Geography of the Physical Environment

Nana Bolashvili
Vazha Neidze *Editors*

The Physical Geography of Georgia

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The Physical Geography of Georgia

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Preface

Physical environment plays decisive role in formation of the people's individuality and way of life. Implementation of new territorial system must serve to well-being of people, revival of economy, and formation of powerful state.

Until recently, knowledge of Georgia was limited, as this now-independent country had been part of the Soviet Union until 1991. Georgia is well-known for its hospitality, wine, and cuisine, and also for the mountain peaks of the Caucasus which reach above 5000 m. Otherwise few people know that there are different languages and ethnic groups in Georgia, that a separate Georgian alphabet exists and that Georgia has a fascinating history of more than 2000 years.

Physical Geography of Georgia presents detailed information with text and accompanying maps for the scientists and students interested in this country.

The scientific and cartographic depictions of Georgia by Georgian scholars date back to the first half of the 18th century. Prince Vakhushti, a family member of King Vahkhtang VI Bagrationi of Kartli (the core region of Georgia), prepared a geographical description of Georgia and adjacent territories as well as geographical atlases. Vakhushti had compiled two manuscript atlases of Georgia, and the maps by Vakhushti evoked strong interest in Russia and Europe. In 2013 the "*Description of Georgian Kingdom*" and the "*Geographical Atlas*" of Vakhushti Bagrationi were registered in UNESCO's, Memory of the World documentary program.

The current book was prepared by the Institute of Geography of Tbilisi State University. The institute, named for Vakhushti Bagrationi, was founded in 1933 and has developed broad experience in carrying out research work. The staff members of the institute have a rich experience in publishing various monographs (complex, sectoral, academic, educational, popular science, etc.) on the geography of Georgia. Under its guidance number of similar publications have been prepared and published in Georgian: *Geography of Georgia* (Part 1—*Physycal Geography* (2000), Part 2—*Social-Economic Geography* (2003)), which is characterized by thoroughly aggravated natural-ecological, political, socio-economic, and demographic situation; *Geography of Georgia* (2013), which unlike the two-volume addition mentioned above, is the first complex work covered both the issues of Physical as well as Human Geography. The monograph discusses the

geographical location, natural conditions, political-geographical, ecological, and socio-economic situation of the country.

The current book represents a strongly revised, updated, and completed edition of the *Geography of Georgia*, published in the Georgian language in 2013. Many scientists of Tbilisi State University (TSU) contributed with new research results. The texts, tables, and maps contain data from the following Georgian statistical sources: the National Statistics Office of Georgia, the Agency of Protected Areas, and the Georgian National Tourism Administration. The main part of the book was performed by the researchers of the institute, but some of the paragraphs were written by the invited qualified specialists from different fields.

The presented work will render significant assistance to the economic, scientific, and educational fields of the country.

Tbilisi, Georgia

Nana Bolashvili
Vazha Neidze

Acknowledgements I would like to express my gratitude to all of those with whom I have had the pleasure to work duringthis project.I am grateful to Ms. Nino Chikhradze for the translations of several chapters.

Contents

Location, Territory, Boundaries

1

Vazha Neidze

Abstract

In this chapter patterns of location, territory and boundaries are discussed. Located in the border area between Europe and Asia, Georgia occupies the central and southern parts of the Southern Caucasus. Configuration of the state's territory has a certain importance for the economic and political development of the country. Georgia has an elongated form, the length of the diagonal which is over 600 km. Except for the state border with Turkey, the number of sections of boundaries with the rest of its neighbors (Russia, Armenia, and Azerbaijan) are still controversial and create a conflict situation. Georgia is distinguished by significant advantages of the number of characteristics of geographical locations compared with the neighboring countries. The issue of Georgia's location is controversial among the experts because the Caucasus is located at the Eurasian crossroad.

1.1 Territory

Georgia is located in the border area of Europe and Asia, which is historically known as the "Caucasus neck". It occupies the central and southern parts of the Southern Caucasus. From the point of view of mathematical-geographical location, Georgia is situated between 41°07′–43°35′ N and 40°05′–46°44′ E.

Historically the area of the territory of Georgia has significantly decreased. In the second half of the seventeenth century, it was 133.1 thousand km^2, at the end of the nineteenth century (in 1886)—102.0 thousand km^2, during the first democratic republic (1918–1921)—91.1 thousand km^2, and during the Soviet period the country lost 20.4 thousand km^2. Currently, the area of the territory of Georgia is 69.7 thousand km^2. According to the size of the territory, the following European countries are far behind Georgia: Netherlands, Switzerland, Belgium, Denmark, Croatia, Bosnia and Herzegovina, Slovenia, Slovakia, Luxembourg, Montenegro, Macedonia, Albania, Moldova, Latvia, Lithuania, and Estonia.

Configuration of the state's territory has a certain importance for the economic and political development of the country. It defines the characteristics of the transport network, internal regional connections, and borderline peculiarities; it affects the border protection, relations with neighboring countries, development of military

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strategy, etc. Conditionally, Georgia has an elongated form, the length of the diagonal which is over 600 km. The parts of its extremely narrow corners are occupied by Gagra (in the northwest) and Dedoplistskaro (in the southeast) regions (municipalities). The geographical center of the country is in Imereti (Kharagauli municipality, at the place of confluence of the Rikotula and Satevzeghele Rivers).

