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Changes in relief of the Azau Valley in Central Caucasus Mts resulting from impact of volcanic activity and glaciers' oscillations during the last 1100 years

Adam Łajczak*

Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland

Abstract: I analysed changes in the relief of the partly glaciated Azau Valley in the Central Caucasus, neighbouring to Elbrus volcanic cone (5643 m a.s.l.) resulting from intensification of volcanic activity and valley glaciers' oscillations during the last 1100 years. Field research, analysis of topographic maps and photographs from the last 140 years as well as information in literature were the basis for my work. I identified the most important geomorphological processes modelling the valley: a lava flow, floods of *jökulhlaup* type, glaciers' transgressions and recessions, erosion of moraines and mass movements on the slopes. I distinguished eight sections of the Azau Valley varied in their relief and being under the differentiated influence of the listed geomorphological processes. The valley under question, represents the Alpine type area of typical cascade like transfer of waste material from the slope to the valley systems and further along its floor. Hanging tributary valleys on the Azau Valley slopes are valleys exporting waste material while the main valley functions as the valley importing waste material. In the period of absence of visible volcanic activity of Elbrus, the fastest changes in the Azau Valley relief take place during the recession of the valley and slope glaciers and of ice cap on this volcano. Findings proof interdependence of intensity of material aggradation in the valley and the amount of moraine deposits which can quickly erode and be transported to the stream channel, easily accessible weathered material derived from marginal ice-free areas as well as on the volume of ice melting water discharging great loads of sediment.

Key words: Azau Valley, Caucasus Mts, glacier oscillation, jökulhlaup effect, Little Ice Age, volcanic activity

Introduction

Glaciated active volcanoes and valleys neighbouring to glaciers can be included into areas of the highest dynamics of erosion and accumulation processes in slope and valley systems. The course of these processes is reflected in quick changes of valley relief that can be noticed even within several to dozen or so years. In such areas the shape of slopes and valley floors is directly or indirectly determined by volcanic phenomena, glacier oscillations, moraine erosion, mass movements - particularly debris flows. The greatest and the fastest changes in these areas modelling take place in the periods of higher volcanic activity, when exceptionally vast amount of water from melting ice may transport a great load of material from the slope to valley floor and further downstream. Such processes and their geomorphological consequences were described in various areas, for example around St. Helen's volcano in the Rocky Mountains and Elbrus in the Caucasus (Tushinsky 1968, Flink et al. 1981, Zolotariev & Seinova 1997, Seinova & Zolotariev 2001, Łajczak 2006), and especially in Iceland (Thorarinsson 1957, Einarsson et al. 1980, Jónsson 1982, Russell et al. 2002, Gudmundsson 2005, Karasiewicz 2005, Russell 2005). The literature is setting the question, refering to all Alpine areas, whether the changes in valleys' relief are faster during glacier transgression or recession (Maizels 1979).

Studies on above mentioned problems took place in the Alpine Azau Valley in Central Caucasus Mountains neighbouring to Elbrus volcano (5,643 m a.s.l.) – the highest summit the Caucasus (Fig. 1).

* e-mail: alajczak@o2.pl

Study area

The Azau Valley 8 km long is situated between the main ridge of the Caucasus made of crystalline rocks mainly granites, reaching 3,760 m a.s.l. here (Mount Kheget) and a volcanic cone of Elbrus (5,643 m a.s.l.) (Figs. 1, 2). Its floor is at an altitude of about 2,100 m a.s.l. (junction with the Terskol Valley) and 3,200 m a.s.l. (the beginning of tongue of the Great Azau Glacier). The Azau Valley is the highest section of the Baksan River valley, which is a tributary of the Terek River. The course of valleys in this part of the Caucasus is related to the main tectonic fractures of SW–NE and NW–SE direction (Bashenina et al. 1974a, b). In the Azau Stream catchment fractures with the direction close to the latter dominate (Fig. 3).

Development of Elbrus volcanic cone started between 3 and 2 million years ago in the place of a deep tectonic split (Tushinsky 1968). The volcanic cone is mainly made of dacitic and basaltic lavas. It is laid on the Palaeogene planation surface formed of granites and metamorphic rocks (Gerasimov 1974). The volcano is considered to be dormant although it was active till the 16th century (Tushinsky 1968). There are two craters on its top and 13 second rank cones on its slopes. The reservoir of lava 10 km wide reaches the height of 2,000 m a.s.l. under the volcanic cone of Elbrus (Koronovsky 1985). The youngest lava flows went down the northern slope of Elbrus 2000–2500 yrs. ago and on the southern slope about 1100 years ago reached the floor of the Azau Valley (Figs. 4, 5). Since then volcanic activity of Elbrus was gradually diminishing. The Persian descriptions from the 16th century call the volcano "fuming mountain"; the name "Elbrus" comes from Persian and means "white plait" (Tushinsky 1968). Now fumaroles exhale only from the eastern younger crater and there are thermal springs around the volcano (Fig. 3).

In the Azau Stream catchment, similarly to the prevailing part of the Caucasus, the landscape is typically Alpine i. e. shaped by glaciers. Contemporary glaciation covers only upper parts of valleys and slopes above the snow line at the altitude 3,700 m a.s.l. There are valley, kar, slope and rock glaciers. The greatest glaciated area in the Caucasus covers the volcanic cone of Elbrus with the ice cap of average width over 25 km and 100 m thick from which nineteen tongues up to 5 km long flow down (Figs. 6, 7). These ice tongues are flowing down to the altitude 2,500–2,800 m a.s.l. Three glaciers: the Great Azau, the Small Azau and the Garabashi are flowing

