites and quartz-mica schists) are concentrated mainly in the MRZ. These complexes are made up of large tectonic slices of the MRZ.

Redeposited material of both metamorphites and granites is abundantly present in Late Paleozoic molasses of the Great Caucasus. Geochronologic data of granite-gneisses-migmatites show that the time of their formation widely ranges from 280-310 Ma up to 500 ± 40 Ma (Somin, 2007). Rb/Sr isochrone dating of potassium-spar granites demonstrated the values of 280 up to 300 Ma (Geology of the USSR, 1964, 1968).

The Scythian platform (SP). Metamorphic and Granite Complexes outcrop in the central part of the Bechasin zone of the SP (Geology of the USSR, 1968). The metamorphic rocks are represented by micaschists, metavolcanoclastolites, sericite-chlorite schists etc. U/Pb ages for zircons of the Beschasin complexes indicate their Late pre-Cambrian-Early Paleozoic origin (Somin, 2007). The metamorphic rocks of the Bechasin zone are intruded by Late Paleozoic granites, granodiorites and quartz diorites, aplites and granite-porphyry.

3.2. Paleozoic Sedimentary Cover

Within the both provinces, Paleozoic sedimentary cover is represented by various facies of terrigene, carbonate, and volcanogene deposits.

Southern province

Continuous Devonian-Lower Carboniferous series of shelf deposits developed in Nakhchevan and at the south of Armenia consist, mainly, of coral-brachiopod limestones (often bituminous), quartzite sandstones, and argillites. Thick transgressive formation of Permian bituminous algae-foraminifera limestones with corals, brachiopods, ammonoids, and conodonts stratigraphically unconformably covers Devonian and Lower Carboniferous deposits (Geology of the USSR, 1970, 1972).

Boundary Zone, Ophiolite Suture Belt

Within the melange of the Lesser Caucasian ophiolite suture belt, there are met limestone blocks with Middle Carboniferous-Permian conodonts.

Northern Province

Within the TCM Paleozoic deposits are represented by shallow-marine and continental volcanogenic-sedimentary rhyolite-dacite-andesite calc-alkaline formation hosting limestone lenses and dated by corals, brachiopods, conodonts and fossil flora as Upper Viséan-Namurian-Bashkirian.

Paleozoic deposits within the Southern Slope of the Great Caucasus, known as phyllites of the Dizi series, outcrop at the central part of the zone and are represented by strongly deformed rocks of relatively deep open marine basin located between island-arc units of the TCM and MRZ. In the continuous succession, there alternate terrigenous turbidites intercalated with phtanites, jasper, olistostromes, rarely volcanoclastics of andesite-dacitic composition, and lenses of marbled limestones. Presence of the Middle and Upper Devonian, Carboniferous and Permian was confirmed by conodonts (from phtanites), corals, crinoids and foraminifera (Kutelia, 1983; Somin, 2007).

Within the MRZ, Late Paleozoic sedimentary cover is composed of the rocks accumulated under subaerial and shallow-marine environments. In the lower part of the Late Paleozoic section, there are coarse clastic continental molasses, locally coal-bearing, with Middle Carboniferous flora. There are registered volcanics of quartz-porphry composition. The higher horizons of the section constrained according to brachiopods to the Upper Carboniferous are represented by shallow-marine terrigenous molasses. The Permian deposits should also be attributed to marine terrigenous facies. The terrigenous rocks alternate with organogene limestones. The limestones contain the following fossils: corals, brachiopods,

gastropods, pelecipods and foraminifera. (Geology of the USSR, 1964 and 1968; Adamia et al., 2003). The FRZ bounded to the north by Pshekish-Tirnaiuz fault and representing sub-lateral narrow trough is a depositary of polyfacial Middle Paleozoic and Upper Paleozoic sediments. The Middle Paleozoic of this zone relates to the facies of relatively deep sea, while the Upper Paleozoic is represented by continental or shallow-water molasse (Geology of the USSR, 1968; Alpine history, 2007).

Within the Middle Paleozoic section of the FRZ, there is a distinguished deep-water hemipelagic siliceous-volcanogenic formation with radiolarites, graptolite argillites, aleurolites, sandstones and siliceous schists (Silurian), terrigenous turbidites with olistostromes and redeposited material of the rocks of ophiolitic association (Devonian-Lower Carboniferous according to conodonts and other fossils). The Lower-Middle Devonian thick terrain is attributed to formations of island-arc – intraarc rifts. The section is topped with the Upper Devonian – Lower Carboniferous formation of terrigenous turbidites, olistostromes and limestones.