The extreme points of the territory of Georgia are: in the north—Aibga Village, in the south—Eldari valley, 1400 m away from Mingachevir reservoir, in the west—Leselidze town, in the east—7 km away from the Sabatlo Village in the southeast which is mentioned as, "Mosabruni" by Vakhushti Bagrationi (Turmanidze and Tsitsagi 2017).

Mainly Georgia is a mountainous country. It is distinguished by complex orographic diversity and an abundance of attractive objects for tourism. Table 1.1 shows the distribution of the territory of Georgia according to the hypsometric levels.

1.2 Borders

The boundaries of a number of countries have been formed on the basis of natural barriers (orographic, hydrographic, and marine). The same is true about Georgia, historical territory which is an entire physical-geographical body surrounded by natural boundaries, according to the opinion of Georgian researchers (P. Ingorokva, I. Javakhishvili, A. Manvelishvili, and others); in the north, it is bordered by the Caucasian Range, in the west—by the Black Sea, in the south—by the "Armenian Upland, from which it is separated by one continuous system of snowy mountains and only with one narrow mouth—from the southeast—Georgia adjoins the Azerbaijan Plain, but even from here it is divided by Hereti desert steppes and Mtkvari—the Rhine of Georgia" (Ingorokva 1990).

Thanks to these natural barriers during the long history "Georgians managed to repel numerous and often more powerful enemies and rescued. The enemies of Georgia also understood this circumstance and therefore, it was very often that they tried to hold and remove the border corners from the territory of Georgia" (Javakhishvili 1919). But for centuries Georgia still "managed to save and protect its territory in natural boundaries" (Manvelishvili 1938).

Over time, along with the reduction of the territory of the country, the boundaries were modified too. For the last two centuries for the country, which was as a part of the Russian Empire and Soviet Union, the legal concept of

Table 1.1 Distribution of the territory of Georgia according to the hypsometric levels (Kekelia et al. 2004)

Hypsometric levels (m)	Territory	
	km^2	%
0–200	7955.4	11.4
200–400	5870.2	8.5
400–600	6512.7	9.3
600–800	6393.5	9.1
800–1000	5480.5	7.8
1000–1200	5358.0	7.7
1200–1400	4638.6	6.7
1400–1600	5073.1	7.3
1600–1800	4653.6	6.7
1800–2000	4239.1	6.1
2000–2200	3906.9	5.5
2200 and higher	9575.3	13.8
Total	69.657	100

the state border was erased. And today, as in 1918–1921, it is a determining factor of sovereign state. Unfortunately, except for the state border with Turkey, the number of sections of boundaries with the rest of its neighbors (Russia, Armenia, and Azerbaijan) are still controversial and create a conflict situation (Neidze 2013).

The westernmost border of Georgia starts at the Black Sea, at the confluence of the Psou River, goes along the river and then goes up to the Mount Agepsta (3256 m). The current territory of the country is mainly stretched from the Mount Agepsta to the Mount Tinovroso in the south of the crest of the main watershed of the Caucasus, but on the section between the mountains of Zilgakhokhi and Shaviklde, the territory of Georgia is spread in the basins of the rivers of Tergi, Asa, Arghuni, and Sulaki (Andis-Koisu) through the northern slopes of the Caucasus. The eastern border of the country begins from the Mount Tinovroso and goes down to the Alazani River, and then runs along the Alazani River almost to the confluence of the Mingachevir water reservoir.

The southern border begins on the Black Sea coast at the village of Sarpi, crosses the end of the northeastern part of the Pontic Range and the downstream gorge of the Chorokhi River, goes along the crest of the Shavsheti Range, crosses the Arsiani Range, goes up to the Erusheti highland with the Potskhovistskali River, crosses the Mtkvari River and Kartsakhi Lake, and the borderline ends near Turkey, at the Mt. Erakatar (3008 m). Then the border with Armenia crosses the river of Debeda passing through the Mt. Okuzdag (2441 m), Mt. Akhchala (3196 m), Mt. Loki, and Mglis Chishkari Pass, goes down the Kvemo Kartli plain, and ends at the Babakiari Range. Further, Georgia-Azerbaijan borderline crosses the Jandari Lake, goes round David Gareja from south, and heads to the Mingachevir water reservoir (Kekelia 2000) (Table 1.2).

1.3 Location

One of the most important notions of geography —the geographical location has a broader content. First of all, it determines the location of

Table 1.2 The main indicators of the borders of Georgia (Nikolaishvili et al. 2009)

Total length of the border, km	2114.78
The length of the land border, km	1802.07
The length of the marine border of territorial waters, km	297.89
The length of the coastal line, km	312.89
The width of territorial waters, nautical mile	12
The width of continental shelf, nautical mile	350
Border length with bordering countries (km)	
Russian Federation	897.7
Krasnodar Krai	84.25
Karachay-Cherkessia	197.14
Kabardino-Balkaria	126.46
Alania	183.94
Ingushetia	52.87
Chechnya	86.37
Dagestan	166.67
Azerbaijan	428.42
Armenia	210.57
Turkey	266.01

country, region, and so on, toward the other territories, which is contextually revealed in their relationship and interconnection. In its description, except for normal indicators (for example, distances), is essential to analyze economic, political, and ecological relations, which, in addition, requires historical understanding.

