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MODERN AND OLD GLACIERS OF GEORGIA

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The "Modern and old Glaciers of Georgia" is the first monograph in English language. The monograph is based on the author's several-year theoretical and field-desk research results, which were obtained during the study of modern and old glaciations of the Georgian Caucasus. As a result of these surveys the latest materials on the modern glaciers morphology, morphometry and dynamics are obtained.

The monograph also examines the variability of the valley glaciers after the Little Ice Age maximum; glaciers dynamics during the historical period has been identified. The reconstruction of glaciation in Late Pleistocene and Holocene has been conducted based on detailed glacial-geomorphological observations.

The monograph in English language is prepared by a financial support of Shota Rustaveli National Science Foundation. "Glaciological Catalog of Georgia" (№AR/151/9-102/13) is a winning project of the Call of National Science Grants in Applied Research of the years of 2014-2016.

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Contents

The monograph is dedicated to the memory of
Dr. Ramin G. Gobejishvili (1941-2014) –
a famous Georgian geographer, glaciologist.

Preface

The monograph is based on the last several year research results, which were obtained during the study of modern and old glaciations of the Georgian Caucasus. As a result of these surveys the latest materials on the modern glaciers morphology, morphometry and dynamics have been obtained, as well as on structure of moraines and the river terraces, geodynamics of the relief, snow and firn lines location.

At various times, we conducted field surveys in almost every glacier basins in the southern and northern slopes of the Georgian Caucasus. Apart from the field researches, we used the remote sensing method. After processing the latest aerial images (Landsat L5, L8 OLI, ASTER) by modern computer programs (ArcGIS, ENVI, PCI Geomatica, Google Earth), we got the quite accurate information about the glaciers difficult to access. This mainly refers to the glaciers that are located in the temporarily occupied Abkhazeti and Tskhinvali region, where it is so far impossible for us to conduct field research. During our research we also used the traditional methods: glacio-geomorphological, cartographical, aerial image processing and petrographic.

The monograph includes a number of new statements and conclusions; among them the following are essential:

1. Principally new numerical and qualitative characteristics of present glaciers and their dynamics have been derived and full databases of Georgia's modern glaciation have been composed;

2. Valley glaciers fluctuation synchronicity has been revealed after the Little Ice Age (LIA) maximum;

3. Reconstruction of the late Pleistocene (Wurmian) and Holocene glaciations has been investigated. The maps of the distribution of the Late Pleistocene glaciation of the Georgian Caucasus have been compiled.

The main theoretical statements and conclusions have been developed in the Vakhushti Bagrationi Institute of Geography in Georgia. In 2014-2015 certain part of the research has been performed in the United States of America, in the Glaciology and Remote Sensing Laboratory of the Climate Change Institute of the University of Maine, also, in 2015-2016 – in Canada, at the University of Northern British Columbia.

Data obtained on present state and dynamics of the glaciers of Georgia can be used for water supply and development of hydropower in the settlements of mountainous areas. Quantitative data obtained on the present state of the nival-glacial system is necessary for the design and construction of the tourist-recreational objects in the high mountain zone, as well as for the development of tourism and alpinism.

We hope that this monograph will be of great assistance for the general public who is interested in any information about glaciers of Georgia.

Special thanks from the author to Ms. Nino Chikhradze for cooperation during the preparation of the Book.

Author will accept all the topic-related comments with gratitude.

Levan Tielidze

The historical overview

Research of glaciers has a long history in the Caucasus. Great Georgian scientist Vakhushti Bagrationi gives the first scientific information on the glaciers of Georgia in the beginning of the 18th century ["There are big mountains, which have the Caucasus to the North from the Black Sea to the Caspian Sea, the height of which is of one day walking and the highest of it is permanently frosty, the length of the ice is of k-l arm, and in summer it breaks and, if a man stays there, he cannot endure the cold even for a short time; and the rivers flow under it, and the ice is green and red, as a rock due to its age"] (Vakhushti, 1941).

After almost hundred years the foreign scientists began to describe the glaciers of Georgia. Information about the glaciers of Georgia can be found in the works of G. Abikh (1865), D. Freshfield (1869), G. Radde (1873), N. Dinik (1890), I. Rashevskiy (1904), etc.