The Upper Paleozoic molasse unconformably rest upon the Middle-Paleozoic deposits of the FRZ, or upon ophiolitic allochthonous sheets of the zone. Within the FRZ as well as in the Bechasin Zone, they are represented by Middle-Upper Carboniferous and Permian continental molasse. Island-arc type subaerial volcanic rocks are developed at the Middle Carboniferous and Permian levels. Age of the deposits is established, mainly, by flora fossils belonging to North Tethyan paleobiogeographic province. At the Upper Permian level, there are carbonate-terrigenous marine deposits hosting bioherm limestone bodies. The formation is dated according to fauna fossils represented by brachiopod, coral pelecipod, algae, sponge, gastropod, ammonoids, foraminifera etc (Geology of the USSR, 1968; Alpine history, 2007).

Within the Bechasin Zone, the Paleozoic deposits (Cambrian-Middle Devonian) are represented by sandy-argillaceous and carbonate shelf facies containing Middle Cambrian trilobites, Silurian graptolites and Silurian-Devonian conodonts.

3.3. Mesozoic – Early Cenozoic

In the extreme south of the region, there remained platformal regime and occurred accumulation of uniform mainly carbonate shelf sediments. The ophiolite belt of the Lesser Caucasus is represented

by rocks of the Tethyan oceanic and back-arc basins, while the northern province demonstrates facies characteristic of active continental margins (Adamia et al., 1981).

Southern Province

Triassic sediments of the southern province are represented mainly by shelf organogene carbonates, while the northern part of this province hosts sediments of the shallow terrigene-coalbearing Upper-Triassic formation (Geology of the USSR, 1970 and 1972). Upper Triassic age of terrigene formation was identified by mollusks and flora fossils.

Jurassic deposits are represented by shelf facies. Within the pre-Araks part of the province, the following formations rest upon the Triassic limestones: diabasic porphyrites with interbeds of tuffs (Lias-Dogger); sandy-argillaceous deposits with interbeds of tuffogene sandstones attributed to Aaleanian-Lower Bajocian stages; sandy-argillaceous-carbonate formation with Upper Bajocian, Bathonian, Callovian ammonites (Geology of the USSR, 1972).

Based on the features of the Albian deposits known in the pre-Araks area and containing abundant fossils of mollusks, it can be considered that this domain during the abovesaid time represented shallow marine basin, the Upper Cretaceous deposits are also represented by shallow-marine and back-arc basin formations (flysch). The Paleocene deposits represented by shallow marine and back-arc basin facies are tightly associated with the Upper Cretaceous ones. Fauna fossils are met as sea-urchin and foraminifera.

In the Eocene, there starts the period of intensive submarine volcanic eruptions under back-arc and shallow-sea basins environment. The volcanics locally alternating with the terrigenous and carbonatic deposits. Besides nummulitides, these deposits include large mollusks, sea-urchins, brachiopods, and corals. The Eocene volcanic belt of the southern province represents a part of the vast andesite belt of Middle Asia, running from the Aegean Sea, through Turkey, the Lesser Caucasus and Iran as far as to Afghanistan.

During the end of the Middle-Late Eocene, volcanic activity sharply decreases and under shallow-marine environment there occurs accumulation of mainly sandy-argillaceous and carbonate sediments. Within the Upper Eocene section, volcanic rocks are represented by thin volcanic band of andesite

composition (Geology of the USSR, 1970; 1972).

Ophiolite suture belt

Mesozoic sedimentary rocks of the suture belt are met within the melange as clastic-blocks of various dimensions. The oldest rocks dated paleontologically are Upper Paleozoic limestones and Upper Triassic limestones and calcareous sandstones with ammonites; basalt and radiolarite associations with Triassic radiolarians. In allochthonous ophiolitic complex, there are distinguished Jurassic-Lower Cretaceous associations. Effusive-radiolarite part of the ophiolite locally hosts lenses of Upper Jurassic-Neocomian reef limestones. The younger ophiolitic association starts with the transgressive Albian-Senomanian, which is represented by flysch and olistostromes. Higher in the succession, they are followed by basalts and Albian-Lower Coniacian radiolarites (Zakariadze et al., 1983; Knipper, 1991). Neoautochthonous complex of the ophiolite belt begins with transgressive formation of Coniacian-Santonian terrigene clastics. The overlying Senonian-Lower Paleogene formations were formed in the analogous back-arc basin, as well as sandy-argillaceous deposits and calc-alkaline andesitic volcanic formations.