Georgia is distinguished by significant advantages of the number of characteristics of geographical locations compared with the neighboring countries. In particular, its seaside location is outstanding, which allows direct connections with the world's maritime states; and the central location in the Caucasus region determined choosing Tbilisi—the country's main city as a residence for the Caucasus government (Viceroy)—being a part of Russian Empire. The Caucasus Mountain Range in the north has also a major climate-division role for the country, which is a natural barrier (protects from the incoming cold air masses from the north), and it is a northern border of Georgia's subtropical zone. Generally, the location of Georgia in the southern latitudes (so-called mathematical-geographical location) leads to the convenience of the natural environment of Georgia in creation of optimal conditions of life for the population. These circumstances have always caused the envy of intruded enemy and their desire to conquer the territory.

The issue of Georgia's location is controversial among the experts because the Caucasus is located at the Eurasian crossroad. Several variants are considered, or the most common viewpoints (Radvani and Beruchashvili 2011):

- The border between Europe and Asia goes along the Kumo Manych depression, which in the past connected the Black and Caspian seas. According to this concept, unity of the Caucasus Range and its northern foothills is a part of Asia;
- Others draw this margin with Iran and Turkey on the political boundaries of the South Caucasus states and assigned the whole Caucasus to Europe;
- The majority of geographers draw the border over the crest of the main ridge of the Caucasus, the main climate boundary, and hydrographic watershed. In this case, the region is divided between Europe and Asia. However, political and physical boundaries do not coincide with each other. With this version, much of Georgia's territory get in Asia, and the parts of the territories of a number of historical–geographical provinces of the country (Khevi, Khevsureti, and Tusheti) are located on the northern slope of the ridge—in Europe;
- According to Herodotus, the border between Europe and Asia is created by the rivers of Rioni and Mtkvari, because of which the territories located north from them he assigned to Europe.

According to the general characteristics of spatial location, Georgia has:

1. A central location in the Caucasus region;
2. A peripheral location toward the European countries; and
3. A neighboring (border) location toward Turkey, Russian Federation, Azerbaijan, and Armenia, which directly border our country.

The emergence of geographical mega and macro locations of Georgia (previously they did not exist), formation of the country as an independent state, attempts to escape the Russia's sphere of influence or integration with the west, as well as the aims of NATO to expand the southern boundaries, conditioned the representation of small Georgia in the political map as a supposed outpost in the southeastern most part of the Europe (Fig. 1.1).

Georgia's meso location should be assessed on the common background of the Caucasus and its bordering, as well as the economic and political relations between the Black Sea region countries and the overall situation. And micro-location requires the analysis of economic-geographical, political, and military-strategic situations of the border regions of Georgia and its separate regions in relation to neighboring

Fig. 1.1 Political-geographical location of Georgia (National Atlas of Georgia, Steiner-Verlag, 2018)

countries. For example, in the north, Georgia is bordered by the Russian Federation, which is actually represented by the autonomous units with non-Russian nationalities. This almost non-contact border area of 820 km long (except the part of contact section of the Apkhazeti Psou, which is now cut off from the country), is less favorable for the economic union, because only three passes (Mamisoni, Rocki, and Jvari) crossing Transcaucasian roads' complex natural conditions and tense conflict situations are characterized as unsustainable. It has evidently improved microlocations on the border regions of Turkey. Among them, the "Sarpi Gate" (Achara), border road of Akhaltsikhe (Samtskhe)—Artaani, and "Kartsakhi Pass" (Javakheti) are notable, which promote the development of Turkey-Georgia relations in the light of the intensification of economic ties (Neidze 2003).

In addition to the physical–geographical (relief, climate, and Black Sea) and political factors, while characterization of location of Georgia, it is also necessary to consider the historical experience and mentality of Georgian people (self-sacrificing struggle for protection of Christianity and aspiration to European cultural values). It can be said that Georgia is located in the south-eastern most part of Europe.

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Geology

2

Irakli Gamkrelidze

Abstract

This chapter presents the general overview of country's geology. The territory of Georgia is a component of the Caucasian segment of the Mediterranean (Alpine-Himalayan) collisional orogenic belt. Lithological character of the sedimentary rocks and composition of submarine volcanites are quite different within the different tectonic zones of Georgia. The territory of Georgia, as a part of the Caucasus, underwent a long and complicated tectonic evolution and contains structures of various types, scales, and genesis. The chapter also discusses the main features of the geodynamic evolution of the Caucasus.

2.1 Introduction

The territory of Georgia is a component of the Caucasian segment of the Mediterranean (Alpine-Himalayan) collisional orogenic belt. Within the territory of the Caucasus, accretionary terranes are distinguished, which are characterized by a specific lithological-stratigraphic section and magmatic, metamorphic and structural features (Fig. 2.1).