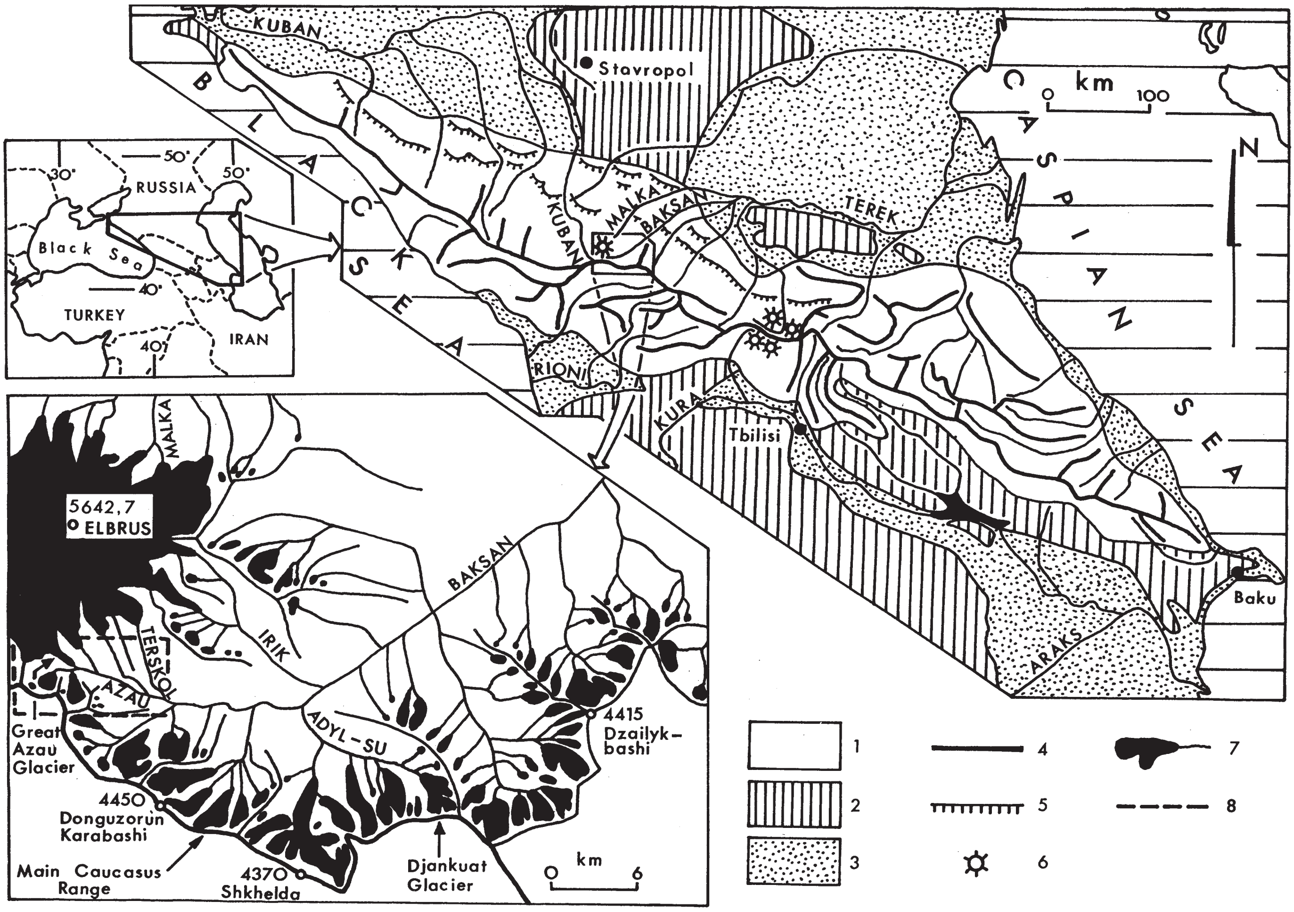

Fig. 1. Location of investigated area (after Tushinsky 1968, Gerasimov 1974, 1980)
1 – range of the Caucasus, 2 – neighbouring mountains and uplands, 3 – lowlands, 4 – main mountain ridges, 5 – cuestas, 6 – volcanic cones, 7 – glaciers, 8 – extent of the thoroughly studied area

Fig. 2. The Azau Valley
In the foreground fragment of the southern slope of Elbrus, further the main ridge of the Caucasus. On the floor of the valley the upper forest limit

down from Elbrus to the Azau Valley. The next glacier Terskol feeds the Terskol Brook going down from the neighbouring valley. From the main ridge of the Caucasus to the Azau Valley considerably two short valley glaciers flow down, five tiny cirque or niche glaciers and three rock glaciers accompanied them (Łajczak 2006).

The extension of contemporary glaciation of the Azau Valley is considerably smaller than Quaternary glaciations when this valley and also a big part of the Baksan valley were totally filled with ice. It is also smaller than the greatest glaciations in historic times. Traces of the Azau Valley glaciations from the period of glaciers' transgression called the Egessen Phase (in Russian the Historic Phase) which took place in the first millenium BC, have not been preserved (Bashenina et al. 1974a). The Little Ice Age in the Russian literature called "transgression of the 1850's" and in languages of the Caucasian nations

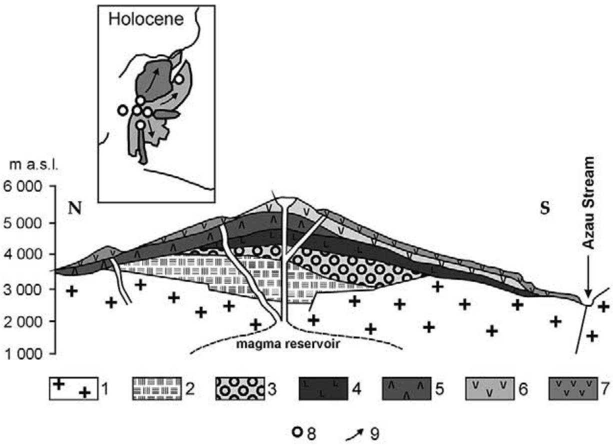

Fig. 4. Geological structure of Elbrus (after Tushinsky 1968, Koronovsky 1985)
1 – granite basement of the volcano, age of lava and other volcanic material: 2 – older than Upper Pliocene, 3 – Upper Pliocene, 4 – Middle Pleistocene, 5 – Upper Pleistocene, 6 – Holocene (older), 7 – Holocene (younger). In upper part of the figure the horizontal distribution of Holocene lava flows is presented: 8 – places with active craters, 9 – main directions of lava flows

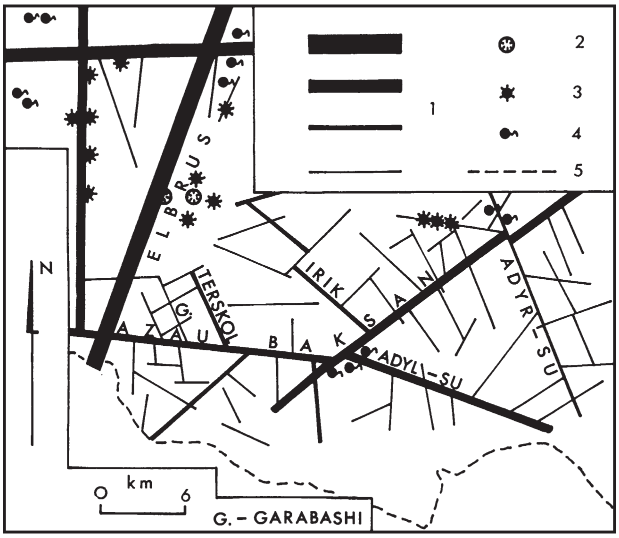

Fig. 3. The course of tectonic fractures within Elbrus and in its southern surroundings (after Bashenina et al. 1974a)
1 – dimentions of fractures (from the biggest to the smallest), 2 – craters, 3 – second rank volcanic cones, 4 – thermal springs, 5 – main ridge of the Caucasus

"Alibek transgression" began in the Caucasus already in 13th century. Till the 19th century two main transgression of glaciers left their traces: in 16th–17th century with maximum of their length about 1700 and in the first half of the 19th century with next maximum of length about 1850 (Tushinsky 1968, Boyarsky 1978). The extent of glacier recession between these two transgressions is not known. Presently 63% of the Azau Stream catchment area is covered with glaciers and almost 90% of this surface is on the southern slope of Elbrus (Łajczak 2006).