Northern Province

Transcaucasian Massif. The TCM, the extreme southern tectonic unit of the Northern Province, in the Triassic-Eocene, has been developing as an island-arc-type unit. The Mesozoic starts with subaerial volcanoclastics of rhyolite composition containing Upper Triassic flora (Adamia et al., 2003). Lower Jurassic and Aalenian layers are built up of arcogenic terrigene clastics and shallow water organogene limestones containing abundant crinoids and brachiopods. The Bajocian stage is represented by tuffurbidites with rare bands of calc-alkaline andesite-basalts, the Bathonian deposits are made up of freshwater-lacustrine coal-bearing sandy-argillaceous rocks followed by variegated lagoon Callovian-Upper Jurassic deposits containing sub-alkaline-alkaline basalts (Geology of the USSR, 1964, 1970 and 1972; Lordkipanidze et al., 1989). The Lower Cretaceous is represented by transgressive basal formation followed by dolomites, organogenic limestones and marls. Facially uniform are, also, the Upper Cretaceous, Paleocene and Eocene deposits built up mainly of neritic organogenic limestones and marls. However, in the Paleocene-Eocene within the TCM, northward of Paleogene andesitic belt of Middle Asia, there originated "rear

basaltic troughs (rifts)” (Lordkipanidze et al., 1989): the Achara-Trialeti dividing the Transcaucasian massif into the Georgian and Artvin-Bolnisi rigid blocks, and the Talysh. Within these troughs, the Paleocene-Lower Eocene is represented by thick formation of terrigenous turbidites, which, in some localities, is associated with dacite-rhyolitic lavas and pyroclastics. They are overlain by Eocene formation of bimodal (basalts, delenites), calc-alkaline, sub-alkaline and alkaline volcanic rocks. In the Talysh, Eocene volcanics are more alkaline (Geology of the USSR, 1972) that is associated with intrusives of sub-alkaline ultra-basic formation: sub-alkali peridotites (age 38-41Ma) and gabbro-syenites (34-36 Ma). In the Late Eocene, there occurs accumulation of mainly terrigenous turbidites with admixtures of volcanoclastic material (Mamedov, 1998; Vincent et al., 2005).

Great Caucasus. Mesozoic-Early Cenozoic basin of the Great Caucasus located behind the island-arc basin of the Transcaucasus inheritably has been developing, at least, from Devonian and throughout Paleozoic and Mesozoic. Lower Jurassic terrigenous turbidites and volcanoclastics of the central part of the Southern Slope Zone conformably follow Triassic levels. The Pliensbachian is, generally, represented by black slate formation. Tholeiitic basalts of MOR-type – pillow lavas and agglomerates- are also confined to this level. The higher, Lower and Middle Jurassic, layers are composed of terrigenous turbidites. Volcanic activity is periodically evident throughout the Liassic (Geology of the USSR, 1964, 1968, 1972; Alpine history, 2008).

During the Aalenian, volcanic eruptions occurring under deep marine environment also demonstrated features of basalt of MOR-type, however, they showed resemblance with island-arc type, too (Lordkipanidze et al., 1989). Along the southern margin of the SSZ, there are widely spread Bajocian calc-alkaline andesite-basalts. The black slate, terrigenous-turbiditic and volcanogenic formations of the SSZ are dated predominantly by ammonites.

After the Bajocian, along the southern side of the basin there were deposited terrigenous sandy-argillaceous marine Bathonian, Callovian and Lower Oxfordian sediments, which northward grade into terrigenous and carbonate turbidites. Two (eastern and western) en echelon positioned flysch basins have been developing, within which turbidite sedimentation lasted almost uninterruptedly throughout Late Jurassic, Cretaceous, Paleocene and Eocene.

Northern slope of the Greater Caucasus – southern margin of the Scythian platform. The northern side of island-arc basin of the Great Caucasus, termed as the Laba-Malka-zone or North Caucasian monocline or Limestone Dagestan Zone etc, during the Mesozoic-Cenozoic is featured by development of continental-shelf deposits. The Triassic, Jurassic, Paleocene and Eocene sections are made of shallow-water—marine and continental rocks (Alpine history, 2007). In the western part of the basin, the Lower and Upper Triassic is represented by carbonatic rocks while within the Middle Triassic there predominate terrigenous clastics. Red-colored continental molasse of the central part of the Northern Slope are dated as Triassic according to palynomorphes.