At the same time, the latest geodynamic settings were created in Mesozoic and Early Cenozoic times when post accretionary formations in places overlapped the borders of older terranes. For example, formations of Mesozoic-Early Cenozoic marginal sea of the Greater Caucasus overlapped the northern margin of the Black Sea-Central Transcaucasian terrane (Gagra-Java and Chkalta-Laila subterranes or zones), were involved in rising of the Greater Caucasus and formed Southern part of the contemporary fold system of the Greater Caucasus. Besides, in Late Alpine, the west and east parts of the Dzirulasubterrane turn into intermountain molassic depression (Kura and Rioni) separated by central elevation zone (the Dzirula massif).

2.2 Stratigraphy and Rock Types of the Different Tectonic Units of Georgia

So long as the degree of metamorphism, lithological character of the sedimentary rocks, and composition of submarine volcanites are quite different within the different tectonic zones of Georgia, the stratigraphic units are considered to

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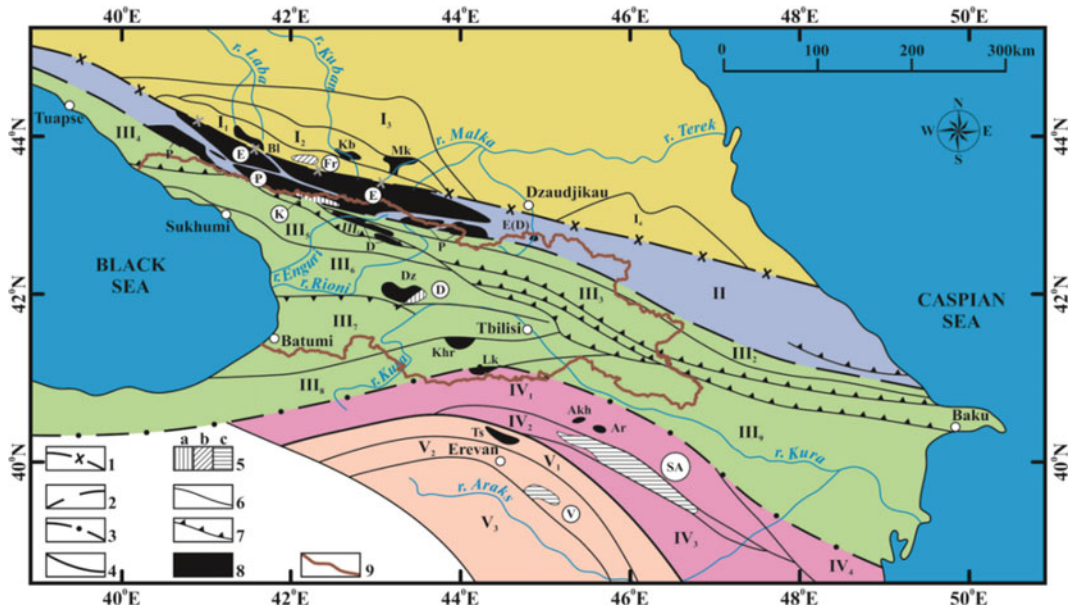

Fig. 2.1 Tectonic subdivision of the Caucasus on the basis of terrane analysis and exposures of the pre-Alpine crystalline basement (Gamkrelidze 1997a; Gamkrelidze and Shengelia 2005; Gamkrelidze 2016). Key: I = Part of Scythian platform involved in Neogene time into rising of the Greater Caucasus); I1 = Forerange zone, I2 = Laba-Malka (Bechasin) zone, I3 = zone of North Cauasian monocline, I4 = Daghestan Limestone zone. Accretionary terranes and subterranes: II = Greater Caucasian terrane; III = Black Sea-Central Transcaucasian terrane. Subterranes: III1 = Chkalta-Laila, III2 = Kazbegi-Tphan, III3 = Mestia-Dibrar, III4 = Novorosiisk-Lasarevskoe, III5 = Gagra-Java, III6 = Dzirula (Georgian Block), III7 = Adjara-Trialeti, III8 = Artvin-Bolnisi, III9 = Middle and Lower Kura; IV = Baiburt- Sevanian terrane. Subterranes: IV1 = Somkhito- Karabakh, IV2 = Sevan-Akera, IV3 = Kafan, IV4 = Talysh; V = Iran-Afghanian terrane. Subterranes: V1 = Miskhan-Zangezur, V2 = Erevan-Ordubad, V3 = Araks. 1 = borders of terranes-ophiolite sutures (here and there presumable) marking the location of small and large oceanic basins: 1 = of Early?-Middle Paleozoic age, 2 = of Neoproterozoic-Paleozoic age, 3 = of Neoproterozoic-Early Mesozoic age, 4 = of Mesozoic age; 5 = ophiolite terranes (obducted plates): 5a = of Neoproterozoic-Paleozoic age 5b = of Paleozoic age, 5c = of Mesozoic age; 6 = borders of subterranes (deep faults or regional thrusts); 7 = detached cover nappes of Alpine age; 8 = exposures of pre-Alpine crystalline basement: GC = Greater Caucasian, D = Dizi series of the southern slope of the Greater Caucasus, Dz = Dzirula, Khr = Khrami, Lk = Loki, Akh = Akhum, Ar = Asrikchai, Ts = Tsakhkunyats; 9 = boundary of the territory of Georgia

be within separate tectonic zones (Gamkrelidze 1997b, 2016; Gudjabidze 2003).

