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Geology

Pre-Alpine Geodynamics of the Caucasus, Suprasubduction Regional Metamorphism and Granitoid Magmatism

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ABSTRACT. It is shown that granitoid magmatism and regional metamorphism of different type, being a reflection of thermobaric field variation in external shells of the Earth, represent a direct consequence of geodynamic settings in various structural units of the Earth's crust and lithosphere of the Caucasus. Geodynamic constructions are based on the conceptions of plate tectonics and horizontal tectonic layering of the lithosphere, which according to geological and geophysical data are established all over the Caucasian region. *© 2007 Bull. Georg. Natl. Acad. Sci.*

Key words: *regional metamorphism, granitoid magmatism, geodynamic settings.*

Introduction

The Caucasus represents a complicated polycyclic geological structure involving mountain foldsystems of the Greater and Lesser Caucasus and adjacent foredeeps and intermountain troughs.

Paleomagnetic and paleokinematic, as well as traditional geological data (character of sedimentation and magmatism, geology and age of ophiolites, paleoclimatic and paleogeographic data) indicate that within the oceanic area of Tethys (with a typical oceanic crust), which separates the Afro-Arabian and Eurasian continental plates, in geological past relatively small continental or subcontinental plates (terranes) were situated, having various geodynamic nature and characterized by specific lithologic-stratigraphic section and magmatic, metamorphic and structural features.

During the Late Precambrian, Paleozoic and Early Mesozoic these terranes underwent horizontal displacement in different directions within the oceanic area of Proto-Paleo-and Mesotethys (Neotethys) and as a result of Variscan, Early Kimmerian, Bathonian and Austrian orogeny they underwent mutual accretion and ultimately joined the Eurasian continent.

The Greater Caucasian, Black Sea-Central Transcaucasian, Baiburt-Sevanian and Iran-Afghanian terranes are identified in the Caucasian segment of the Mediterranean mobile belt, which in geological past represented island arcs or microcontinents (Fig. 1) [3].

In terms of modern structure they represent accretionary terranes of the first order separated by trustworthy or supposed ophiolite sutures of different age. Terranes of the first order, in their turn, consist of great number of subterranes delimited as a rule by deep faults or regional thrusts. They were considered earlier as separate tectonic units (zones) of the Caucasus. Besides, in many places of the Caucasian region there are ophiolite terranes – relicts of the oceanic crust of small or large oceanic basins overthrust (obducted) from the above-mentioned ophiolite sutures.

It should be especially noted that the Earth's crust of the Caucasus is tectonically layered. [2, 4-6].

Similar tectonic layering has recently been reported from many regions of the world. It has also been traced throughout the whole central segment of the Mediterranean mobile belt. One of the authors of this paper (I. Gamkrelidze) had for a long time (1976-1990) been in a position to investigate the nappe structures of the Mediterranean belt and to prove the existence of deep-seated