The Lower and Middle Jurassic is composed mainly of terrigenous clastolites. Shallow-marine facies alternate with continental coal-bearing ones. Starting from the Callovian and until the Eocene there remains shallow-marine environment (Geology of the USSR, 1968; Alpine history, 2008).

3.4. Syn- and Post-Collisional Stages, Late Cenozoic

The Oligocene is considered as a beginning of syn-collisional (or orogenic) stage of development of the Caucasus (Geology of the USSR, 1964, 1968, 1970, 1972). Paleogeographic environment changed significantly: inversion of the relief took place and deep-water basins were replaced by mountain ranges of the Great Caucasus and Lesser Caucasus. Domains of shallow-water basins of platform type of pre-collisional stage sank down and turn into intramontane depressions that accumulated molasse deposits. The deposits of the Oligocene-Lower Miocene, resulted from accumulation in semi-closed basins of Paratethys, at the most part of the territory of the Caucasus are represented by argillaceous-sandy gypsiferous facies termed Maykopian series. Only at the end of the Miocene, shallow-sea environment is replaced by subaerial one and simultaneously the clastic material becomes coarser. Marine environment of sedimentation remains only within the territories adjacent to the Black Sea and Caspian Sea basins (Adamia et al., 2007).

Starting from the Late Miocene (~12 Ma ago) and as far as the end of the Pleistocene, in the central part of the region, simultaneously with formation of molasse troughs and accumulation of coarse molasses, there occur volcanic eruptions in subaerial

conditions. Volcanic highlands and plateaus were formed in Armenia, west of the central Azerbaijan (Kelbajar), Javakheti (Georgia); Elbrus, Chegem, and Keli plateau, Kazbegi etc in the Great Caucasus. Emplacement of small hypabyssal postcollisional intrusions occurred in the Transcaucasus, Great Caucasus, and pre-Caucasian terrains. Two main stages of volcanic activity are distinct: Late Miocene-Early Pliocene and Pliocene-Quaternary. According to their mineral-chemical composition the rocks of the both stages are attributed to calc-alkaline and sub-alkaline series. Data on absolute age demonstrate that the first stage of eruption happened ~12-6 Ma, while the second - ~3,5-0,05 Ma ago (Geology of the USSR, 1964, 1968, 1970, 1972; Adamia et al., 2007).

Eastern Black Sea and South Caspian Basins

The Eastern Black Sea (EBS) and South Caspian Sea (SC) basins unconformably overlie different structures of adjacent lands. The coastal lines of the both basins cut several main tectonic units of the Western Great Caucasus, Mountainous Crimea, Transcaucasus, Lesser Caucasus, and eastern Pontides (EBS); Eastern Great Caucasus, Caucasian Talysh and Iranian Garadag (SC). All these tectonic units locate north of the North-Anatolian-Lesser Caucasian ophiolite suture, which marks location of the oceanic Tethys in the wake of the northward-dipping subduction zone active, at least, throughout Late Paleozoic-Mesozoic (Adamia et al., 1981).

Eastern Black Sea. Geological structure of the Earth crust of the EBS and adjacent land have been studied over many decades by several generations of geologists and geophysicists from various countries (Neprochnov et al., 1964; Mindeli et al., 1965). According to some researchers, deep-water depression of the Black Sea deprived of granite layer represents a new structure formed mainly during the Late Cretaceous, Paleocene-Eocene and resulted from disruption and rifting of the Transcaucasian massif - paleo-island arc (Adamia et al., 1974, 1981).

Several tectono-sedimentary units of the Western Caucasus-eastern Pontides have their submarine prolongations in the EBS. The Paleozoic-Mesozoic-Early Cenozoic structural-sedimentary unit of the Southern Slope of the Great Caucasus, back-arc long-living basin, corresponds to the northern pre-Caucasian (and pre-Crimean) off-shore zone. The Shatsky high, which is the submarine prolongation of the northern branch of the Transcaucasian island-

arc (Northtranscaucasian arc) delineates at the north deep oceanic-suboceanic depression of the Eastern Black Sea. At the south, the oceanic deep depression is confined by the Andrusov and Arkhangelsky highs (Tugolesov et al., 1984) that correspond to the subaerial paleo-island-arc tectono-sedimentary unit of the eastern Pontides (Turkey) – Southern Transcaucasus (the Artvin-Bolnisi Block, Georgia). Thus, deep “granite-free” area of the Eastern Black Sea is bounded to the north (the Shatsky high) as well as to the south (the Andrusov and Arkhangelsky highs) by these structures. The Achara-Trialeti, Late Cretaceous-Early Paleogene rift structure, positioned at the prolongation of the “granite-free” segment of the Eastern Black Sea basin, is also located in between the two branches of the earlier undivided Transcaucasus.

