2 Main Factors of Glaciers Formation

Abstract

This chapter includes the relief and climatic factors of glaciers' generation in Georgia. There are described the individual sectors of Caucasus and also those branch ranges, which are related to the distribution of modern glaciers; also, on the example of mountainous weather stations of Georgia, there are considered the climatic conditions (air temperature, atmospheric precipitation, snow cover) that play a decisive role in the maintenance of modern glacial cover.

Keywords

Georgian Caucasus Mountains · Air temperature · Atmospheric precipitation · Snow cover

2.1 Orography and Relief

The high mountainous relief of the Greater Caucasus is favorable for the existence of glaciers in Georgia. The Greater Caucasus mountain range is stretched along the territory of Georgia at ~750 km; the glaciers are concentrated in the southern and partly, in the northern slopes of the watershed range, as well as in the side range and branch ranges of the Greater Caucasus. According to the morphological and morphometric characteristics the Greater Caucasus can be divided into three parts within Georgia—Western, Central, and Eastern.

The Western Caucasus region includes the part, which is located to the west of the Dalari Pass. It has a sublatitudinal direction in Georgia. The relief of its southern slope is characterized by complex orographic structure. The main watershed range is the highest morphological unit here (Fig. 2.1). The Greater Caucasus branch ranges of Gagra, Bzipi, Chkhalta (Abkhazeti), and Kodori are also sharply distinguished morphologically and morphometrically. Endogenic and exogenic relief-creating processes, which have been acting during the entire Neogene–Quaternary period, participated in the formation of modern relief of the Western Caucasus (Geomorphology of Georgia 1971).

The main watershed range. Its morphological characteristics are as follows: the orographic certainty, longitudinal extent, horst-anticline

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Fig. 2.1 Southern slope of the Western Caucasus main watershed range to the east of the Mount Atsgara (*photo by* R. Gobejishvili)

structure on the surface of which the crystalline core is exposed, and slopes asymmetry. The southern slope is a tectonic step, which runs steeply toward the bottom of the alongside gorges (Astakhov 1973).

By morphological features the main watershed range of the Western Caucasus can be divided into three parts in its turn: western, central, and eastern. The central part is the highest, which is stretched among the Marukhi and Klukhori Passes; height of some of the peaks exceeds 3700 m here.

Within the Western Caucasus the numerous submeridional branch ranges are separated from the main watershed range. Among them can be noted Chibikha, Khita, Khutia, Klichi, and Ghvaghva. They are the watersheds of the basins of the Kodori River right tributaries. The heights of the individual peaks exceed 3000 m.

The axial section of the main watershed range is composed of crystalline rocks of Lower Palaeozoic and Precambrian ages. The mountainous region's line built by these rocks gradually becomes narrow from the east to the west. The following two formations can be distinguished by petrographic composition: (1) crystalline shales, gneisses, phyllites, and marble of the Precambrian and Lower Paleozoic age, into which sometimes the granite intrusions are intruded; and (2) the Lower Paleozoic granitoids (Geology of the USSR. V. X).

Weathering and exaration action of modern and old glaciations are important in formation of the crest of the main watershed range. The result of the exogenous processes is the presence of frequent comb-like forms with the pointed peaks (carlings), narrow and deep passes, and quite wide glacial cirques. A crest of the main watershed range is located in the nival zone above the firn line and its morphological features create favorable conditions for the formation and existence of modern glaciers there.

The Kodori Range is a well-expressed orographic unit in the Western Caucasus (Fig. 2.2). Height of some of the peaks exceeds 3600 m here. Central part of the range has the latitudinal direction; its height increases and some peaks (M. Khojali) exceed 3000 m. Its western part is rather long and its hypsometric indices are behind the others. The central and western parts are composed by the Bajocian porphyrites. Morphostructurally it belongs to the Kodori and Lechkhumi semi-inversed ranges (Astakhov 1973).

The tectonic and erosion processes have the leading role in the formation of morphosculptural

Fig. 2.2 Kodori range (*photo by* L. Tielidze)

forms of the relief of the Kodori range, and the nival–glacial processes—in the formation of the crest of the range.