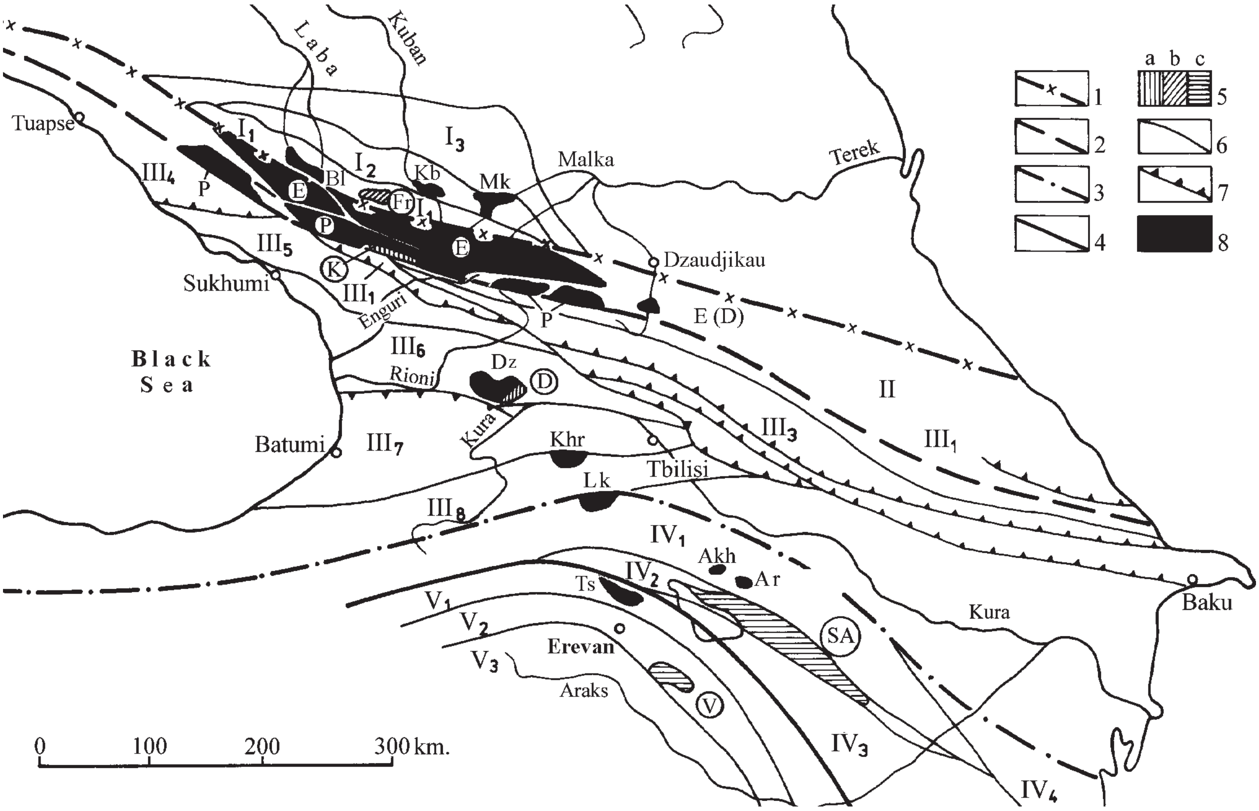


Fig.1. Tectonic zoning of the Caucasus on the basis of the terrane analysis [3] with additions.

I. Part of Scythian platform involved in Neogene time into rising of the Greater Caucasus: I_1 - Forerange zone, I_2 - Bechasyn zone, I_3 – zone of North Caucasian monocline; Accretionary terranes of the first order and subterranes: II - Greater Caucasian terrane; III - Black Sea-Central Transcaucasian terrane. Subterranes: III_1 - Chkhalta-Laila, III_2 - Kazbegi-Tphan, III_3 - Mestia-Dibrar, III_4 - Novorosiisk-Lazarevskoe, III_5 - Gagra-Java, III_6 - Dzirula, III_7 - Adjara-Trialeti, III_8 - Artvin-Bolnisi, III_9 - Middle and lower Kura; IV - Baiburt-Sevanian terrane. Subterranes: IV_1 - Somkhito-Karabakh, IV_2 - Sevan-Akera, IV_3 - Kafan, IV_4 - Talysh; V - Iran-Afghanian terrane. Subterranes: V_1 - Miskhan-Zangezur, V_2-Erevan-Ordubad, V_3 - Araks.

1-4 - ophiolite sutures, marking the location of small and large oceanic basins: 1 – of Early? - Middle Paleozoic age, 2 – of Late Precambrian - Paleozoic age, 3 – of Late Precambrian-Early Mesozoic age, 4 – Mesozoic age; 5 - ophiolite terranes (obduction sheets): 5_a – Late Precambrian age, 5_b - Paleozoic age, 5_c - Mesozoic age; 6 - borders of subterranes (deep faults or regional thrusts); 7 - detached cover nappes; 8 - exposures of pre-Alpine crystalline basement.

Lettered separate exposures: Kb – Kuban, Mk – Malka, Bl – Blib, P - Pass subzone of the Main range zone of the Greater Caucasus, E - Elbrus subzone of the Main range zone, E(D) - Dariali exposure of the Elbrus subzone, Dz – Dzirula, Khr – Khrami, Lk – Loki, Akh – Akhum, Ar – Asrikchai, Ts – Tsakhkunyats.

Letters in circles - Ophiolite terranes (obduction sheets): - Fr – Forerange zone, K - Klich, D - Dzirula, SA - Sevan-Akera, V - Vedi.

nappes in the basement of the Alps, Western and Central East Carpathians, northern Apusenides, Bohemian massif, Rhodopian crystallinicum, Pannonian basin, Transcaucasian massif and crystalline core of the Greater Caucasus [1, 2].

At the same time, this layering was not given due regard in the solution of some geological problems, including petrogenetic modelling, in particular, that of the genesis of Caucasian metamorphites and granitoids.

Just in such an aspect, on the basis of plate tectonic theory and the conception of tectonic layering of the lithosphere, regional metamorphism and granite formation processes are considered in the paper. Suitable natural laboratory, accessible in the Caucasus, provides a basis for the investigation of likely problems.

Paleotectonic Reconstructions and Geodynamic Settings of Metamorphic and Granitoid Complexes Formation

Magmatism and metamorphism of different type, being a reflection of thermobaric field variation in the external shells of the Earth, represent direct consequence of geodynamic settings in various structural units of the Earth's crust and lithosphere. A model revealing tectonic settings of realization of magmatism and metamorphism and their connection with other endogenic processes participating in the formation of the Earth's crust can be constructed exactly on the geodynamic basis [5].