One of the first foreign travelers, who visited the Caucasus in the 19th century, was Douglas Freshfield (1869). He wrote in the account of a visit in 1868 that the Caucasus was known less than the Andes and Himalaya. Merzhbacher (1901, cited Horvath 1975) found evidence of glacier advances in recent centuries in a valley of the central Caucasus. Ruined buildings lay close to glacier tongue and local legends and songs told of a glacier near Ushguli (the mountain village in Georgia), probably the Khalde glacier, then six miles away from the village, having advanced and destroyed all of it but for the church. The people still held an annual festival in thanksgiving (Grove 1988), etc. All this information greatly assisted us in determining the dynamics of the individual glaciers.

In the years of 1880-1910 the topographical surveying of the Greater Caucasus was carried out. On the basis of the created maps K. I. Podozerskiy (1911) compiled the first detailed catalog of the glaciers, which still has not lost its importance, but it must be mentioned, that the errors were made during its compilation. A. L. Reinhardt (1916, 1917) noted these errors further, who compiled the new catalogue for many glacial basins of the investigated region and defined the location of the snow line. The research conducted by A. Reinhardt is of high quality and more reliable by its scientific value in comparison with its previous researchers.

Interesting researches were conducted by V. Rutkovskaya (1936) in connection with the 2nd International Polar Year. In 1932-1933 the glaciation of the Enguri River was studied and the dynamics (in the one-year period) of the individual glaciers were identified.

In 1959 P. A. Ivankov gave us the total number and area of glaciers of the study area based on the new topographic maps and the aeroimages of 1946. In the same

year P. Kovalev (1961) described the glaciers in details and carried out their labeling.

Much work has been conducted by D. Tsereteli for the study of the glaciers of Georgia, who in 1937 together with Al. Aslanikashvili surveyed several glaciers and in 1963 gave us the dynamics of the glaciers during the period of 1937-1960.

Particularly should be mentioned the great and versatile work, which was done by the Glaciological Laboratory of Vakhushti Bagrationi Institute of Geography, the multiannual work of which is summarized in the 1975 year's edition of the Catalog of Glaciers, as well as by the Hydrographical Division of the Hydro-Meteorological Institute, which published the work about the Glaciers of the Greater Caucasus (Editors: V. Tsomaia and E. Drobishev, 1970).

It should be also noted the many years research of various glaciers in the major river basins by R. Gobejishvili. It can be considered his honor that after the 1990s the glaciological studies have not been stopped in Georgia.

L. Maruashvili, D. Ukleba. T. Kikalishvili, G. Kurdghelaidze, D. Tabidze, R. Khazaradze, O. Nikolaishvili, V. Tsomaia, O. Drobishev, R. Shengelia, R. Gobejishvili, K. Mgeladze, T. Lashkhi, Sh. Inashvili, N. Golodovskaia, L. Serebruanny, A. Orlov, O. Nadirashvili, N. Zakarashvili, A. Rekhviashvili, O. Samadbegishvili and others studied the glaciers of Georgia according to the river basins.

Glacial-geomorphological works were being carried out from 1968 (R. Gobejishvili). The largest glaciers of the different river basins were surveyed by the photo-theodolite method, such as: Zopkhito-Laboda, Kirtisho, Brili, Chasakhtomi, Edena, Khvargula, Boko, Buba, Tbilisa, Adishi, Chalaati, Dolra, Kvishi, Ladevali, Shkhara, Namkvani, Koruldashi, Marukhi, Klichi and the cirque type glaciers of the Klichi basin.

Finally, we would like to say, that since 30s of the 20th century until now the observation on the Western, Central and Eastern Caucasus glaciers in Georgia has a nearly continuous nature. Glaciology group of the Vakhushti Bagrationi Institute of Geography is still conducting the constant monitoring of the glaciers of Svaneti, Abkhazeti, Racha and Kazbegi Caucasus.

Introduction

The glaciers are indivisible part of the environment and are a good indicator of the past and current climate change (Tielidze et al., 2015a). Alpine glaciers are an important component of the global hydrologic cycle. Glaciers can help to regulate stream flows in regions where water is stored during cold wet times of the year and later released as melt water runoff during warm dry conditions (Beniston, 2003; Earl and Gardner, 2016). The most serious impact of vanishing mountain glaciers undoubtedly concerns the water cycle from regional to global scales. Glacier melting will probably dominate sea level rise during our century (Meier et al., 2007).

Distribution and diversity of glaciers on the Earth determine their grouping in separate regions by foreseen of the external conditions of existence of glaciers. Such zoning allows us to better understand the characteristics of glaciers' regime and the synchronism of their action in different regions, as well as to relate the distribution of glaciers to the general circulation of the atmosphere and the relief orography.