The Chkhalta (Abkhazeti) range stretches in parallel to the main watershed range and is 12–17 km away from it. Morphostructurally it is a 7–8-km-wide horst-synclinal range, which has a sublatitudinal direction (Astakhov 1973). The relief is distinguished by a deep fragmentation with the depth of 1000–1500 m. Orographic axis of the range almost coincides the synclinorium axis, which is composed of Bajocian porphyrites and intrusive and effusive rocks of the Mesozoic age; the slopes of the syncline are composed of the Upper Lias shales. The synclinorium is bordered by fault lines on the north and south. As it was mentioned above, the northern fault line is presented as a tectonic step. In the lower mountain zone the erosion–accumulation processes have a leading role in the creation of morphological forms of the Chkhalta range relief, while the upper tiers of the range are created by the nival–glacial processes.

The Bzipi range has a latitudinal direction. It is composed of Mesozoic sediments, while its eastern part is of Bajocian porphyrites. The eastern part of the range is known as the Chedimi range and hypsometrically is the highest one. The Mount Khimsa (3034 m) is its highest peak, to the northern slope of which there are the small glaciers. The traces of old glaciation are well preserved in the high places of the Bzipi range.

The Central Caucasus sector is the highest hypsometrically; it is characterized by a complex geological structure and is very interesting by glacial geomorphological point of view. Its western boundary coincides with the Dalari pass and runs along the Enguri–Kodori Rivers' watershed (Kharikhra range), while its east boundary coincides with the Jvari Pass and then runs along the bottom of the river gorges of Tergi–Bidara–Mtiuleti's Aragvi (Maruashvili 1971).

Orographic structure of the southern slopes of the Central Caucasus is different from the similar slopes of the Eastern and Western Caucasus. It is characterized by a large extent and great depth of fragmentation. Erosion and tectonic processes are important in the formation of modern relief, while the glacial processes—in the high mountain zone.

In terms of the glaciers distribution, the several orographic units can be distinguished in the Central Caucasus: the ranges of Svaneti, Samegrelo, Letchkhumi, Shoda-Kedela, and others.

Two sections—Svaneti and Racha-Dvaleti—can be distinguished in the **main watershed range** according to the geomorphological and geological features.

In the entire Greater Caucasus the **Racha-Svaneti** section (Fig. 2.3) is the highest hypsometrically (4000–5000 m), heights of some of the peaks exceed 5000 m. Its crystal core, which is built of Pre-Paleozoic and Paleozoic formations, is uplifted by a dome-block motion and is naked due to erosion processes. One of the main morphostructural elements of the zone is the main overthrust. The fault length falls by the angle of 35–50°, and therefore, the old crystalline core is overthrusted on the Lias shales on the north. Amplitude of the fault (overthrust) makes several kilometers, and its origination took place in the Oligocene (Gamkrelidze 1966). In this section the main watershed range is presented as a horst-anticline morphostructure (Astakhov 1973). This section in the Caucasus is characterized by deep gorges, steep slopes, and active, powerful action of modern relief-forming processes; it is a major center of modern and old glaciations.

The Dvaleti (east) segment (Fig. 2.4) of the main watershed range is behind the Racha-Svaneti Caucasus hypsometrically. Height of some of the peaks reaches 3800–3900 m. The crest of the main watershed range is coiled, landforms of the relief are characterized by soft contours, and above 3200 m the relief is rocky with comb-like forms due to the activity of weathering processes. In structural terms it belongs to the Shovi–Pasanauri subzone of the Mestia–Tianeti zone. It is composed of the Upper Jurassic and Cretaceous ages flysch and is characterized by a very complex and tense tectonics (Geology of the USSR. V. X 1964).

Many branch ranges come out from the Central Caucasus main watershed range, such as Shdavleri, Tsalgmili, Ghvalda, Kareta, Bodurashi, Mkhvrelieti, Gormaghali, Java, Kharuli, etc. Leading role in the formation of their relief belongs to the nival–glacial processes, especially, in the Late Pleistocene and Holocene.