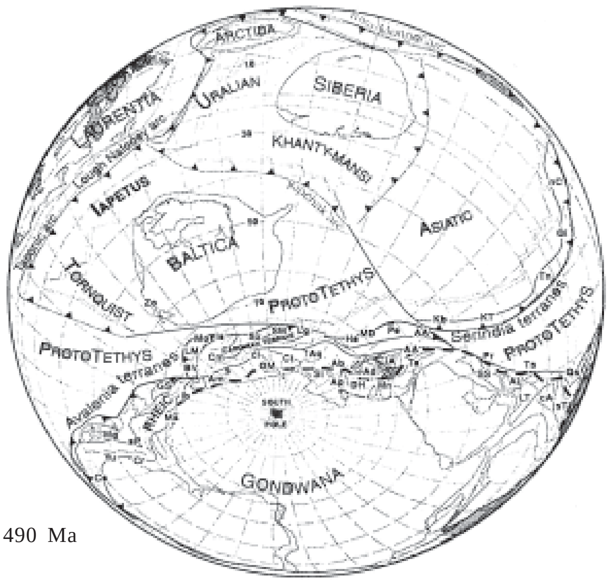


Fig.2. Early Ordovician reconstruction after G. Stampfli and G. Borel (2002). Broken line – place of the opening of the future Paleotethys.

The most important for reconstruction of geodynamic settings is to establish the nature and location of paleooceanic basins. The existence of oceanic realm in the area of the Mediterranian belt in Neoproterozoic is shown by a number of various global reconstructions. The birth of the Prototethys at that time is also confirmed by the existence of ophiolites of Late Precambrian age not only in its southern periphery (the Anti-Atlas, the Arabian-Nubian shield, the Loki, Murguz and Tsakhkunyats massifs), but also in the northern periphery of the belt (the Alps, Bohemian and Dzirula massifs).

The newest plate tectonic reconstructions are made at the global scale [8], as well as for Variscan-Alpine orogeny [7].

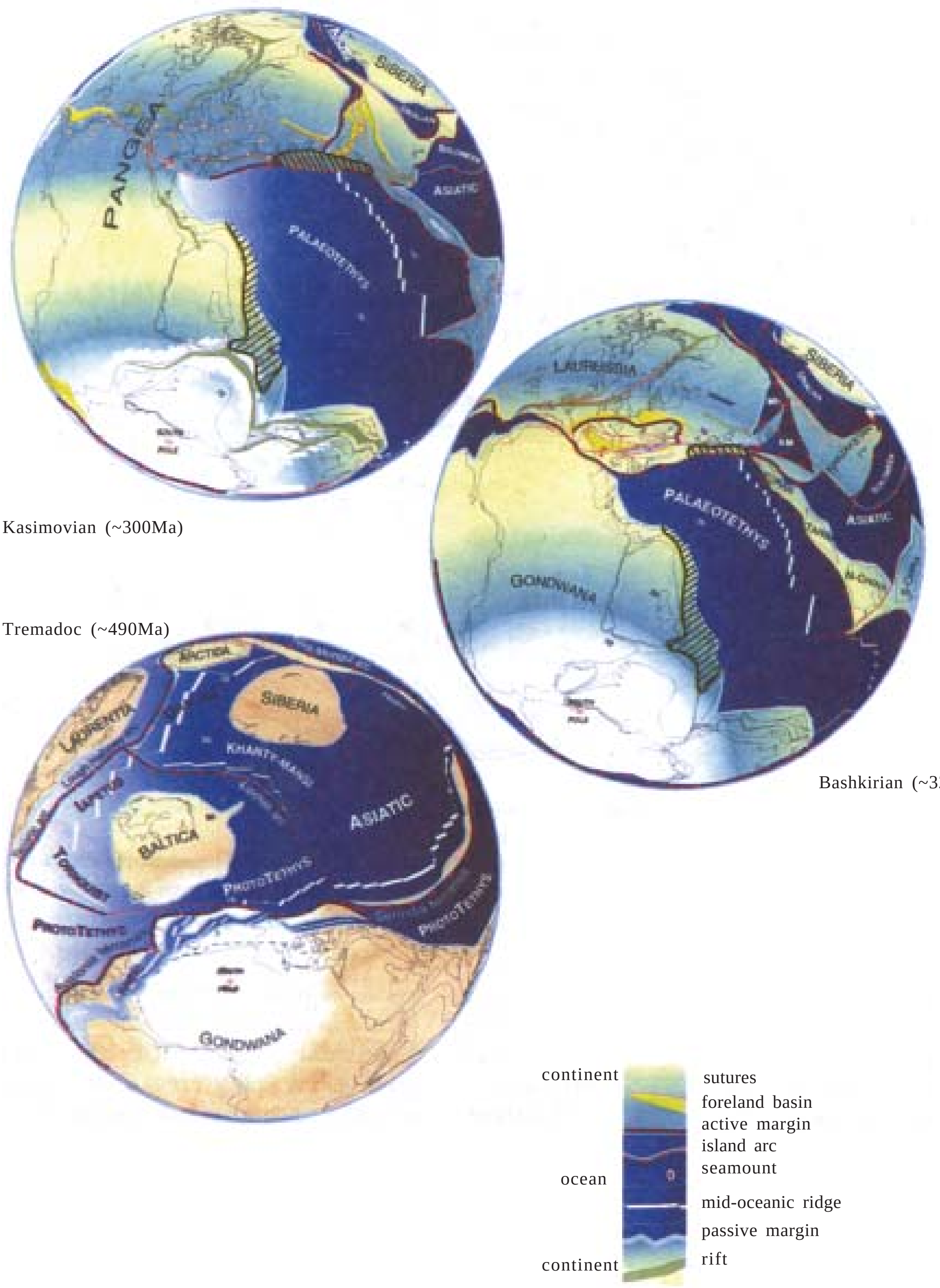
For global plate tectonic reconstructions [8] integrated data on dynamic plate boundaries, ocean spreading rates, restored synthetic oceanic isochrones and major tectonic and magmatic events were used [8]. According to these reconstructions (Fig. 2 - 5) at the beginning of Ordovician (~ 490 Ma. ago), the Prototethys was located in the West between Baltica and Gondwana land and in the East between Gondwana and the so-called Serindia terrane. Later, in Silurian time, on the periphery of the Gondwana land, detachment of the Han superterrane and generation of a narrow rift zone of the Paleotethys ocean took place. Paleotethys location coincides with our supposition about its location in the Caucasian region. In particular, southern terranes of the Caucasian segment of the Mediterranian belt (Iran-Afghanian and Baiburt-Sevanian) are located on the northern periphery of the Gondwana land, but northern ones (Black Sea-Central Transcaucasian and Greater Caucasian) are located in the southern periphery of Laurussia (see Fig. 3 and 4).