The Azau Valley and tributary valleys are glacial throughs above which – from the side of the main ridge of the Caucasus – elevate narrow ridges with rocky slopes or with rocky walls with culminations formed as pikes and karlings (Fig. 2). Inclination of the southern slope of Elbrus is smaller than the opposite slope of the main ridge of the Caucasus. It diminishes alongside the altitude and is the lowest at the altitude 4,000–4,500 m a.s.l., and further towards both culminations of the volcano grows to over 60° (Fig. 5). On this slope, a form of which is diversified, are nu-

Fig. 5. View to volcanic cone of Elbrus from the south
Visible two culminations, ice-cap with flowing tongues

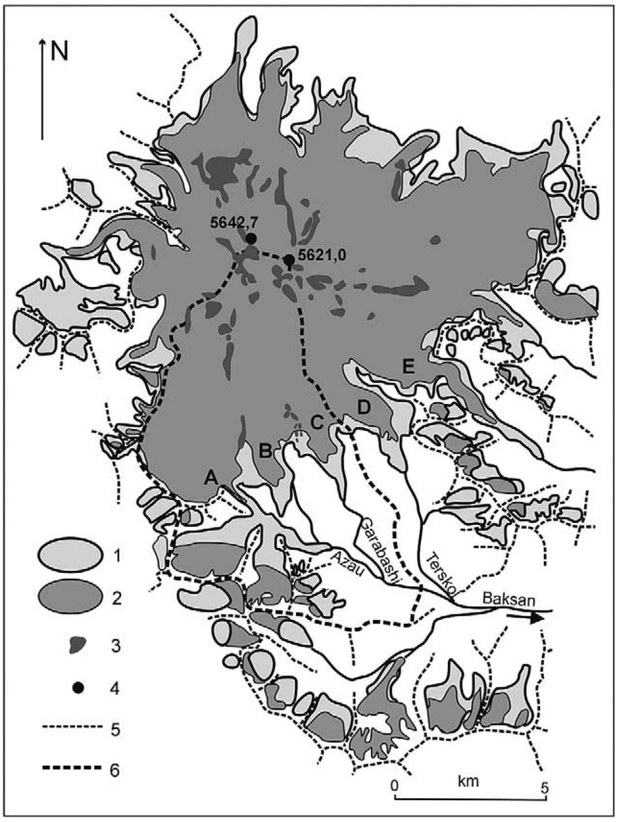

Fig. 6. The present-day distribution of glaciers on Elbrus volcano and its southern surroundings (after Tushinsky 1968; Koronovsky 1985; satellite photograph 1990)
1 – areas glaciated in 1887 and now totally deglaciated, 2 – limit of glaciers in 1990, 3 – lava flows exposed over ice-cap on Elbrus, 4 – craters, 5 – main ridges around Elbrus, 6 – limit of catchment of the Azau Stream to gauging station at Terskol village. Glacial tongues flowing from ice-cap on Elbrus to south: A – Great Azau Glacier, B – Small Azau Glacier, C – Garabashi Glacier, D – Terskol Glacier, E – Irik Glacier

merous lava flows of various age, from which at greater altitudes only few protrude from under the ice cover. The longest and the youngest lava flow distinct in the relief of the southern slope of Elbrus has its beginning under the ice cap and reaches the floor of the Azau Valley, where separates the Great Azau Glacier and the Small Azau Glacier (Figs. 4, 6). Above the Garabashi glacier under the ice cap of Elbrus small volcanic cone has been documented (Koronovsky 1985). The southern slope of Elbrus is divided into valleys only in the bottom part, glacial throughs in this area are incised to the granite basement only in their lowest parts (Tushinsky 1968, Bashenina et al. 1974b). Characteristic feature of all glacial throughs in the catchment of the Azau Stream are steep, abrupt slopes dismembered of numerous gullies accompanied by rockfall gravity sorted talus cones of various sizes. Valley floors are padded with moraines and glacifluvial deposits of high thickness, in the lower section of the Azau Valley up to 200 m (Tushinsky 1968, Koronovsky 1985).

Precipitations in discussed area of the Caucasus exceed 2,000 mm and concentrate in summer season (Gerasimov 1980). Strong intensity of snow avalanches is the other climatic factor influencing the strength of slope processes (Tushinsky 1968, Gerasimov 1980). There are following vertical zones in the Azau Valley (see Fig. 2): pine forest up to 2,100 m a.s.l., birch-pine forest (2,100–2,300 m a.s.l.), rhododendron shrub (2,300–2,700 m a.s.l.), alpine grassland (2,700–3,000 m a.s.l.). Higher up to the snow line 3,700 m a.s.l. are rocky slopes and boulder fields. Now, about 40% of the Azau Stream catchment surface is padded with boulder or regolith wast mantles including moraines denuded as the result of glacier recession since 1850 (Łajczak 2006). Erosion of these mantles results from snow avalanches of ground type and from May to October when air temperature is above 0°C, results from heavy rainfalls that activate debris flows and locally landslides (Zolotariev & Seinova 1997, Seinova & Zolotariev 2001).

The history of Azau Valley relief research

In the studies on relief of the Azau Valley as in the whole Caucasus the scientists, since the thirties of the 20th century concentrated on structural foundations of valley courses, longitudinal profiles, shape of slope (for example Bashenina et al. 1974a, b). In the sixties of the 20th century and later there were many publications on the development of volcanic cone of Elbrus, the youngest activity of this volcano and age of lava flows (Tushinsky 1968, Bashenina et al. 1974a, b, Koronovsky 1985). Geomorphological and sedimentation effects of volcanic eruptions were mentioned as visible in general relief features of valleys in the neighbourhood of Elbrus such as the Azau Valley, valleys of the upper Kuban and upper Malka rivers.