The final stage of development of the Eastern Black Sea basin and adjacent land, e.i. the neotectonic development phase of the region, starts in the Oligocene when convergence of Eurasian and Africa-Arabian lithospheric plates entailed reduction of the Tethys Ocean, inversion of relief, replacement of former back-arc basins by mountain-folded constructions (the Great Caucasus, Lesser Caucasus, Pontides, and Mountainous Crimea) and formation of intermontane molasse depressions (Colchis-Black Sea) at the place of island-arc system. Semi-closed basins accumulated mainly fine-clastic molasse (low land). Only from the end of the Miocene (Late Sarmatian) within the intermontane depressions predominate accumulation of coarse molasse (high mountain relief).

South Caspian basin. The Earth crust of the South Caspian basin is heterogenous. Its peripheral parts are featured by continental crust, and only the deepest “granite-free” parts of the basin deprived of “granitic” layer demonstrate oceanic/suboceanic type of the crust (Gagelgants et al., 1958; Neprochnov, 1968). Oceanic/suboceanic crust of the SCB as well as oceanic crust of the Black Sea was formed during the Late Cretaceous-Eocene north of the northward dipping subduction zone. Off-shore prolongation of the Late Cretaceous-Eocene rift structure of the Caucasian Talysh, apparently, is “granite-free” part of the SCB (Adamia et al., 1974, 1981; Vincent et al, 2005). Northern segments of the SCB are correlated with the Kura-Arasian foreland of the TCM and Eastern Great Caucasus. The northern part of the Caspian Sea is underlain by structures of the Scythian/Turanian platform.