19 regions have been distinguished on the Earth based on Randolph Glacier Inventory (RGI) (Pfeffer et al., 2014), which is intended for the estimation of total ice volumes and glacier mass changes at global and large-regional scales. It is supplemental to the Global Land Ice Measurements from Space initiative (GLIMS). Production of the RGI was motivated by the preparation of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) (GLIMS Technical Report). As a result of the mentioned inventory, the Caucasus is presented together with the Middle East (as one region) (Fig. 1), but the Caucasus is much larger than the Middle East by the modern glaciation size and it will be interesting if we consider it as a separate region in our work.

The Caucasus Mountains are aligned west-northwest to east-southeast between 40-44° N and 40-49° E and span the borders of Russia, Georgia, Armenia and Azerbaijan. They consist of two separate mountain systems: **the Greater Caucasus** extends for ~1300 km between the Black Sea and Caspian Sea, whilst **the Lesser Caucasus** runs parallel but approximately 100 km to the south. The Caucasus mountains originate from collision between the Arabian plate to the south and the Eurasian plate to the north and the region is tectonically active with numerous small earthquakes (Stokes, 2011).

According to location the Greater Caucasus is divided into three parts: Western**,** Central and Eastern. The borderline among them runs near the meridians of the Mount Elbrus (5642 m) and the Mount Kazbegi (5033 m). In the mountainous system of Caucasus the highest is the Central Caucasus. Several peaks are higher

than 5000 m (e.g. Elbrus, Dikhtau, Shkhara massif and Kazbegi). It is in this section the Europe's highest peak Elbrus (5642 m) with its glacial complex.

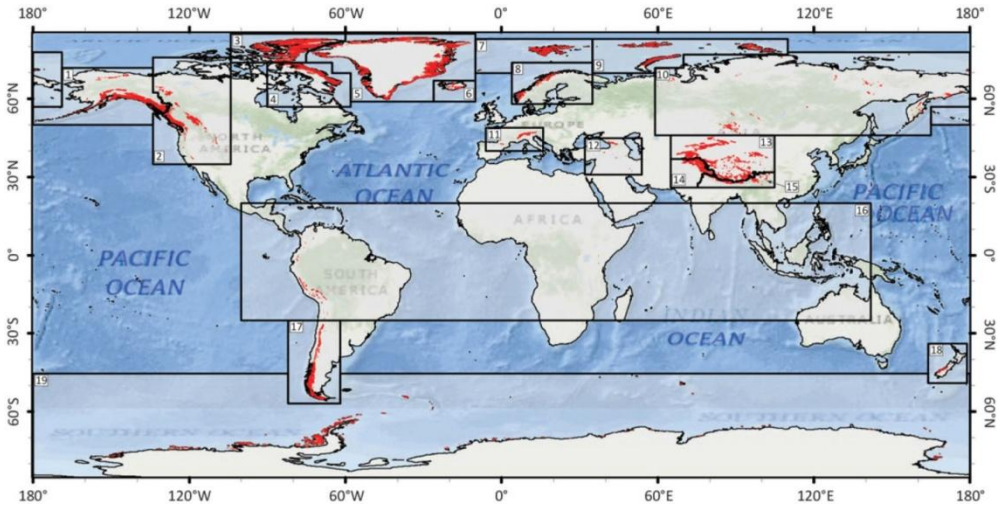

Figure 1. First-order regions of the Randolph Glacier Inventory (version 4.0). 1. Alaska; 2. Western Canada and US; 3. Arctic Canada North; 4. Arctic Canada South; 5. Greenland Periphery; 6. Iceland; 7. Svalbard; 8. Scandinavia; 9. Russian Arctic; 10. North Asia; 11. Central Europe; 12. **Caucasus and Middle East**; 13. Central Asia; 14. South Asia West; 15. South Asia East; 16. Low Latitudes; 17. Southern Andes; 18. New Zealand; 19. Antarctic and Subantarctic (Pfeffer et al., 2014).

The Caucasus Mountains are characterised by strong longitudinal gradients that produce a maritime climate in the west and a more continental climate in the east. Trends in precipitation, for example, reveal that westernmost areas typically receive around three to four times as much as eastern areas (Horvath and Field, 1975). The southern slopes are also characterized by higher temperatures and precipitation, which can be up to 3000-4000 mm in the southwest (Volodicheva, 2002). Much of this precipitation falls as snow, especially on windward slopes of the western Greater Caucasus, which are subjected to moist air masses sourced from the Black Sea (Stokes, 2011).