The first descriptions and photographs of glaciers in the Azau Valley and its neighbourhood were taken by the German geographer H.W. Abich (1852, 1871). They register maximum glaciers' extent during their second transgression in the Little Ice Age i.e. in the mid 19th century (Fig. 8). Further changes in glacier extension in the Azau Valley can be seen on topographic maps from 1887, 1933 and 1962, in satellite photograph from 1990 as well as descriptions published in 1910 and 1947 and first of all in photographs of these objects taking of which started in 1933 and taken four times between 1957 and 1978. Glaciological Station of the Moscow State University carries out research on glacial extent in the widest range of the Djankuat Glacier in the Adyl-Su Valley situated 25 km eastwards from the Azau Valley (see Fig. 1). This research work uses lichenometric methods (Boyarsky 1978). The furthest ranges of this glacier in the Little Ice Age were dated

Fig. 7. Fragment of ice-cap on the southern slope of Elbrus
Visible clefts in the ice and outcrops of lava flows. In the background the main ridge of the Caucasus

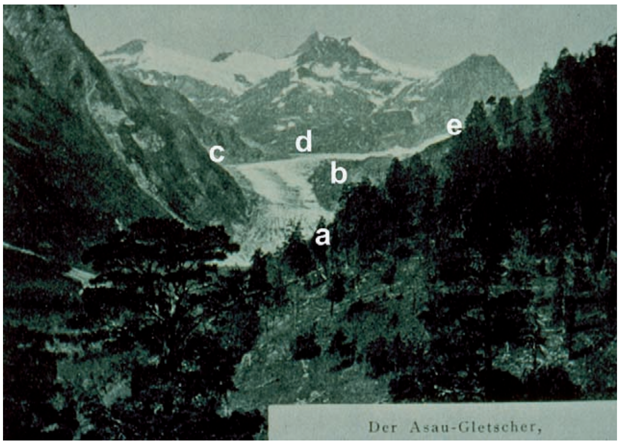

Fig. 8. The tongue of the Great Azau Glacier in the photograph by Abich (1871)
On the right fragment of the southern slope of Elbrus, on the left the main ridge of the Caucasus. a – present location of the Moscow State University Station on the Azau Clearing (*Polyana Azau*), b – the lowest part of the youngest lava flow (ca. 1100 BP), c – Mount Kheget slope undercut by the glacier, d – elevated part of the glacier above the gorge and lava flow, e – present position of glacier front

at about 1700 and 1850. In the case of the Great Azau Glacier much attention in literature was paid only to its extent in the mid 19th century and to its later recession (Abich 1852, 1871; Tushinsky 1968; Zolotariev & Seinova 1997; Seinova & Zolotariev 2001), but its earlier extension during the Little Ice Age was not mentioned.

Studies initiated by Tushinsky (1968) on snow avalanches are carried out near Elbrus. Due to the activities of the Moscow State University Station on the Azau Clearing which started in the seventies of 20th century the scope of studies has been broadened, studies on debris flows and dynamics of river channels have begun (Zolotariev & Seinova 1997, Seinova & Zolotariev 2001). Scientists stated various stages of the 19th century moraine ramparts preservation, transgression and later recession of glaciers and the lack of such forms from earlier transgression of glaciers (Tushinsky 1968). Ramparts of lateral moraines situated at high altitudes considered to be as places where debris flows are formed (in Russian literature they are called *syelas*), particularly when they are filled with ice (ice-cored moraines). The Russian scientists attribute the leading role in remodelling the Azau Valley to debris flows, similarly as in the whole Caucasus region (Zolotariev & Seinova 1997, Seinova & Zolotariev 2001).

Except some information given by Tushinsky (1968) and Koronovsky (1985) not much has been said about the role of volcanism in modelling of the Azau Valley (the same refers to valleys of the upper Kuban and upper Malka rivers on the opposite side of Elbrus). Attention was paid to high thickness of glacifluvial deposits in the valleys around Elbrus. This thickness is the greatest at the mouths of brooks fed by the largest glacial tongues on this volcano. This is why the supply of material from Elbrus the Azau Valley and further to the Baksan Valley, through the Garabashi, the Terskol and the Irik brooks makes longitudinal profile of sequence of valleys between above mentioned tributaries is convex. Nevertheless according to Bashenina et al. (1974a) uneven longitudinal profile of the Azau Valley and further the Baksan Valley depends on the geological structure. According to the cited authors convex thresholds of the valley floor occur on the contact between granites and metamorphic rocks, and downstream between these rocks and sedimentary ones.

Descriptions of lava flows now protruding from the ice cover up to 200 m, show past size of short lasting period of ice melting on the cone of Elbrus resulting from volcanic activity (Koronovsky 1985). Effects of former melting of huge mass of ice on the Elbrus were also documented by geophysical tests of the ice cap. They indicate the occurrence of layer of clastic sediment inside the ice on the depth of 60–100 m (Bashenina et al. 1974a, b). This layer of sediment makes the embracing similar to ice-cored moraine which preceding the Great Azau Glacier front. According to cited authors these remnants of ice-cored moraine inside the ice cap of Elbrus originate from the period preceding the Little Ice Age and they are probably connected with the last lava flow about 1100 years ago.

Scope and aim of studies

Scope of studies concerned the detailed geomorphological mapping of the Azau Stream catchment below the snow line (scale 1:5,000) being the basis of contemporary relief of this landscape analysis. Maps, photographs and descriptions of the Great Azau Glacier and some events from the newest history of the Azau Valley and its surroundings were analysed. On the basis of this together with the results of three times repeated transverse levelling of the valley, the spatial differentiated rate of changes in this valley relief was proven. Basic studies were carried in October, 1990 and suplementary ones in 1993, 1999 and 2002.

The aim of this paper is to analyse changes in the Azau Valley relief which took place during the last 1100 yrs. under the influence of volcanic activity of Elbrus distinguishing direct and indirect impact of volcanism and effect of glacier range oscillations with particular attention to their recession during the last 150 yrs. This work aims at presenting the studies more detailed than the previous ones carried out by the Russian geomorphologists.

Methods

Geomorphological studies in the Azau Valley were carried out during my visit at the Moscow State University Station situated on the Azau Clearing. Later, suplementary field works were carried out on the basis of information obtained from the literature. This resulted in the included geomorphological map of the Azau Valley, the first so detailed, which is presented in this paper for the first time (Fig. 9).

I paid particular attention to distribution of lateral moraine ramparts the course of which was correlated to: glaciers' extent demonstrated on topographic maps from 1887 (Pastukhov's map), 1933 and 1962, glaciers' extent described in the literature (additional extension from 1848, 1873, 1910 and 1947 yrs.) and precisely presented in the photographs from 1881, and photographed four times between 1957 and 1978 and the satellite photograph of this part of the Caucasus from 1990. The record of the Djankuat Glacier extension in the neighbouring the Adyl-Su Valley has been kept since 1700 (Boyarsky 1978), and on the basis of analogy there were attempts to find geomorphic proves indicating not only maximum extent of glaciers in the Azau Valley in the mid 19th century (which was easier due to existing cartographic material and the literature), but also those from the period 150 years earlier. Results of these investigation are discussed in the next part of this paper. Knowing distribution and age of moraine ramparts in the Azau Valley which were formed during the maximum extent of glaciers in the Little Ice Age and consecutive stages of their recession starting in the mid 19th century, fifteen geomorphologic profiles across the valley were performed. They encompassed fragments of slopes with moraines of various ages. Repeated observations along these profiles in listed dates, and the analysis of photographs taken earlier allowed to determine the rate of moraines' degradation and trend of changes in slope and valley floor relief resulting from deposition of glacifluvial material. Having above mentioned data and results of repeated field observation, changes of glaciers' front extension in the Azau Valley after 1850 were determined. Planned visit to this valley in summer 2008 in order to repeat observation was impossible. Presented findings concern the period up to 2002 although some facts i. e. further changes in the extent of the Great Azau Glacier front – brought up to date on the basis of information obtained from the Russian geomorphologists from 2007. During field works attention was paid to glacifluvial sediment framework discriminating the source of material deposited on various depth i. e. deriving from the volcanic slope or from granite slope of valley.