The pre-Alpine metamorphic complexes outcrop within the Greater Caucasus (Main Range and southern slope zones), in the Black Sea-Central Transcaucasian terrane (Dzirula and Khrami massifs), and within the Baiburt-Sevanian terrane (Loki massif) (Fig. 2.1).

The oldest (Precambrian and Lower-Middle Paleozoic) rocks are exposed in all the tectonic units (Fig. 3.1). They are represented by gneisses, migmatites, crystalline schists, and amphibolites within the Main Range zone of the fold system of the Greater Caucasus, the Georgian Block (in the so-called Dzirula massif), and the fold system of the Lesser Caucasus (in the so-called Khrami and Loki massifs) (Gamkrelidze and Shengelia 2005). Paleozoic rocks are exposed in the central part of the southern slope of the Greater Caucasus as well. They are represented mainly by black shales, phthanites (cherts), sandstones, turbidites, olistostromes, lenses of marbles, and calc-alkaline andesite-daciticvolcanoclastics. Their visible thickness reaches 2000 m. This is the so-called Dizi Series, in which faunally (by corals, foraminifera, and

conodonts) the Devonian, Carboniferous, and Permian are established. Comparatively weakly metamorphosed Paleozoic sediments are exposed in the Dzirula massif as well. These are the allochthonous plates of the so-called "phyllitic suite", which are in contact with Upper Paleozoic granitoids and Paleozoic and Precambrian gabbro- amphibolites and serpentinites. The latter are meta-ophiolites (Gamkrelidze et al. 1981). Precambrian and Paleozoic meta-ophiolites within the crystalline core of the Greater Caucasus and in Somkhito-Karabakh zone (in the Loki massif) are present as well.

The Upper Paleozoic rocks are also developed in all tectonic units. In the Main Range zone, crystalline rocks are overlain by weakly metamorphosed sandstones, conglomerates, and argillites, which contain Upper Carboniferous-Lower Permian marine fauna (marine molasse).

Continental and coastal calc-alkaline rhyolitic volcanic rocks and coal-bearing argillites with lenses of reef limestone are known in the Dzirula and Khrami massifs. Lower-Middle Carboniferous corals, brachiopods, foraminifers, and terrestrial flora have been found in this formation in the Khrami massif.

Mesozoic and Cenozoic formations are developed in all tectonic units of Georgia (Gamkrelidze 1997b, 2016; Gudjabidze 2003).

Triassic sediments are observed in the Dizi Series apart from the above-mentioned Upper Paleozoic deposits. To the Triassic also belong dacitic-rhyoliticvolcanics, quartz sandstones, and siltstones with variable thickness (80–500 m), which crop out in the Dzirula massif and contain flora of Triassic age.

Lower Jurassic-Aalenian sediments that everywhere rest transgressively are spread throughout all tectonic units of Georgia.

In the fold system of the Greater Caucasus, these deposits are more than 5000 m in thickness and are represented by black shales, sandstone turbidites, rhyolitic (in the lower part), and tholeiite-basaltic (in the upper part) lavas, and their pyroclastics.

In the Georgian Block, Lower Jurassic sediments (80–90 m thick) crop out only along the edges of the Dzirula massif and are represented by arkosic sandstones, gravelstones, conglomerates, clays, and red zoogenic limestones containing rich marine fauna (Ammonitico Rosso facies).

In the southern parts of the Khrami and Loki massifs, the Lower Jurassic consists mainly of terrigenous deposits (120–600 m thick).

In the central part of the fold system of the Greater Caucasus, the Bajocian stage is represented by sandstone–siltstone flysch, shales and marls, and elsewhere by a thick (3500 m) volcanogenic series, which contains marine fauna and consists mainly of calc-alkaline-basaltic, andesite-basaltic, and andesite-dacitic lavas and pyroclastics. Tephroturbidites, sandstones, and conglomerates are rather scarce.

The Bathonian Stage in the fold system of the Greater Caucasus is represented by sandstone-siltstone flysch, and by regressive coal-bearing terrigenous deposits (65–200 m) on its southern slope (in the Gagra-Java zone).

In the Central and Eastern parts of the Southern slope of the Greater Caucasus (Mestia-Tianeti zone), the Upper Jurassic sediments which follow conformably to the Middle Jurassic slates consist mainly of calciclastic flysch (1100–1500 m). On the rest of the territory, they lie transgressively and discordantly.

In the Western and Eastern parts of the Gagra-Java zone, an Upper Jurassic marine facies are present. In the lower part, it is represented by sandstones and clays (120–200 m), and in its upper part by reef limestones (400–900 m). A rich marine fauna (ammonites, corals, etc.) is found in these sediments. To the south and within the Georgian Block, gypsum-bearing lagoonal-continental terrigenous (Kimmeridgian-Tithonian) deposits and to a lesser extent alkaline basalts, trachytes, and pyroclastics are present.

Upper Jurassic shallow-water limestones and marls, alternating with calc-alkaline basalt-andesite-dacitevolcanics, are exposed at the Western edge of the Khrami massif and in the Somkito-Karabakh zone also.