This ocean reached the maximum width at the end of Carboniferous (see Fig. 3) and began shortening in Permian (~280-250 Ma. ago) (see Fig. 4) At the rear of the Paleotethys, in the northern periphery of the Gondwana land, Cimmerian superterrane detachment resulted in the generation of the main axis of Neotethys. The Lesser Caucasian bay of this ocean arose later within the Eurasian continent (see Fig. 4), which also completely corresponds to our conception.

Geological information and paleomagnetic data referring to separate regions are not completely applied in these global reconstructions. This has been indicated by the following in the Caucasian region: disregarding the existence of some exposures of Late Precambrian - Paleozoic ophiolites and paleomagnetic data indicated seemingly inheriting the development of the Paleotethys from Prototethys and preserving the relict oceanic basin up to the Middle Jurassic. For this reason the opening line of the future Paleotethys is unnaturally drawn on the northernmost edge of Gondwana (see Fig. 2 and 3). Therefore, in making the palinspastic sections of the Caucasus from the above-mentioned global paleoreconstructions we have used the following data: approximate size of oceans at separate stages of their development, location of big continental masses in the space and absorption age of middle oceanic ridge of the Paleotethys in the subduction zone. Principal attention was paid to specific geological (nature of magmatism, peculiarities of lithologic-stratigraphical section, geology and age of ophiolites), as well as to available paleomagnetic data for the Caucasian region.

The location of the suture line of the Paleotethys Ocean in the Caucasus has been debated for a long time. According to I. Gamkrelidze [1], this line sits between the Black Sea-Central Transcaucasian and Baiburt-Sevanian terranes, i.e. along the northern periphery of the contemporary Somkhit-Karabakh subterrane (see Fig. 2). This is proved by geological and paleomagnetic data, which correspond to criteria of paleomagnetic reliability.