Mentioned cartographic materials and majority of old photographs, as well as abundant geomorphological literature of the Caucasus and particularly on the Azau Valley were rendered in the Moscow State University Station on the Azau Clearing.

Results

Relief of the Azau Valley today

The Azau Valley is a typical glacial through, but the relief of its southern slope is fundamentally different from northern one (Fig. 9). Inclination of the southern slope formed of granite is on average 45° and in its lower and upper parts on the whole length of the valley often exceeds 60°. As a result of glacial undercut of slope, tributary valleys are hanging and below them there are glacial polished thresholds of slope. Numerous rocky gullies dissect the slope along which talus material is moving to active debris cones in the upper part of the valley and to paraglacial fans in the lower part of the valley. Lateral moraine ramparts have strongly eroded due to the high slope gradient and on the steepest fragments of slope they have completely eroded. They are preserved only on the slope in the upper part of the valley and in lateral hanging valleys. Moraine material is eroded by debris flows.

The northern slope of the Azau Valley has twofold form. Its bottom part is made of the same granite rocks as the southern slope, while above 300 m over the floor of lower section of the valley and over a 100 m the floor of its upper part this slope is made of volcanic rocks. The front part of old lava flows there are rocky walls high up to 100 m which landslides and rockfalls have modelled. The lower granite part of slope is steep (to about 50°) and above the walls made of volcanic rocks the inclination of the slope diminishes to 20°–30°. Inclination of glaciated southern slope of Elbrus in its central part does not exceed 30° and not lower than at altitude 4,500 m a.s.l. it quickly changes and exceeds 60° at both culminations of volcano. In the bottom part of northern

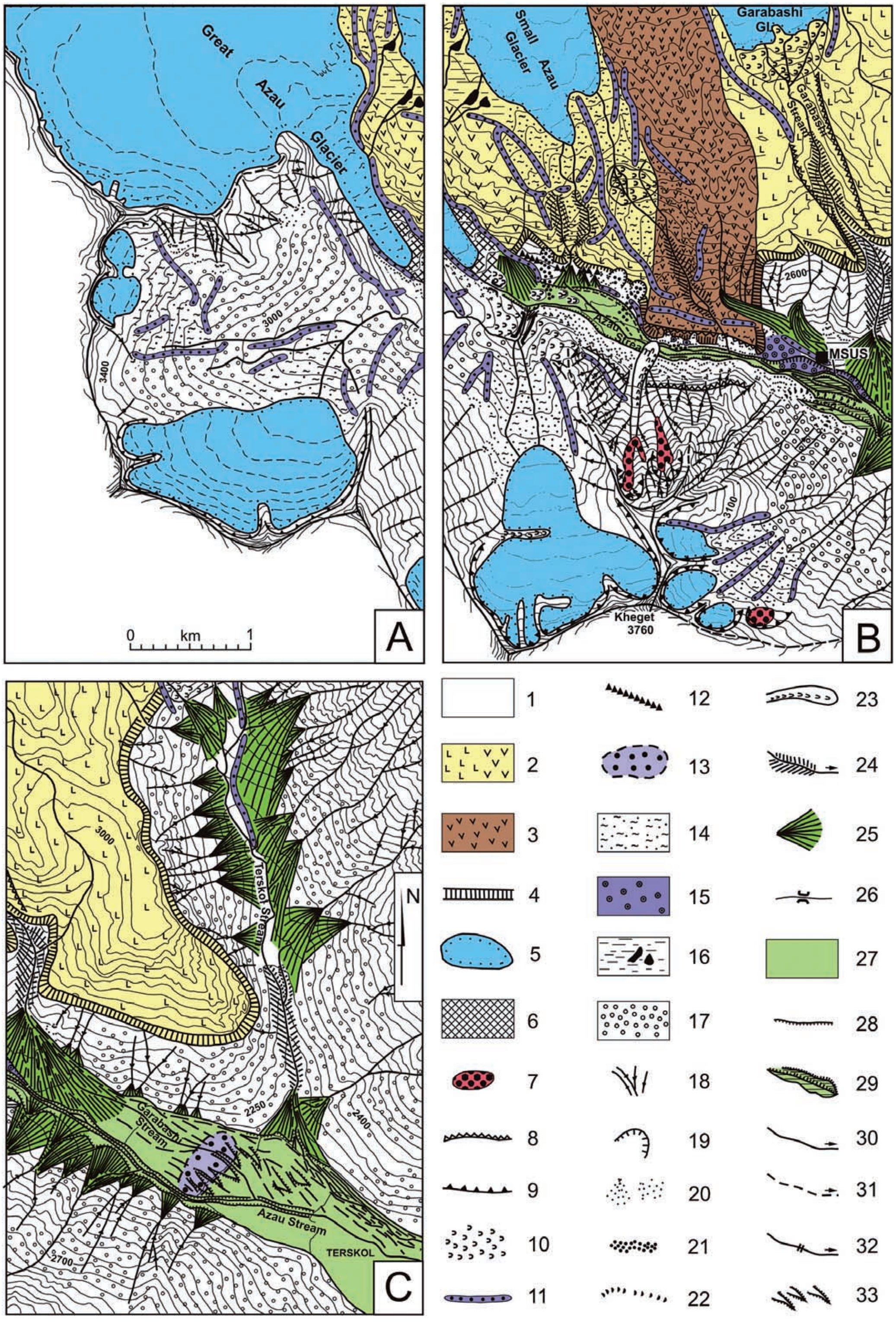

Fig. 9. Geomorphological map of the Azau Valley (by the author)