The Samegrelo range has a sublatitudinal direction. By morphological and morphometric signs it is divided into three parts. Hypsometrically the highest are the western and eastern sections, which mostly consist of porphyrites of Bajocian series; in the western section the outcrops of shales and sandstones of the Jurassic age can be seen under the porphyrites in some places. Shape of the relief is formed by rocky and peaky mountains; the height of some of the peaks exceeds 3000 m. The central part of the range is of 300–400 m lower and is composed of Lower Jurassic age easily decaying rocks, which give the soft contours to the relief. The Samegrelo range was formed in the conditions of the eugeosynclinal inversion of the southern slope of the Greater Caucasus and belongs to the semi-inversed ranges (Astakhov 1973). Modern relief of the Samegrelo range was formed in the

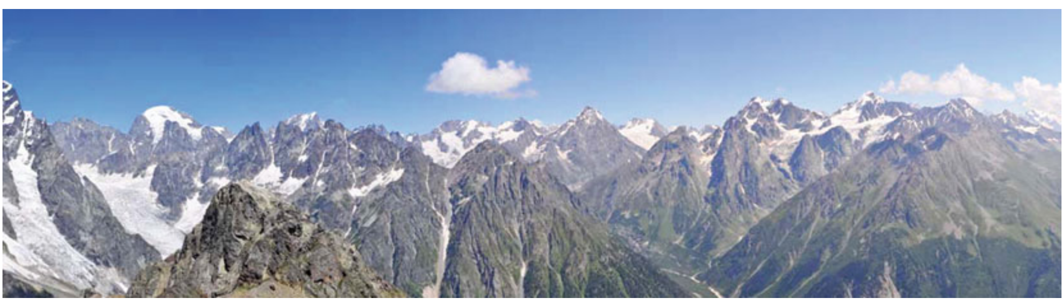

Fig. 2.3 Svaneti Caucasus (*photo by* L. Tielidze)

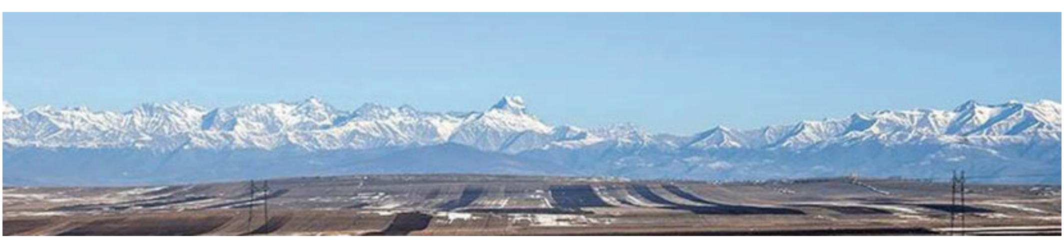

Fig. 2.4 Dvaleti Caucasus (*photo by* R. Gobejishvili)

Pleistocene by interaction of tectonic and erosion processes, and high mountain zone there is a well-preserved trace of glaciation activity in the Late Pleistocene and Holocene periods.

The Svaneti range is distinguished by the height of the relief, as well as the area and the number of glaciers from the other ranges located in the southern slope of the Greater Caucasus (Fig. 2.5). It is divided into three parts morphologically and morphometrically. The height of the eastern section is somewhat lower than that of the central one; here only the Mount Dadashi reaches 3535 m and there are several glaciers in its slopes. The central section of latitudinal direction, which is the highest and the height of some peaks exceeds 3700–4000 m (Mount Lahili, 4009 m), is located among the Lasili and Leshnuri Passes. Almost all glaciers of the Svaneti range are located here. The western section of the Svaneti range is much lower than the central one; heights of its peaks do not exceed 3300 m and there are no modern glaciers there.

Some scholars (Astakhov 1973) consider the Svaneti range as an individual morphostructure—the Svaneti anticlinal range. It is built mainly of shale—sandstone flysch suite of the Lower Jurassic age. The westernmost part of the range is built of Bajocian porphyrites. Outcrop of the Upper Jurassic period carbonate flysch can be found in the Atkveri Pass. Its central part is built of metamorphic formations of Paleozoic age. Characteristics of the building rocks determine mainly the soft forms of the relief here. In the formation of relief forms an active role belongs to the erosion and glacial processes along with the tectonic ones. Steep and rocky slopes dominate in the nival zone.