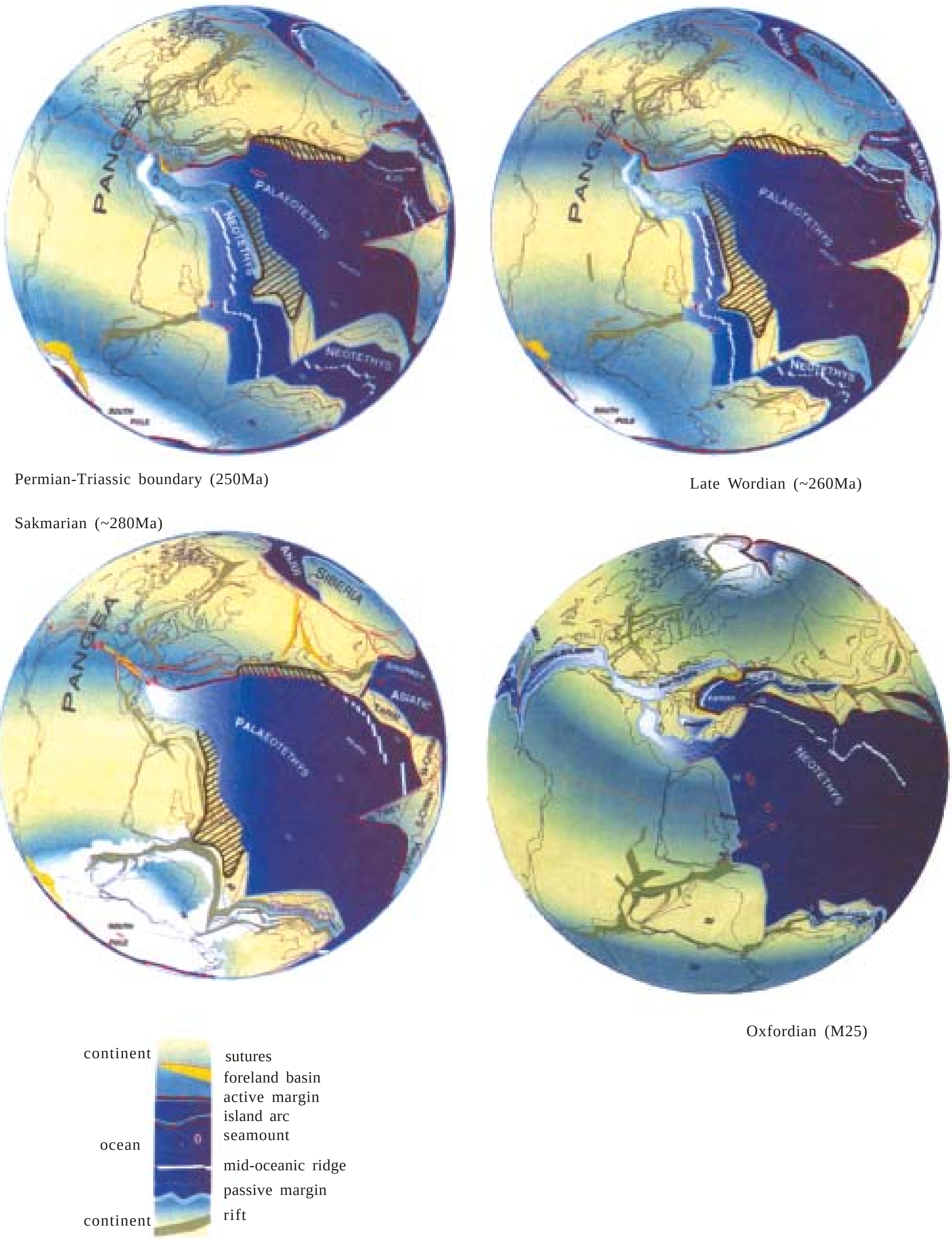
The paleomagnetic data obtained for Carboniferous volcanites of the Dzirula and Khrami massifs with paleolatitude – 12^0-13^0 n.l. is close to the paleolatitude of the southern periphery of the Eastern-European continent in the Late Paleozoic (8-9^0 n.l.), whereas the paleolatitude of rocks of the same age from Daralagez (South Armenia) and Elburs is 22^0 s.l. [9]. Hence, there is quite a large gap taken up by the ocean. This gap, inherited from the Paleozoic, is also preserved here in Triassic and Early-Middle Jurassic. In particular, on the one hand, paleolatitudes of Early-Middle Jurassic rocks of the Loki massif region of the Somkhit-Karabakh zone are 22^0 n.l., and on the other hand, paleolatitudes of rocks of the same age of the Dzirula massif are 27-29^0 n.l. [9]. This fact shows that these two regions in Early-Middle Jurassic were separated from each other by 6-7^0 (see Fig. 6). At the same time these two regions, according to their geological structure, have very different geological history in Paleozoic and Mesozoic. In



Location of southern terranes of the central segment of the Mediterranean belt (Baiburt-Sevanian, Iran-Afghanian).

Location of northern terranes of the same segment (Black Sea-Central Transcaucasian, Greater Caucasian).

Fig.3. Plate tectonic reconstruction after G. Stampfli and G. Borel (2002) with additions.



Permian-Triassic boundary (250Ma)

Late Wordian (~260Ma)

Sakmarian (~280Ma)

Oxfordian (M25)

Fig. 4. Conventional signs see in Fig 3.