There is a variety of Cretaceous deposits in Georgia. Within the Greater Caucasus fold system (in the Mestia-Tianeti flysch zone), the Lower Cretaceous is developed in the form

of calciclastic and siliciclastic flysch (750–1600 m), which conformably follows the Upper Jurassic flysch. In the south and within the Georgian Block, the old formation, including crystalline rocks of the Dzirula massif, is overlain transgressively by Lower Cretaceous rocks (300–550 m). In the main, limestones are developed within this area. Only in the middle of the section appear marls and clays (Albian Stage) and glauconitic sandstones (Cenomanian Stage). Reef limestones of Urgonian facies (Barrenian Stage) and ammonitic limestones (Aptian Stage) are distinguished in the Lower Cretaceous.

In the Upper Cretaceous sediments of the Mestia-Trileti Flysch zone, siliciclastic (in the lower part) and calciclastic (in the upper part) flysch (500–900 m) prevail. Within the Gagra-Djava zone and Georgian Block, they are spread mainly as shallow-water limestones, marls, and glauconitic sandstones (250–1200 m), whereas to the west in the Dzirula massif, an alkali basalt-phonolitic series (70–300 m) occurs locally.

In the Adjara-Trialeti zone, the Upper Cretaceous is represented by a volcanogenic suite with calc-alkaline-basaltic composition, which in the lower part also contains the Albian Stage. Stratigraphically higher, upper Turonian-Senonianlimestones and marls (300–1200 m) follow.

In the Arthvin-Bolsini Block and Lock-Karabach zone, transgressive Upper Cretaceous sediments are present, which subdivide into three parts. A Cenomanian volcanogenic- carbonate series (900–1200 m) overlaps directly the Khrami and Loki massifs and Jurassic rocks. Ascending the section, there follows a basalt-andesite-dacite-rhyolite series (1100–3300 m) of Turonian-Santonian age. The uppermost part (Campanian–Maastrichtian) is represented by shallow-water limestones and marls with interlayers of acidic tuffs (300–350 m).

Paleogene deposits are found in all tectonic units. In the southern slope of the Greater Caucasus, the Paleocene-Eocene is represented by sandstone–siltstone flysch (600–850 m). In the southern part, the Upper Eocene is built up of olistostromes (10–400 m).

In the Georgian Block, the Paleocene and Eocene consist of an alternation of limestones and marls (30–400 m). In the middle part of the Lirolepis horizon, a horizon of marls is distinguished, which begins the Upper Eocene.

In the Adjara-Trialeti zone, the Danianis are built up of limestones and marls, whereas the transgressive Paleocene-Lower Eocene consists of sandstone–siltstone and clastic limestone flysch (Borjomi flysch), the thickness of which increases from west to east (1500–3000 m). These are followed by a very thick Middle Eocene volcanogenic suite, which in the western part of the zone is represented by tholeiitic and shoshonitic, mainly basaltic, submarine volcanics, and tephro-turbidites, whereas in the eastern part there are calc-alkaline and tholeiitic, mainly andesitic rocks, olistostromes, and tephro- and sandstone–siltstone turbidites. Its thickness increases from east to west (1000–5000 m). In the Artvin-Bolnisi zone and the Somkhito-Karabakh zone, a Middle Eocene volcanogenic suite is built up of calc-alkaline basalt-andesite-dacite-rhyolite volcanics (1200–2700 m) and transgressively overlaps Cretaceous and Jurassic rocks and the Loki Crystalline Massif.

In the Adjara-Trialeti zone, the Upper Eocene is distinctly transgressive and consists of marls, clays, sandstones, and gravelstones (500–1500 m), whereas in the western part of the zone, it consists of andesitic-basaltic volcanoclastics (1000 m).

Oligocene deposits (mainly the Maikop Series) are generally represented by thin-bedded gypsiferous clays, which contain fish scales and sandstones. This series continues in the lower part of the Miocene, too. It outcrops in the Gagra-Djava zone, in the Georgian and Artwin- Bolnisi blocks, and in part of the Adjara-Trialeti zone. Its thickness is rather variable (250–3000 m).

Neogene formations are present only in molasse depressions. The Lower Miocene, as was mentioned, belongs to the Maikop Series. Further up the section, the Miocene is represented in the lower part (Middle Miocene-Middle Sarmatian) by marine molasse (clays, sandstones, conglomerates, limestones, and marls), and in the

upper part (upper Sarmatian-Pliocene) by marine and continental molasse (conglomerates, sandstones, sands, and clays). There are very distinct unconformities at the bases of the Miocene, Meotian Stage, and Upper Pliocene.

In the Artvin-Bolnisi zone and Somkhito-Karabakh zone, and partially in the southern part of the Adjara-Trialeti zone, the Neogene is represented by subaerial calc-alkaline andesites, andesite-dacites, and dolerites. Their upper part includes the Pleistocene and Quaternary, too. In the lower part (Upper Miocene-Lower Pliocene) subaerial volcanics contain a rich terrestrial flora, and in the Upper Pleistocene there is mammalian fauna.