The Lechkhumi range has a submeridional direction from the Mount Pasismta (3779 m) to the Mount Chudkharo (3562 m), and the sublatitudinal direction—from the Mount Chudkharo to the west. Hypsometrically the highest is the central part of the range called Chudkharo–Samertskhle massif. The Letchkhumi range is sharply asymmetric. Its northern slope is shorter than the southern one. The relief is built of Jurassic age flysch suites, but the Sori anticline slopes and the Chudkharo–Kupri syncline core are built of Bajocian porphyrites. In structural–lithological terms, the subzone has many common both with the South Caucasus fold system and Georgian block as well. It belongs to the Kodori and Lechkhumi semi-inversed ranges (Astakhov 1973), which experience hard wash out at the neotectonic stage. Along with the other processes the nival–glacial processes play an active role in the relief.

The Shoda-Kedela range is divided by the Rioni River into two parts; the erosion depth reaches 1500–2000 m here. Its crest is much coiled, which is a result of the reversal river erosion. The range is a horst-synclinal range morphostructurally, which is built of the Upper Jurassic and Lower Cretaceous ages carbonate flysch. The range is accompanied with the young fault lines by sides, resulting in the activation and uplifting of Early Alpine synclinorium. These processes are underway even today. The Shoda-Kedela range is quite high, and some of its peaks exceed 3500 m. The nival–glacial

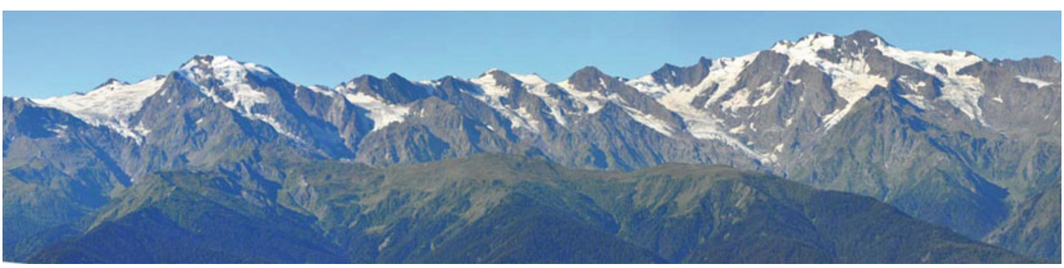

Fig. 2.5 Svaneti range (*photo by* L. Tielidze)

processes are also remarkable along with the erosion–tectonic processes in the creation of morphosculptural forms of the relief.

The Eastern Caucasus (Fig. 2.6). To it belongs the part of the Greater Caucasus Range, which is located to the east of the Georgian Military Road (the Jvari Pass). Both the southern and northern slopes of the Caucasus range get within the Georgia's boundaries. Its maximum width makes 60 km. The Eastern Caucasus is quite high hypsometrically; its peaks—Kuro, Komito, Shani, Amgha, Tebulosmta, etc.—exceed 4000 m, though, because of the relatively dry climate and morphological features of the relief, the modern glaciers are more poorly represented in the Eastern Caucasus than in the hypsometrically lower Western Caucasus.

The Eastern Caucasus is entirely built of shale-sandstone suites of the Jurassic age and Cretaceous flysch. In some areas there are outlets of intrusions of different ages (Dariali granites, diabases of Chaukhi and Chimgha rocks); tectonic structure is complex, and it is characterized by isoclinal and inverted to the south folds. Alongside the fault lines, which are complicated by overthrusts, faultings and shearings are of great importance in the formation of the relief structures.

By orographic point of view, the crossing gorges and ranges of meridian direction prevail in the Eastern Caucasus. This general picture is violated by the Pirikita range and Tusheti depression, which have the general Caucasian direction. Vertical zoning of the exogenous morphological complexes can be vividly seen in the relief. The nival–glacial zone is presented discretely and is connected to the separate massifs located above 3300–3500 m. According to the morphological and morphostructural signs, here can be distinguished the main watershed and side ranges with their branches and the Tusheti depression.