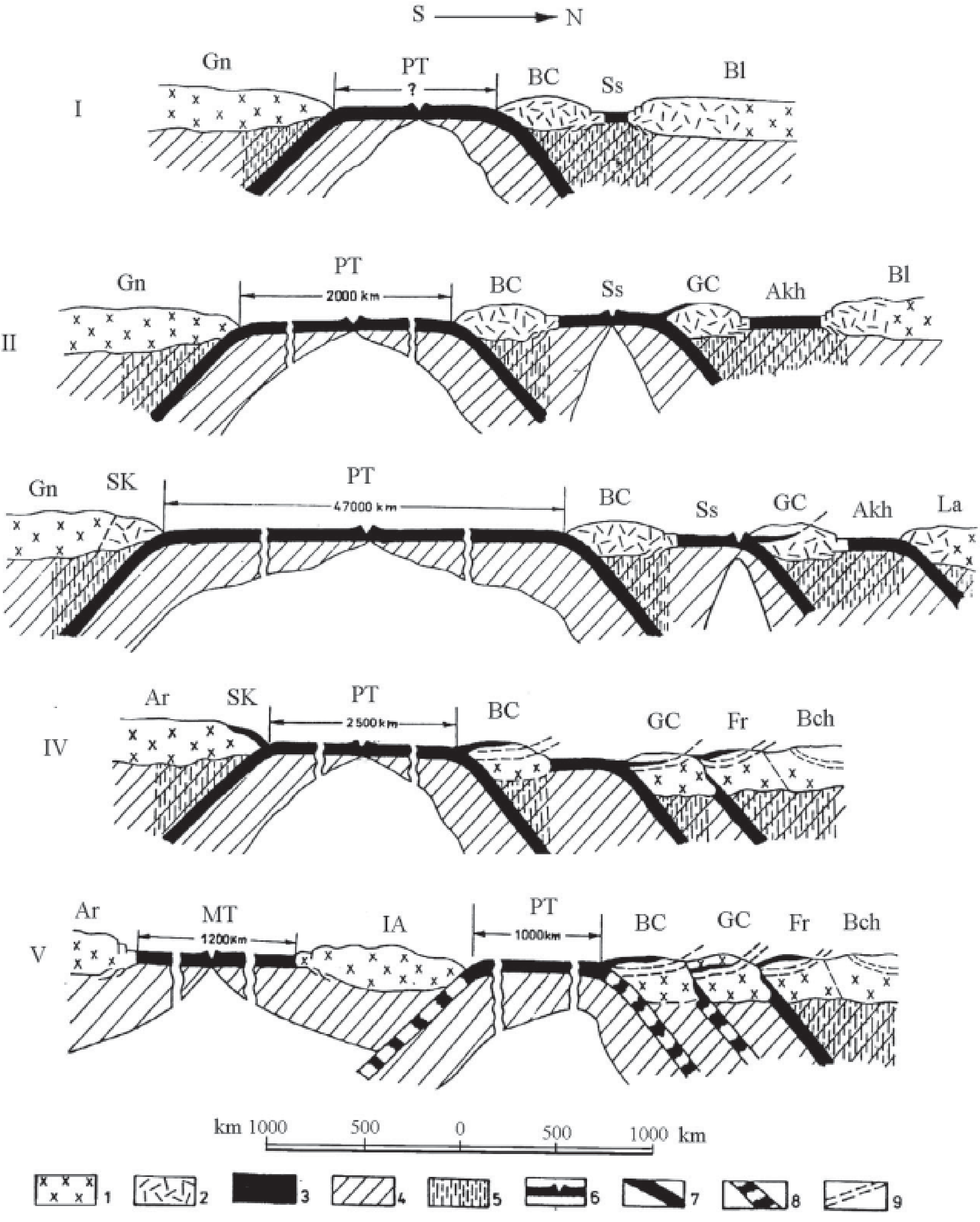


Fig. 5. Schematic palinspastic profiles of the Caucasian segment of the Mediterranean mobile belt for: I. Late Precambrian (Neoproterozoic), II. Late Cambrian, III. Devonian, IV. Early and Middle Carboniferous, V. Late Triassic. (vertical scale is exaggerated approximately five times).

1-continental crust, 2-subcontinental crust, 3-oceanic crust and obducted ophiolites, 4-upper mantle, 5-streams of heat, fluids and magmatic melts in mantle, 6-Middle oceanic ridge, 7-subduction zones, 8- inactive subduction zones, 9-surfaces of tectonic layering of the Earth's crust.

Paleooceanic basins: PT – Proto-Paleotethys, Ss – of the Southern slope of the Greater Caucasus, Akh – Arkhis, MT – Mesotethys. Continental plates: Gn – Gondvana, Bl – Baltica, La – Laurussia, Ar – Arabia. Terranes: BC – Black sea-Central Transcaucasian microcontinent, GC – Greater Caucasian island arc, IA – Iran-Afghanian microcontinent. contemporary tectonic zones: SK – Somkhito-Karabakh, Fr – Forerange, Bch – Bechasin.

particular, the Somkhit-Karabakh zone basement age by all data is purely Variscan, in contrast to the northern part of the Transcaucasian massif and the Greater Caucasus with Grenvilian-Baikalian core. In the Early-Middle Jurassic, contemporary Artvin-Bolnisi and Adjara-Trialeti zones (subterranes) were represented by high-eroded land, but in the south within the Somkhit-Karabakh zone in the Middle-Late Jurassic, calc-alkaline volcanic series accumulated rather intensively.

If these reasonings are correct, it can be supposed that Proto-Paleotethys was developing during the Early Mesozoic, as well, and was closed only in Middle Jurassic (Bathonian) orogeny. In favor of such assumption we refer to: the existence of serpentinite melange in the eastern periphery of the Loki massif (very close to the supposed ophiolite suture), transgressively overlain by Late Jurasic turbidite-olisostrome suite and data about ophiolites of Northern Anatolia that directly follows the supposed ophiolite suture, where the number of geologic, paleobiogeographic and paleofloristical data also indicate the existence of the oceanic basin of the Paleotethys developing in Early Mesozoic, as well.

The existence of Paleozoic or older oceanic basins is supposed as being in the area of the contemporary Greater Caucasus (Fig. 5). It is confirmed by the Paleozoic ophiolites in the Fore Range zone and the Klich, Kassar and Damkhurts ophiolitic sheets and their analogues in the Greater Caucasus Main Range zone. The location of this oceanic basin (or basins?) is debatable.