According to the conditions of relief, the northern slope of the Caucasus is more favorable for formation of glaciers than the southern one. This is contributed by high hypsometry and extremely partitioned slopes, gorges and depressions, represented by wide cirques of Wurm period.

In the Caucasus the current number of glaciation is ~2000 with a total area of ~1100 km^2 and volume ~68 km^3 (Radić et al., 2014). ~33% of the glaciers of the Caucasus is located in Georgia (Fig. 2). These Glaciers are an important source of

water for agricultural production in Georgia, and runoff in large glacially-fed rivers (Kodori, Enguri, Rioni, Tskhenistskali and Nenskra) supplies several hydroelectric power stations. Glacial melt waters are one of the main factors in river runoff formation in the mountainous areas of Georgia. It is necessary to know Glacial waters daily volatility for mountaineering, tourism and mountainous areas of livestock and other sectors of operation. Glacier melt water is also important in terms of water supply in the mountainous regions of Georgia. In the mountainous regions (Svaneti, Kazbegi, Racha and Abkhazeti), in addition to the tourist - recreational purposes, a great role owned the glacial landscapes in the development of the recreational facilities.

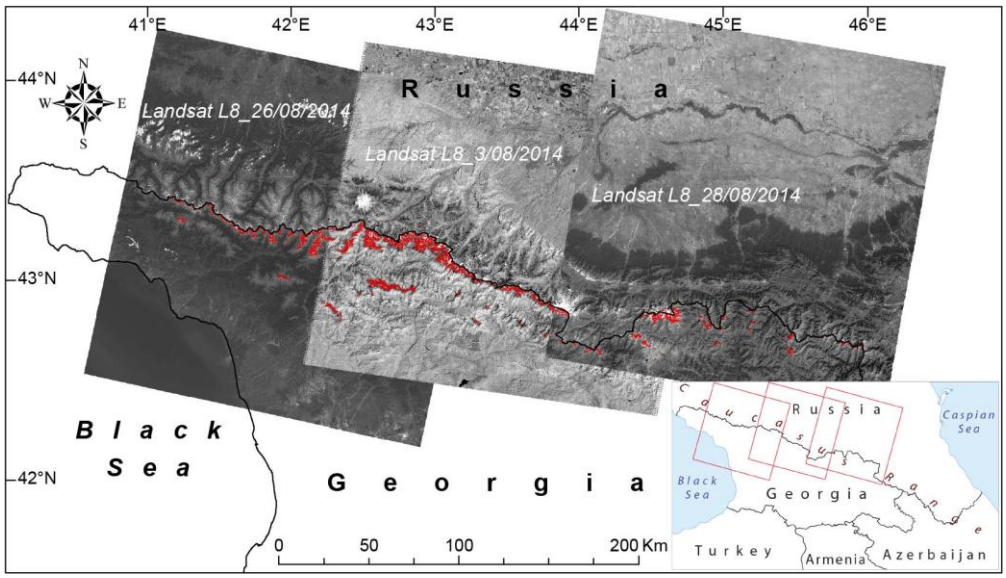

Figure 2. Georgian Caucasus glacier outlines (in red) derived from Landsat 8 (panchromatic) imagery.

Also glacier outburst floods and related debris flows are a significant hazard in Georgia and in the Caucasus (Bogatikov et al., 2003). Unfortunately, such hazards are relatively common in this region and have led to major loss of life. In September 20 of 2002, for example, Kolka Glacier (North Ossetia) catastrophic ice-debris flow killed over 100 people (Evans et al., 2009), and in May 17 of 2014, Devdoraki Glacier (Georgia) catastrophic rock-ice avalanche and glacial mudflow killed nine people. Future trends in glaciers variations are thus a topic of considerable interest to the region.

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The authors of the photos used in the Book: **Levan Tielidze, Ramin Gobejishvili and Fabiano Ventura.** The photos of the glaciers made by the Italian photographers **Vittorio Sella** and **Mor Von Dechy** in the 19th century and the 19th-20th centuries photos of the glaciers kept in the fund of the Museum of Geography at Tbilisi State University are also used.

The authors of the maps used in the Book are: **Ramin Gobejishvili and Levan Tielidze.**

In the front cover page: Chalaati glacier, 1890. Photo by Vittorio Sella.

In the back cover page: Tviberi glacier, Upper - 1884. Photo by Mor Von Dehcy, Lower - 2011. Photo by Levan Tielidze.