The main watershed range has a sublatitudinal direction. The highest peak of the range is the North Chaukhi—3842 m and the heights of the peaks—Roshka and Shaviklde are within 3500 m; and the passes are located at a height of 2300–3200 m. The main watershed range is mainly composed of the Jurassic age schists and sandstones. Against the background of the old glacial relief, the modern nival–glacial landscape is connected with the separate massifs in the form of islands.

The Khokhi range. Only the southern slope of its eastern part gets within the boundary of Georgia (Fig. 2.7). It is the highest massif in the eastern Georgia; height of some of the peaks exceeds 4500 m. The lowest pass is located at 3700 m. The Khokhi range is composed of shales and sandstones of the Lower Jurassic age, which are often destroyed by diabase veins. The young effusive series widely participate in the structure of the radially fragmented Kazbegi massif. Shape of the relief is a result of glacier, old glacial, volcanic and erosion forms, and their interrelations.

The intermountain depressions of synclinal origin are located between the main watershed

Fig. 2.6 Eastern Caucasus (*photo by* R. Gobejishvili)

Fig. 2.7 Khokhi range (*photo by* L. Tielidze)

range and its branches. Among them the remarkable are as follows: Zemo and Kvemo Svaneti, mountainous Racha, Liakhvi, and Truso. The relief is built of the Jurassic age suites. The erosion–accumulation and tectonic processes have the main role in the modeling of the relief. The glaciers of the Late Pleistocene period have a certain role in the creation of morphostructural forms.

The Side range is presented in the Eastern Caucasus in the form of separate massifs, the integrity of which is violated by the erosive action of the river. There are quite high peaks in these massifs—Kamghismaghali (3741 m), Chimghismaghali (3851 m), and Tebulosmta (4493 m). The main orographic units are the watersheds of the meridian direction. The main role in the formation of the relief belongs to the tectonic and erosion processes, which were also active before the neotectonic stage. There are nival–glacial processes only on the crests of the ranges and high massifs.

The side range of latitudinal direction and 42-km long, called Pirikita range, is orographically well expressed in the relief from the Mount Tebulosmta to the Mount Diklosmta. It is the highest range in the Eastern Caucasus, and height of some of the peaks exceeds 4000 m. And the modern glaciers are located namely in the slopes of these peaks. Among other processes the nival–glacial processes have important role in the formation of the relief of the Pirikita range. There are intermountain isocline depressions among the main watershed range and the Side range. Such depressions are located in the headwaters of the Asa, Arghuni, and Andaki Rivers. It should be noted a deeply dissected Tusheti depression of latitudinal direction.

The Late Pleistocene glaciation traces are well preserved in the Greater Caucasus other branch ranges of lower hyphsometry (Bzipi, Racha, Kharuli, Mtiuleti) and in the number of the ranges of the southern Georgian highland. We give their brief geomorphological description when considering the old glaciations.

2.2 Climatic Conditions

Complex orographic peculiarities of the relief of Georgia determine the variety of climatic conditions, particularly the strong fragmentation of the mountain gorge relief is notable, as well as the basic orientation of the mountain ranges, the height alternation, and also the exposure and slope inclination. Variability of climate elements is well reflected in the differentiation of natural processes.

Air temperature is a very necessary element of climate and is a leading factor in the snow-ice cover creation. The Caucasian thermal regime is mainly determined by its geographical location, solar radiation, subsurface feature, atmospheric circulation, and relief. Therefore, the air temperature is characterized by high contrast (Kordzakhia 1967).

January is usually the coldest month in Georgia, but in the high mountain regions

(2700–2800 m) February is often the coldest month. Stable frosty periods at a height of 2000–3000 m last from November to May, and above 3000 m from October to July. The average January temperature is −8 °C at a height of 2000 m and the coldest month is −16 °C at a height of 3600 m (Gobejishvili 1995). The average monthly temperature of the warmest month—August—varies from +14 to +17 °C at about 1500 m of altitude, falling to +7.6 and +3.4 °C, respectively, at 2800 and 3600 m (Gobejishvili 1995). Average multi-annual air temperature ranges from +5.9 °C (Mestia, 1906–2013, 1441 asl) to −5.7 °C (Kazbegi, 1907–2009, 3653 asl) (Tielidze 2016).