1 – slopes built by granite rocks, 2 – by older Holocene lavas, 3 – the youngest lava flow (ca. 1100 BP), 4 – volcanic rock walls, 5 – glaciers, 6 – dead ice, 7 – rock glaciers, 8 – vertical limit of slopes undercut by glacier within U-shaped valley, 9 – vertical limit of glacially steepened slopes around cirques, 10 – roche moutonnees, 11 – fragments of frontal and lateral moraine ramparts formed in 19th and 20th centuries, 12 – traces of lateral moraine ramparts visible as conical mounds of debris, 13 – fossilized frontal moraine rampart from about 1700, 14 – preserved ground moraine, 15 – ground moraine with dead-ice forms, 16 – lacustrine sediments with accompanying shallow lakes, 17 – fields of boulders on slopes, 18 – rocky gullies, 19 – niches of landslides, 20 – rockfall gravity sorted talus cones and slopes, 21 – tongues of landslides, 22 – larger solifluction tongues, 23 – multi-annual snow patch, 24 – V-shaped incisions deepened glacial troughs, 25 – alluvial fans / paraglacial fans, 26 – small gorges, 27 – flat valley floor overbuilt by glacifluvial material, 28 – erosional scarps in valley bottom, 29 – 2 m and 5 m terraces upstream of former frontal moraine rampart from ca. 1850, 30 – channels of permanent streams, 31 – channels of seasonal streams, 32 – waterfalls, 33 – incisions of flat valley bottom in surroundings of fossilized frontal moraine rampart from ca. 1700. A large number of debris flows is not marked. Contour lines every 50 m. MSUS – location of the Moscow State University Station

slope of the Azau Valley, ramparts of even the youngest lateral moraines have eroded. These ramparts have been preserved on higher less inclined fragments of the slope. In the relief of northern slope of the Azau Valley the youngest basaltic lava flow formed about 1100 years ago and which flowed to the bottom of the valley distinguishes. It is preceded by narrow gorge with vertical slopes and which typical U-shaped profile formed during the transgression of the Great Azau Glacier in the Little Ice Age (Tushinsky 1968, Koronovsky 1985). The floor of the gorge is the place of intensified deposition of slope material and of avalanche snow (which does not melt before winter), therefore there is a vast snow bridge over the Azau Stream in this place.

Preserved ramparts of lateral moraine indicate the position of particular glaciers during their maximum extension in the mid 19th century and also during their further recession (Tushinsky 1968, Koronovsky 1985). Only in hanging valleys on the southern slope of the valley and in front of glacier tongues on slopes of Elbrus fragments of frontal moraine ramparts have been preserved, which shows the extent of glaciers during their recession in the last 150 years (cited cartographic material). Ramparts of frontal moraines have been preserved on the least inclined fragments of slopes of the Azau Valley. On the Azau Valley floor these moraine ramparts from 19th and 20th century have not been preserved (Tushinsky 1968, Koronovsky 1985), which tells us that they have either totally eroded or covered with younger deposits. Only fragments of frontal moraine rampart of the Great Azau Glacier formed most probably during its maximum extent about 1700 are visible (Łajczak 2006). Frontal moraine ramparts have not been preserved on the floors of glacial throughs dividing the bottom Elbrus southern slope. V-shaped valleys are incised in the above mentioned bottoms.

Moraine ramparts on the slopes particularly these at their feet limit the extent of debris flows, retain or limit displacement of material coming from rock falls, slides and solifluction. Depressions between slope and lateral moraine ramparts function as local basins of accumulation can be found at various heights above the floor of the Azau Valley. After these bassins are filled and breaking in moraine ramparts continuity due to their erosion, removal of material earlier deposited in these areas begins. Particularly big amounts of material removed in this way are observed as a result of frontal moraine ramparts erosion. These ramparts are at foreland of now significantly reduced glaciers on the southern slope of the valley, some of which turned into rock glaciers. Below such places on the floor of the Azau Valley big paraglacial fans are formed, though the biggest alluvial fan in this valley is located at junction with the Garabashi Valley at the feet of Elbrus cone. The main source of the material forming this fan are not eroded moraines but dissected and deepened glacial through of the Garabashi Valley.

Material removed from the slopes of the Azau Valley is deposited in particular sections of its floor with various intensity. Therefore the valley has staircase longitudinal profile. There have been distinguished the following sections of the valley varying in shape and intensity of slope material deposition:

A – section of the valley covered with a tongue of the Great Azau Glacier 1.5 km long and 200–300 m wide (Fig. 10). Because of the steepenest of this place there is a glacier cascade below which dead ice and ice-cored moraine is deposited and from under which glacial polished granite are cropping out. Lateral moraine ramparts occuring up to 300 m above the glacier indicate its shrinking during the last 150 yrs.,

B – 1.5 km long section of the valley downstream ice-cored moraine of the Great Azau Glacier to the front of lava flow being a gorge (Figs. 11, 12). On the 300 m wide floor of the valley there is deposited coarse grained glacifluvial material originating from the eroded moraines as well as landslides, rock falls and debris flows. There are numerous debris cones. Profile of the valley floor is staircase, glacial polished rocks cropping out from the ice are gradually covered with glacifluvial material till are fully burried. Short fragments of lateral moraine ramparts are preserved only on the southern slope of the valley at the height up 300 m above its floor, on the northern slope they were eroded to such an extent that they are preserved on small areas only in the form of small conical mounds of debris,

C – 100–200 m narrow and 1 km long gorge at the front of the youngest lava flow (Fig. 13). In the frontal part of this lava flow there are visible vertical basaltic columns over 50 m high. At the feet of both slopes of the gorge there are numerous active debris cones. During the last transgressions of the Great Azau Glacier there was only enough space in the

Fig. 10. Upper part of the Azau Valley
In the background the Great Azau Glacier tongue and dead ice. On the right fragment of the southern slope of Elbrus, on the left the main ridge of the Caucasus

Fig. 11. Glacifluvial material formed of boulders covering the floor of the highest section of the Azau Valley
On the right fragment of the southern slope of Elbrus on which are singular conical mounds of debris on the place of previous lateral moraine rampart, on the left the main ridge of the Caucasus. In the background a front of the Great Azau Glacier

Fig. 12. Bottom part of the southern slope of Elbrus in the highest section of the Azau Valley
The rampart of the lateral moraine has almost totally eroded, in this place are singular conical mounds of debris. Big dimensions of slope material deposition on the floor of the valley. In the background the lowest part of the youngest lava flow (ca. 1100 BP)

Fig. 13. Gorge in the Azau Valley
On the left the front of the youngest lava flow with exposed basalt columns over 50 m high. Snow bridge over the Azau Stream. View down the valley

gorge for a part of its mass, the rest of the ice was flowing over lava flow, that's why lateral moraine ramparts occur on this lava flow at the height up 300 m above the floor of the valley (see Fig. 8). On craggy granite slope moraines have not been preserved. Snow avalanches descending from Mount Kheget form a thick cover of avalanche snow on the floor of a gorge,

D – 0.8 km long but almost 500 m wide section of the valley downstream of the lava flow which ends in the place of eroded frontal moraine of the Great Azau Glacier formed in the mid 19th century. Superposition of former frontal moraine onto vast alluvial fan of the Garabashi Brook caused damming up the Azau Stream and glacifluvial material accumulation. Further erosion of these deposits, two terraces were formed: about 2 m and 5 m. Paraglacial fans are more numerous at the base of the southern slope of the valley. In this part of the Azau Valley there are no longer even traces of lateral moraine ramparts also. Rampart of frontal moraine of the Great Azau Glacier from the mid 19th century was either eroded or fossilized,