References

- Adamia Sh., Chkhotua T., Kekelia M., Lordkipanidze M., Shavishvili I., Zakariadze G., 1981. Tectonics of the Caucasus and adjoining regions: implications for the evolution of the Tethys ocean. *J. Structural Geology*, Vol.3, #4, pp 437-447, London.
- Adamia Sh., Gamkrelidze I., Zakariadze G., Lordkipanidze M., 1974. Achara-Trialeti trough and problem of origin of the deep marine trough of the Black Sea, *Geotectonica*, # 1, 78-94 (in Russian).
- Adamia Sh., Lebanidze Z., Svanidze Ts., Shavishvili I., 2003. Late Paleozoic-Triassic geodynamic evolution of Georgia (Caucasus). *Boll. Soc. Geol. It.*,+ volume speciale, #2, 213-218.
- Adamia Sh., Mumladze T., Sadradze N., Tsereteli E., Tsereteli N., Varazanashvili O., 2008. Late tectonics and geodynamics of Georgia (SW Caucasus). *Georgian International Journal of Science and Technology*, v. 1, iss. 1, 77-107.
- Agamalyan V., 2004. The Lesser Caucasus earth crust formation and evolution in the collision zone of Paleotethys. 5th International Symposium on Eastern Mediterranean Geology, Thessaloniki, Greece. Chatzipetos and Palvides (eds), 17-20.
- Alpine history of the Great Caucasus, 2007. Yu. Leonov (ed). Moscow, GEOS, 1-367 (in Russian).
- Bartnitski Y., Dudaori O., Stepanyuk L., 1989. Geochronology of Phanerozoic granitoides from folded areas of Eastern Europe. 5th Working Meeting, Isotopes in Nature, Leipzig, Proceedings, 1-10.
- Bogdanovski O., Zakariadze G., Karpenko S., Zlobin K., Pukchovskaia V., Amelin I., 1992. Sm/Nd age of gabbros from tholeiitic ophiolite series, Sevan-Akera zone (Lesser Caucasus). *Ophioliti*, 17(2) 259.
- Gagelgants A., Galperin E., Kosminskaya Ch., Krakshina R., 1958. Structure of the Earth's crust of the central part of the Caspian Sea according to deep sounding. *Dokladi Academy of Sciences USSR*, v. 123, # 3, 520-522 (in Russian).
- Geology of the USSR. Georgian SSR., 1964. Gamkrelidze P. (ed). Moscow, Nedra, v. X, 1-655 (in Russian).
- Geology of the USSR. North Caucasus., 1968. Andruschuk V. (ed). Moscow, Nedra, v.IX, 1-760 (in Russian).
- Geology of the USSR. Armenian SSR., 1970. Aslanian A. (ed). Moscow, Nedra, v. XLIII, 1-464 (in Russian).
- Geology of the USSR. Azerbaijanian SSR., 1972. Azizbekov Sh. (ed). Moscow, Nedra, v. XLVII, 1-520 (in Russian).
- Knipper A., 1991. Upper Triassic-Early Jurassic sedimentary breccias in the ophiolite suture of the Lesser Caucasus. In: Peters et al. (eds). *Ophiolite Genesis and Evolution of Oceanic Lithosphere*. Ministry of Petroleum and Minerals, Sultanate of Oman, 705-713.
- Kutelia Z., 1983. New data on the stratigraphy of the Dizi series (Svaneti). *Bulletin of Academy of Sciences of Georgia*, vol. 109, #3, 585-588 (in Russian).
- Lordkipanidze M., Meliksetyan B., Djarbashian R., 1989. Mesozoic-Cenozoic Magmatic Evolution of the Pontian-Crimean-Caucasian Region. IGCP Project 198: Evolution of the Northern Margin of Tethys. *Mem. de la Soc. Geol. France, nouvelle serie.*, 154 (11), pp 103-124.
- Mamedov M. 1998. Petrology of the Late Cretaceous and Eocene formations in the Lesser Caucasus and Talysh. Doctoral Thesis. (in Russian with English abstract). Tbilisi, 1-72.
- Mindeli P., Neprochnov Y., Pataraiia E., 1965. Identification of the area deprived of granitic layer in the Black Sea depression according to deep seismic sounding and seismic data. *Izvestia of Academy of Sciences of the USSR, series geological*, # 2, 15-23 (in Russian).
- Neprochnov Y., 1968. Structure of the Earth's crust of epicontinental seas: Caspian, Black and Mediterranean, *Canadian J. of Earth Sciences*, 5, 1037-1043.
- Neprochnov Y., Neprochnova A., Zverev S., Mironova V., Bokun R., Chekunov A., 1964. New data on the structure of the Earth of the deep Black Sea to the south of Crimea. *Dokladi of Academy of Sciences of the USSR*, v. 156, # 3, 561-566 (in Russian).
- Phillipot P., Blitcher-Toft J., Perchuk A., Costa S., Gerasimov V., 2001. Lu/Hf and Ar/Ar chronometry supports extreme rate of subduction zone metamorphism deduced from geospeedometry. *Tectonophysics*, 342, 23-38.
- Somin M., 2007. Structural position and geodynamic conditions of formation of metamorphic complexes of the Great Caucasus and Cuba (in Russ). Doctoral thesis. O. Shmidt Institute of Earth Physics, RAS, Moscow, 1-56.
- Tugolesov D., Gorshkov A., Meisner L., Solov'ev V., Khakhalev K., (1984). Structure and development history of the Black Sea depression. 27 International Geological Congress, Moscow, August, 1984, v. 3, 77-78 (in Russian).
- Vincent S., Allen M., Ismail-Zadeh A., Flecker R., Foland K., Simmons M., 2005. Insights from the Talysh of Azerbaijan into the Paleogene evolution of the South Caspian region. *GSA Bulletin*, v. 117, 11/12, 1513-1533.
- Zakariadze G., Dilek Y., Adamia S., Oberhänsli R., Karpenko S., Bazylev B., Solov'eva N., 2007. Geochemistry and geochronology of the Neoproterozoic Pan-African Transcaucasian Massif (Republic of Georgia) and implications for island arc evolution of the late Precambrian Arabian-Nubian Shield. *Elsevier, Gondwana Research* 11, 97-108.
- Zakariadze G., Karpenko S., Basilev B., Adamia Sh., Oberhänsli R., Solovieva N., Ljalikov A. 1998. Petrology, geochemistry and Sm-Nd age of pre-Late Hercynian paleoceanic complex of Dzirula salient of Transcaucasian massif. *Petrology*, v. 6, # 4, 1998, 422-444 (in Russian).
- Zakariadze G., Knipper A., Sobolev A., Tsamerian O., Vishnevskaya V., & Kolesov G., 1983. The ophiolite volcanic series of the Lesser Caucasus. *Ophioliti*, 8, 439-465.