Amount of **atmospheric precipitation** has a great impact on the scales of modern glaciation. Interaction of atmospheric circulation processes and local physical–geographical factors determines the distribution of precipitation. It is important to notice the close location of the Black Sea and the barrier direction of the Greater Caucasus mountain range, which protects Georgia from the intrusion of the cold air masses from the north. Average multi-annual precipitation ranges from 400 to 4500 mm in Georgia. In addition, amount of atmospheric precipitation decreases from the west to the east and from the south to the north. Orographic features of individual regions, first of all, the height of the relief, exposition, slope inclination and the direction of the river gorges towards the humid air masses violate this regularity (Kordzakhia 1967).

Southern slopes of the Bzipi, Kodori, Samegrelo, Svaneti, Lechkhumi, and Shoda-Kedela ranges and the high mountain zone of the Greater Caucasus are characterized by abundant precipitation. Amount of precipitation is ~1600–2300 mm. Intermountain depressions are more characterized by aridity—~900–1600 mm. In the Eastern Caucasus the amount of precipitation varies from ~900 mm to ~1600 mm above ~2000 m and in the depressions—from ~700 mm to ~900 mm.

At the height of ~1000 m the snow cover melting starts in average in the first half of April, and at the height of ~2000 m—in the middle of May—the snow occurs early in the glaciers surface and melts late. Snow is redistributed under the impact of snow avalanches and wind. Two types of snow redistribution are mainly distinguished: (1) when the snow redistribution occurs within the same basin, and (2) when the snow is redistributed from one to another basin. Existence of the glaciers in the Greater Caucasus is mainly stipulated by the accumulation of excess snow.

Wind. The Caucasus mountain system is characterized by the diversity of wind directions. Western winds dominate throughout the year in the mountain slopes. Wind direction in the crest of the Greater Caucasus is stipulated by the general circulation of the atmosphere; here all year round western moist winds are blown. The seasonality in wind speed direction is well expressed in the high mountain and medium mountain areas.

The average annual wind speed varies from ~0.4 m/s (Shovi) to ~6.3 m/s (Kazbegi). The lowest wind speed (~0.4–2.0 m/s) is in the Greater Caucasus river gorges (Kordzakhia 1967).

Maximum monthly average wind speed in the high mountain areas of the Greater Caucasus is during the cold spell (November–March). The lowest wind speed values are in the summer months (June–August), as there is no mountain gorge circulation in the upper layers. In the river gorges the average monthly wind speed does not exceed ~2.7 m/s (Ambrolauri), while on the crests of the ranges and passes the wind speed reaches ~7.6 m/s (Kazbegi) (Kordzakhia 1967).

Strong winds are rare in the deep gorges of the Greater Caucasus Rivers, but they are of one direction, which is stipulated by the layout of the river gorges. The western winds with the speed more than ~40 m/s dominate in the high peaks and crests. This pattern is particularly well observed during the winter period.

The snow cover is unevenly distributed in the Greater Caucasus range; snowfall in the western Caucasus is greater and snow cover lasts for a longer period than in the eastern Caucasus. The average snow cover in the eastern Caucasus is ~110 days at ~1500 m a.s.l., ~145 days at ~2000 m a.s.l., and ~195 days at ~2500 m a.s.l. In the western Caucasus snow cover extends for ∼135, 182, and 222 days, respectively. In the eastern Caucasus the average depth of snow cover is ∼21–40 cm at ∼1500–2000 m elevation, and more than 100 cm at ∼2000–2500 m (Gobejishvili 1995; Tielidze 2016).

Thus, we conclude that the occurrence of the glaciers of Georgia is stipulated by the climatic conditions of its territory, the impact of the Black Sea, geological structure, and the relief's morphometric and morphological peculiarities.

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