Data on magnetic anomalies indicating spreading of the ophiolite belt of the Northern Caucasus show that side by side with oceanic basin, located to the south from the contemporary Main Range zone, in Early and Middle Paleozoic between the contemporary Fore Range and Main Range zones another, the so-called Arkhiz oceanic basin was located representing the “motherland” of ophiolite nappes of the Fore Range zone. With the consideration of zircon age of the Buulgen complex amphibolites (600±20 Ma), the existence of N-MORB type rocks in composition of Klich, Kassar and Damkhurts ophiolitic sheets, as well as paleomagnetic data, can be assumed, that the Southern Slope oceanic basin of the Greater Caucasus was laid in Late Precambrian as relatively small spreading basin. As a relict of this basin, most part of which was “absorbed” in the subduction zone along the southern edge of the Greater Caucasian island arc, Paleozoic-Triassic deposits of dizi series can be considered to be formed on the southern passive margin of this ocean under conditions of continental slope [5].

Later (apparently in Early-Middle Paleozoic) the Arkhiz basin began to develop. Judging from the nature of the volcanic complex of the Fore Range zone ophiolite association, this basin belonged to the marginal sea type.

In Neoproterozoic and Paleozoic under suprasubduction conditions on the peripheries of the above-mentioned large and small oceanic basins regional metamorphism and granite formation took place.

The evidence of the oldest regional metamorphism in the Caucasus can be observed in Tsakhunyats massif of the Iran-Afghanian terrane, the lower structural stage of which is part of Middle Proterozoic and older craton. However, within the Caucasian segment of the Alpine belt, signs of the oldest regional metamorphism (Grenvilian) we can observe in the gneiss-migmatite complex of the Dzirula massif, of the Greater Caucasus Main Range zone and, apparently, of the Khrami massif [5].

The main stages of regional metamorphism and granite formation are bound up with Grenvilian, Baikalian (Panafrican), Late Baikalian (Salairian), Early and Late Caledonian and Variscan orogeny. They were stipulated by the functioning of subduction zones by both sides of Proto-Paleotethys and along the northern peripheries of comparatively small oceanic basins of the Arkhiz and Southern Slope of the Greater Caucasus [5].

Regional metamorphism, mainly of low and moderate pressure and correspondingly high and moderate temperature, and formation of pre- and synmetamorphic granitoidic complexes of sodium series took place in pre-Variscan time, in the northern and southern continental margins of the Paleotethys. It should be noted that according to new data here in places heightened and high pressure metamorphism are observed. In the Late Baikalian orogenic phase, the same events took place also in the northern periphery of the oceanic basin of the Southern Slope of the Greater Caucasus.

Since the Middle Paleozoic subduction began to appear also along the northern periphery of the Arkhiz marginal sea (see Fig. 5). However, the existence of the spreading zone in the basin seems to be doubtful. Consequently, it is more accurate to use the term pseudosubduction, which, as is generally known, means that subduction is not in direct connection with spreading.

Processes of regional metamorphism with P-T conditions analogous to pre-Variscan metamorphism are connected with Variscan orogeny. Although in the deepest subsided parts of metamorphic complex (the Blib autochthonous complex of the Fore Range zone) and in the sole of the Shaukol nappe in the Bechasyn zone high baric type of metamorphism is established. At the same time, intensive tectonic layering of the Earth’s crust and formation of granitoids, mainly of potassic series, took place. This orogeny covers a range of geological time from the latest Devonian (Famennian) to Late Visean (about 17-18 Ma.). Due to the existence of appointed succession of vital geological events in clearly limited time intervals, manifestation of several orogenic phases can be assumed in the Caucasus. Specifically, with the Early Variscan (Bretonian) orogeny (at the end of Devonian and beginning of Early Carboniferous), regional metamorphism of the most Lower-Middle Paleozoic rocks of the Caucasus and formation of synmetamorphic granitoids is connected. Also we assume the evidence of Saurian orogeny (seemingly in Turneasian), which corresponds to the most important pre-Alpine time of nappe formation in the Caucasus. And here, at last, Late Variscan orogeny with processes of intensive granite formation is established.

During the Saurian orogeny, dynamic events were the most important, provoking, in the first place processes of tectonic layering of the Earth's crust and its shortening, which in their turn provoked the origin of additional dissipative heat and melting of potassic granites in Late Variscan time. With Saurian phase there coincides overthrusting of ocean crust fragments of Proto-Paleotethys on the Black Sea-Central Transcaucasian microcontinent together with sedimentary rocks formed within its continental slope (the Chorchana-Utslevi complex). In the Saurian phase, overthrusting of metamorphic sheets of the Loki massif, including Precambrian ophiolites, and ophiolites of the Akhum and Asrikchai inliers on the other, southern continental periphery of the Paleotethys took place.

The formation of the system of N-vergent nappes of the Fore Range zone (including ophiolite nappes), S-vergent nappes of the Khasaut synform of the Bechasyn zone, and also overthrusting of large Macera nappe from the Pass sub-zone to the Elbrus sub-zone of the contemporary Main Range zone of the Greater Caucasus were connected with the same orogeny.

The next, Late Variscan (Sudetic) orogeny was the time of the formation of all the potassic granites (except the Pass sub-zone poor in K granitoids) in the Caucasian region, of regressive metamorphism of constituent rocks, and of the origin of true continental crust in it. These processes were connected with activities of all subduction zones.