Quaternary deposits are distributed very irregularly. These consist of river terraces, moraines of three glaciation periods, and a volcanic formation in the form of volcanic cones and lava flows (in the Greater Caucasus, to the south of Kazbegi, and on the Trialeti Range in the Borjomi region). There are also vast accumulation plains in intermontane areas.

2.3 Tectonic Structure

The territory of Georgia, as a part of the Caucasus, underwent a long and complicated tectonic evolution and contains structures of various types, scales, and genesis (Gamkrelidze et al. 2013; Gamkrelidze 2016).

Tectonic structures of the pre-Alpine basement are characterized by the existence of several deep-seated nappes including obducted ophiolites (Gamkrelidze and Shengelia 2005).

Alpine structures have a different character in the various tectonic zones. The northeastern tectonic unit of Georgia, the fold system of the Greater Caucasus, is characterized by a distinctly expressed asymmetry in its structure: southward verging, often isoclinal folding on the southern slope and quiet, poorly folded, or monoclinal structures on the northern slope. Large, southward-directed nappes are developed also on its southern slope (Gamkrelidze 1991, 2016). The above-mentioned structures provide evidence of the leading role of Late Alpine underthrusting of the comparatively rigid Georgian Block under the Greater Caucasus during its deformation (intraplate subduction).

The northern boundary of the Georgian Block, in its western part, is formed by a deep fault, which in the sedimentary cover manifests itself as a regional flexure. Study of the structural peculiarities of the Georgian Block has shown that its central and western parts are characterized by a mosaic-block structure of the basement and occurrence of typical above-fault folds in the sedimentary cover. In the eastern area of subsidence of the Georgian Block, its cover is detached and shifted toward the south together with the nappes of the southern slope of the Greater Caucasus (Gamkrelidze 1991, 2016).

The Adjara-Trialeti zone of the Lesser Caucasus, which is situated to the south of the Georgian Block is, on the whole, an anticlinorium and is characterized by block-fold structures. To the west from the Dzirula massif along the northern margin of this zone, an overthrust nappe is developed.

The Artvini-Bolnisi zone consists of two different tectonic units: the Javakheti zone (in the west) and the Bolnisi zone (in the east). In the young (Neogene-Pleistocene) volcanic cover of the Javakheti zone, sublatitudinal gentle folds are observed. Two deep submeridionalseismogenic faults are established which served as conduit channels for young volcanics. The Bolnisi zone includes the horst-like Khrami salient of pre-Alpine basement and the territory covered with Cretaceous and Paleogene volcanic rocks. Brachyanticlines and steep faults of various orientations are developed to the south in a sedimentary cover, which generally forms a gentle syncline.

The northeastern wedge of the Somkhito-Karabakh zone forms part of Georgia and is characterized by echelon-like disposition of internal anticlinoria. In the core of a sub- latitudinal Loki anticlinorium, the pre-Jurassic crystalline basement is exposed. The axis of this structure plunges in both western and eastern directions and causes periclinal closure of the sedimentary cover.

The fold and fault systems of the Adjara-Trialeti, Somkhito-Karabach, and the Artvini-

Bolnisi zones were formed as a result of the manifestation of Late Alpine (Neogene) tectonic movements with the displacement of masses from south to north (Gamkrelidze 1991, 2016).

2.4 Geodynamic Evolution and Paleotectonic Reconstructions

The aforesaid data about geological structure, character of sedimentation and magmatism, geology, and the age of ophiolites, side by side with paleomagnetic data and global plate tectonic reconstructions (Stampfli and Borel 2002) allow us to consider the main features ofthegeodynamic evolution of the Caucasus and adjacent areas (Gamkrelidze 1986; Gamkrelidze and Shengelia 2005; Gamkrelidze 2016).

As a result of horizontal displacements of the ancient East European and African platforms, as well as of certain lithospheric plates within the Mediterranean belt during the Precambrian- early Mesozoic, the generation and development of oceanic basins took place. In the present structure of the Earth's crust, these basins are marked by rocks of ophiolitic association.

The most ancient of these oceans, the Proto-Paleotethys, developed in the course of time from the Precambrian up to the Middle Jurassic (Fig. 2.2). At this time, the Caucasian province was an active continental margin of Europe. The southern, Lesser Caucasus part of the Transcaucasus massif was located at the margin of the Paleotethys and belonged to the northern margin of the Iran-Afghanian plate (Gamkrelidze 1986).

Side by side with the Proto-Paleotethys Ocean during the Neoproterozoic and Paleozoic, relatively small oceanic basins of the southern slope of the Greater Caucasus and the so-called Arkhis basin (between the Main and Fore Range zones of the Greater Caucasus) are developed.

In the rear of the gradually closing Paleotethys, the joining together of Iran and Arabia and the generation of Neotethys had been taking place already since the Triassic.

The next extension occurred during the early Jurassic and beginning of the Middle Jurassic. At the northern active margin of the Paleotethys, the Transcaucasus island arc and marginal sea of the Greater Caucasus can be discerned (Fig. 2.3).

One can suppose that the Lesser Caucasus branch or bay of the Tethys was formed in the rear of the closure of the Paleotethys since the end of the Middle Jurassic.