E – section of the valley encompassing the whole length (1.3 km) of the base of alluvial fan of the Garabashi Brook (Fig. 14). The fan is active and being extended by clasts of basalt diameter up to 0.3 m. Basalt blocks and less often granite blocks (diameter up to 3 m) are common in many places of the fan and inform us about much greater flows of the Garabashi Brook which use to shape this area in the past. There is a pine forest in this fragment of the valley and it is gradually burried which proves that the fan of the Garabashi Brook is still being extended. The floor of this section of a valley up to 800 m wide is covered by this fan, so the channel of the Azau Stream incised to 10 m depth is on peripheral area at the base of the right slope of a valley. Such a shape of the valley floor as well as undercut of all paraglacial fans only at the base of the southern valley slope as a scarp a dozen or so meters high of rectilineal run indicates a vast amount of water flow from the Garabashi Valley to the Azau Valley. The terrace about 30 m high at the base of the left slope of the valley present above alluvial fan (D section of the valley) may indicate high aggradation of this fragment of the Azau Valley as a result of growth of the Garabashi Brook fan till the time the Azau Stream deeply dissect its base,

F – the low section of the valley from the alluvial fan of the Garabashi Brook to the frontal moraine rampart of the Great Azau Glacier of about 1700 (Fig. 14). Valley section length 0.7 km, width 0.8 km. Features of this part of valley are similar to the higher one. Numerous dry braided channels of the Garabashi Brook functioning during its extensively intensified flow distinguished it,

G – 0.3 km short but 1 km wide section of the valley in the place where the fossilized frontal moraine

Fig. 14. Lower part of the Azau Valley
On the left fragment of the southern slope of Elbrus, on the right the slope of the main ridge of Caucasus. a – the Azau Stream, b – alluvial fan of the Garabashi Brook, c – location of fossilized frontal moraine rampart of the Great Azau Glacier from about 1700, d – undercuts of paraglacial fans at the feet of the southern slope of the valley. Visible debris flows and solifluction tongues on the slopes. View down the valley

rampart of the Great Azau Glacier from 1700 cropps out (Fig. 14). This rampart of unknown height was almost totally covered with the material transported by the Garabashi Brook. In numerous dry erosional clefts up to 5 m deep, top parts of basalt and granite boulders are visible. They could have been transported to this place only by the Great Azau Glacier,

H – flat-bottomed section of the valley to the mouth of the Terskol Brook, 0.8 km long and up to 1,100 m wide (Fig. 14). Alluvial fans are less numerous and are smaller, the dissection of the Azau Stream channel is also more shallow. The feature of this part of the valley, is the contrast between its wide and flat floor and steep slopes indicating the high thickness of deposited glacifluvial material in the glacial through.

Geomorphological consequences of lava flow to the valley about 1100 years ago

The last episode of lava flow reaching to the Azau Valley floor, took place of about 1100 years ago in the warm period of Holocene (Tushinsky 1968, Koronovsky 1985). Geomorphological results of this lava flow were twofold.

The lava flow of about 100 m thick in its lower part dammed up the valley and formed a barrier lake, which for some time functioned as a deposition basin (No 1) which accumulated material delivered by proglacial brooks. Traces of old lacustrine sediments indicate this process. When the basin was formed probably material transported from the southern slope of Elbrus by vast amount of water from melting ice was being filled the fastest. Later this basin was also filled with material delivered from the opposite granite slope. Eroding of the lowest part of the lava flow by the Azau Stream and later widening the gorge formed in this place by transgressing the Great Azau Glacier during the Little Ice Age made possible removal of lacustrine sediments from this part of the Azau Valley. Few granite pebbles, in the lower part of southern slope of Elbrus occurring on the volcanic rock basement were found by the author, can be recognised as the only trace of these sediments in the place of their primary occurrence. These pebbles must had been transported from the main ridge of the Caucasus from the opposite slope of the valley and were most probably deposited during advanced filling of dammed lake. Site location of these pebbles exclude the possibility of their supply by the Great Azau Glacier. If damming the Azau Valley by the lava should be considered manifestation of direct influence of volcanism on modelling this area then aggradation with sediments of ca. 2 km long part of the valley which was higher and their later removal can be recognized as a form of indirect effect of volcanic impact.

Another geomorphological result of indirect volcanic impact on the shape of the Azau Valley is the shift of the right valley slope in place of the gorge in front of lava flow, i.e. in section C of the valley (see Fig. 9 B). This shifting of the slope resulted from undercutting it by the Great Azau Glacier during transgressions in the Little Ice Age. Photograph taken by Abich (1871) shows characteristicly bent of tongue of the Great Azau Glacier in this part of the valley, the tongue undercuts the right slope at the Mount Kheget (3,760 m a.s.l.) (Fig. 8). This slope undercut has a greatest inclination (60°–70°) on the whole investigated area elevated up to 300 m above the floor of the Azau Valley, this is in the altitudinal zone defined by remnants of lateral moraine ramparts. Dense network of rocky gullies dissect the slope and at their mouths are active talus cones.

Geomorphological consequences of intensified activity of Elbrus volcano till the 18th century

In the later period only indirect influence of volcanic activity of Elbrus on modelling the Azau Valley was marked. Toponymics of the area and spoken tradition of autochtonic Balcar people living in this part of the Caucasus since the 13th century, indicates episodes of catastrophic flows of the Azau Stream and its tributaries outflowing from Elbrus' glaciers (Koronovsky 1985). These great flows of *jökulhlaup* type were probably caused by temporary activation of some second rank volcanic cones covered by the ice cap of the volcano. Such great flows have not been later recorded since the beginning of the 19th century. Also presently observed water stages of the Azau Stream in gauging station at Terskol village do not indicate even short- lasting anomalies in the size of flow from the catchment of this stream. It may mean that the last catastrophic floods in the Azau Valley took place between the 13th and 16th century when the activity of Elbrus was still recorded ("fuming mountain") and when this area was already seatled by Balcar people. Possibly such incidents could still occur in the 18th century. Genesis of the following Balcar names may indicate incidents of *jökulhlaup* type: "Azau" – valley, brook, clearing ("a bad place, one should run away from"), and "Garabashi" – one of the glacial tongues flowing towards the south from the ice cap of Elbrus and being the beginning of the Azau Stream tributary of the same name ("mountain giving water"). These names mentioned by Abich (1852, 1971) and marked on Pastukhov's map (1887) originate probably from the period preceeding expansion of glaciers during the Little Ice Age. The Great Azau Glacier covering, later almost of the whole valley could not have been perceived by local shepherd people as a catastrophic phenomenon, because even now this area is not even temporarily inhabited. Second rank volcanic cone which was the main cause of catastrophic floods in the Azau Valley is the cone under the Garabashi Glacier on the southern slope of Elbrus. This thesis may be confirmed by the relief of the Garabashi Valley below the Garabashi Glacier and the relief of the area at the junction of this valley to the Azau Valley (Fig. 9). U-shaped Garabashi Valley is rejuvenated by V-shaped deep to over 200 m incision (Fig. 15). A similar situation can be observed below neighbouring the Small Azau and the Terskol glaciers, but the depth of glacial throughs dissection is much smaller there. This deepening of the Garabashi Valley must have taken place in the conditions of numerous extremaly high flows, and observing this phenomenon by autochtonic population took place since the 13th century only. As a deep incision in the bottom of this valley was not significantly remodelled during the Garabashi Glacier transgression in the Little Ice Age, it may be supposed that it might have been deepened during episodically catastrophic flows also in the 18th century.