At the very end of the Variscan orogeny, extraordinary fast (instantaneous in a geological sense) exhumation of deeply subsided parts of the Earth's crust took place. The first pebbles of microcline granites of the Main Range zone, forming in the depth of 4-5 km, in Upper Paleozoic neoautochthonous complex of the Fore Range zone, already appear in Middle Carboniferous (in Westphalian). The same situation can be observed in the Dzirula crystalline massif, where the clastic material with fragments of Late Variscan microcline granites are observed in the upper part of the neoautochthonous complex including the period – Upper Visean – Upper Carboniferous – Permian (?). All these show that within the Black Sea-Central Transcaucasian and Greater Caucasian terranes exhumation of Late Variscan granites took place mainly at the end of the same orogeny. Such instant raising of the crust and exposure of abyssal rocks can be attributed to the summary manifestation of isostasy processes, conditioned by high buoyancy of the consolidated crust lightened by that time, its shortenning and intensive erosion.

An Andian type large volcanic belt existed in Late Paleozoic on the southern periphery of Eurasian plate developing during Late Permian-Triassic. Hence, it could be assumed that at that time the activity of the northernmost subduction (pseudosubduction) zone was preserved (see Fig. 5). Later, in the Early, Middle and Late Jurassic subduction zones functioned along the northern and southern peripheries of the relict basin of the Paleotethys, where the formation of very thick volcanic series of calc-alkaline composition took place.

Considerable tectonic movements in the Caucasus were manifested during Early Cimmerian (Indosinian) orogeny. In the greater Caucasus this phase featured overthrusting of Paleozoic dizi series to the north, as well as overthrusting of the Elbrus sub-zone infrastructure to the south – into the Pass sub-zone. Early Cimmerian orogeny took place in the Dzirula, Loki, Akhum and Asrikchai massifs, where it causes a folding of Early-Middle Paleozoic metamorphites and intensive milonitization of the Dzirula massif microcline granites.

Thus, Early Cimmerian orogeny, which occurred almost in all terranes of the Caucasus, completes the formation of the structure of its metamorphic basement.

The specifics of some of regional metamorphism and granite formation processes in separate terranes of the Caucasus is worth mentioning. In particular, all terranes of the first order (superterranes), as well as the southern edge of the Scythian platform are characterized by manifestation of polymetamorphism processes, though in various terranes, which differ from each other by geological structure and history, separate stages of regional metamorphism became unequally apparent. For instance, Grenvilian regional metamorphism is observed only in the Greater Caucasian, Black Sea-Central Transcaucasian and Iran-Afghanian terranes, whereas the Baikalian metamorphism can be observed only in the Scythian platform and Iran-Afghanian terranes. Late Baikalian metamorphism took place only in the Greater Caucasian and Black Sea-Central Transcaucasian terranes. Caledonian regional metamorphism strictly characterizes the Scythian platform and the Greater Caucasian terrane. Early Variscan (Bretonian) metamorphism is observed almost in all terranes of the Caucasus, excluding the Iran-Afghanian terrane, and southern edge of the Scythian platform. Late Variscan metamorphism also comprises almost the whole Caucasus excluding the Fore-Range zone (Scythian platform) and Iran-Afghanian terrane.

Within separate terranes, as well as in the Scythian platform, synchronously or almost synchronously with principal stages of metamorphism (connected with the main phases of tectogenesis), formation of pre-syn- and postmetamorphic granitoids of different type took place.

Observed occurrence at different times and diversity of endogenic activity in various terranes of the Caucasus show the asynchronism of episodic activity of subduction zones on different sides of the oceanic basins separating these terranes.

გეოლოგია

კავკასიის ალპურამდელი გეოდინამიკა, რეგიონული მეტამორფიზმი და გრანიტწარმოშობა

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მოყვანილია ახალი გეოლოგიურ-პეტროლოგიური მონაცემები, რომლებიც მნიშვნელოვნად ცვლის წარმოდგენებს კავკასიის ალპურამდელი კრისტალური ფუნდამენტის ამგები ქანების ასაკისა და ურთიერთდამოკიდებულების შესახებ. განხილულია აგრეთვე პოლიციკლური რეგიონული მეტამორფიზმის და სხვადასხვა ასაკის გრანიტოიდული კომპლექსების ხასიათი.

ნაჩვენებია, რომ სხვადასხვა ტიპის გრანიტოიდული მაგმატიზმი და რეგიონული მეტამორფიზმი, ასახავს რა დედამიწის გარე გარსებში თერმობარული ველის ცვალებადობას, წარმოადგენს კავკასიის დედამიწის ქერქისა და ლითოსფეროს სხვადასხვა სტურქტურულ ერთეულში გეოდინამიკური პირობების უშუალო შედეგს. გეოდინამიკური რეკონსტრუქციები ეფუძნება ფილების ტექტონიკისა და ლითოსფეროს ჰორიზონტალური ტექტონიკური განშრევების კონცეფციებს, რომლებიც გეოლოგიური და გეოფიზიკური მონაცემების თანახმად დასტურდება მთელ კავკასიის რეგიონში.

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