The closure of the Neotethys Ocean, as well as of the Paleotethys relic basin, occurred as a result of movements that spread from north to south. In particular, only the northern part of the Caucasian segment of the Mediterranean belt was affected by the Bathonian (Adygean), Late Cimmerian (pre-Cretaceous), and Austrian (pre-late Cretaceous) movements. These epochs of tectonic activity are associated with the intense manifestation of andesitic volcanism and granitoidplutonism due to the processes of subduction on the continental margin of the oceanic basins (Fig. 2.3).

The movement of the Austrian phase closed the Lesser Caucasian branch of the Mesotethys. At that time, ophiolite nappes were formed in the Lesser Caucasus.

The subsidence that began in the Paleocene reached a maximum in the Eocene, especially in the Middle Eocene, and it was accompanied by calc-alkaline volcanic activity throughout the Lesser Caucasus. Northwards, this was substituted mostly by the basaltic sub-alkaline series of the Adjara-Trialeti rift (see Fig. 2.3).

The subsequent phases of Alpine tectogenesis caused the accumulation of molasse deposits, total compression, and final formation of the present-day structure of the Caucasus (Caputo et al. 2000).

The abundance of andesitic and andesite-dacitic volcanism and granitoidplutonism in the orogenic stage can be related to the continuing activity of subduction zones (intraplate subduction).

At the same time, at the location of maximum compression of the Mediterranean belt caused by an active northward sub-meridional advance of the Arabian Plate, a vast transecting transverse set of extensional fissures developed which was responsible for the penetration of orogenic volcanism far into the continent, in a zone of Transcaucasian transverse uplift.

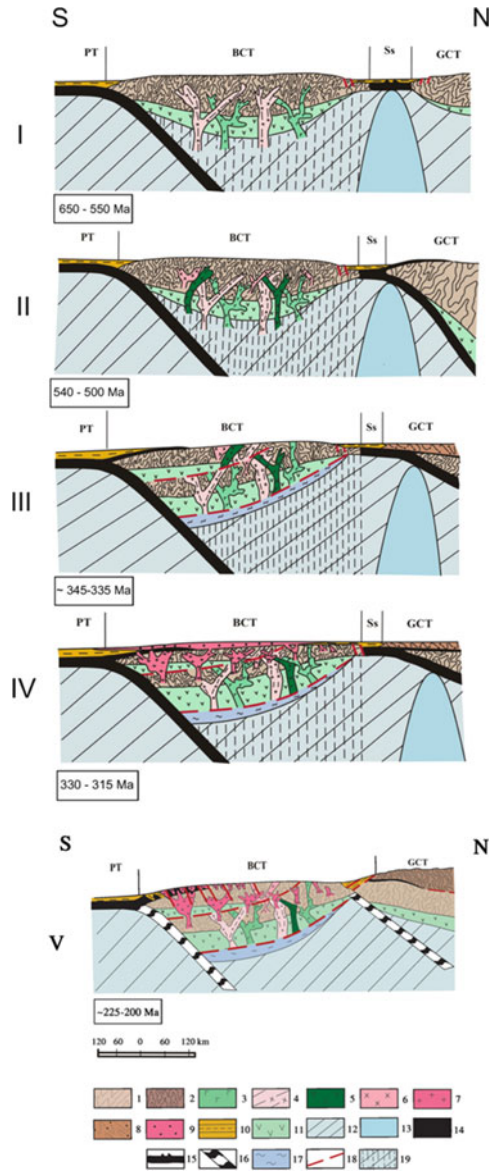

Fig. 2.2 Palinspastic profiles of the Mediterranean belt for: I—Cadomian stage, II—Late Baikalian stage, III—Bretonian (Saurian) stage, IV—Late Variscan (Sudetian) stage, V—Early Cimmerian (Indosinian) stage (Gamkrelidze and Shengelia 2005). Vertical scale is exaggerated approximately for three times. By representation of pre-Alpine extend of terranes the magnitude of Alpine shortening is not taken into account. 1—Grenville plagiogneiss-plagiomigmatite complex with concordant schistose and boudinated bodies of metabasites, 2—rocks of infrastructure within the Elbrus subzone of the Main Range zone of the Greater Caucasus, 3—Neoproterozoic gabbroids, 4—Cadomianorthogneisses, 5—Cambrian gabbros, gabbro-diabases, diabases, 6—Late Baikalian-granitoids, 7—Late Variscanpotassic granites, 8—Lower-Middle Paleozoic mainly pellitic sediments within the Greater Caucasian terrane, 9—Upper Paleozoic rhyolite tuffs, 10—sediments of the oceanic floor and continental slope, 11—basaltic layer of the Earth's crust, 12—upper mantle, 13—astenosphere, 14—oceanic crust including obducted ophiolites, 15—Middle oceanic ridge, 16—inactive subduction zones, 17—"crust astenolayer" (astenolens), 18—overthrust surfaces and other faults, 19—streams of suprasubduction heat, fluids and magmatic melts in mantle. Paleooceanic basins: PT—Proto-Paleotethys, Ss—small oceanic basin of the Southern slope of the Greater Caucasus. Continental plates: BCT—Black Sea—Central Transcaucasian terrane, GCT—Greater Caucasian terrane (island arc)