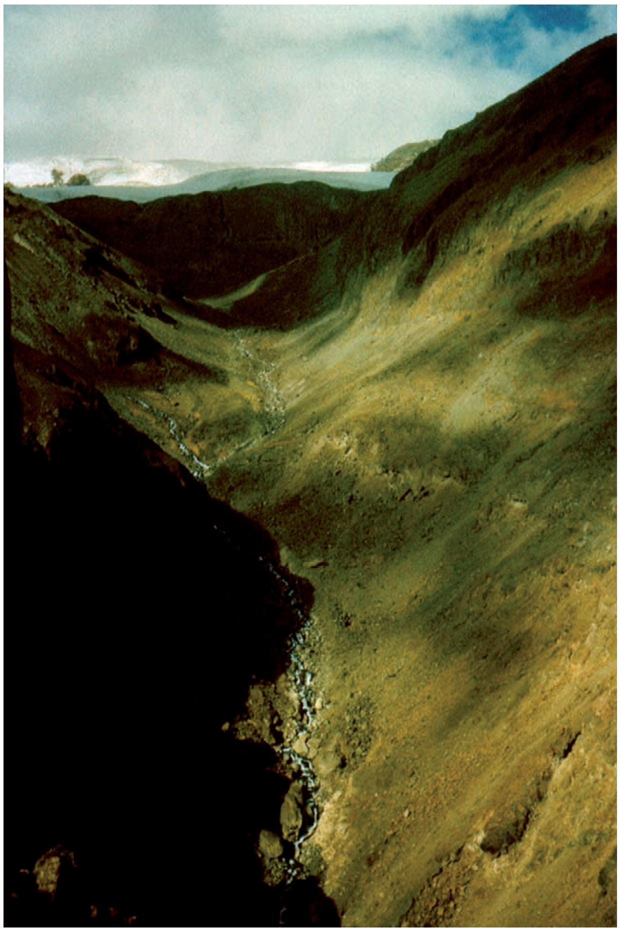

Fig. 15. U-shaped Garabashi Valley remodelled by a deep up to 200 m V-shaped erosional incision
In the background above the valley the front of the Garabashi Glacier

Material removed from the deepened through of the Garabashi Valley has made the greatest alluvial fan in the Azau Valley, that is made of basalt and granite blocks with the diameter up to 3 m (Figs. 16, 17). The dimensions of this fan are much greater than other alluvial fans in this valley, including fans connected with other brooks flowing from Elbrus glaciers (Fig. 9), which was noticed in the work of Bashenina et al. (1974a). It is 800 m long and at the feet about 1,300 m wide (section E of the valley). This fan was being thickened in the period of investigation, but its development began much earlier (Zolotariev & Seinova 1997, Seinova & Zolotariev 2001).

The next geomorphological proof confirming occurrence of high flows which took place in the Azau Valley and were generated by melting great ice mass above the Garabashi Valley is the network of nowadays dry and wide braided channels which occupies a wide area of the valley bottom starting from the base of the above mentioned alluvial fan (section F of the

Fig. 16. Uppermost part of alluvial fan of the Garabashi Brook
Visible coarse grained material in this part of the fan

Fig. 17. Alluvial fan of the Garabashi Brook
On the right the southern slope of Elbrus. In the foreground the braided channels of the Garabashi Brook

valley). They are up to 10 m above the channel of the Azau Stream, so their formation was not connected with activity of this stream but with the water flow from the Garabashi Valley (Fig. 9 C).

Water outflowing from the episodically quickly melting Garabashi Glacier, in the Azau Valley was partly flowing down along the base of the right slope of the valley and was undercutting paraglacial fans. Formed in this way, a dozen or so meters high scarp has almost straight course and is a characteristic element of the relief of this valley (Fig. 9 C). As a result of the scarp dissection by the flows dewatering the main ridge of the Caucasus within older paraglacial fans there are being formed the younger, smaller inserted fans. They are also being undercut by the Azau Stream but in lesser degree than the older ones.

In the longitudinal profile of the Azau Valley there is 4 km long convex threshold on its floor there in the place of the thickest layer of glacial and glacifluvial deposits – this is the region of alluvial fans of the Garabashi and the Terskol brookes and of the fossilized frontal moraine of the Great Azau Glacier which appears between these fans. This indicates the greater dimension of glacifluvial material deposition in this section of the valley, mainly during catastrophic flows of the Garabashi Brook, than the amount of material transported downstream. The difference between the supply and offtake of the glacifluvial material is on this section of the Azau Valley greater than in the higher part of the valley which does not udergo pressure of catastrophic flows generated by activating volcanism in this area. Comparing transverse profiles of the discussed section of the Azau Valley, with the profiles of the highest section of this valley and of neighbouring deep valleys where thickness of glacifluvial deposits is small, the thickness of sediments filling the Azau Valley sections from E – H can be estimated at about 200 m. It is possible that thickness of these sediments is the greatest within the fan of the Garabashi Brook neighbouring fossilized left slope of the Azau Valley.

Accumulation of a large amount of glacifluvial sediments in the Azau Valley upstream of the fan of the Garabashi Brook (sedimentation basin No 2) should also be included into the indirect geomorphological consequences of episodically intensified volcanic activity of Elbrus (before 18th century). This fan in the period of its quick superimposition played the role of the dam restraining movement of material in the channel of the Azau Stream. On the other hand in the period of the lack of volcanic activity the fan of the Garabashi Brook, similarly to deposits accumulated upstream was being dissected. A 30 m terrace present at the feet of the left slope of the valley, extending between the youngest lava flow and the fan of the Garabashi Brook – section D of the valley (Fig. 9 B), documents the scale of changes in modelling of the Azau Valley in the neighbourhood of the mouth of the Garabashi Valley due to activation of the fan of the Garabashi Brook and later the Azau Stream channel deepening.

Influence of glaciers oscillation and rampart moraine erosion on the relief of the valley during the last 300 years

Maximum extent of glaciers in the Azau Valley in the mid 19th century and their extent in various periods during the last 150 years were reconstructed on the basis of occurrence of lateral moraine ramparts preserved into various degree. Frontal moraines of these glaciers either totally eroded or were covered with glacifluvial deposits. From moraines originating during earlier transgression in the 17th and the 18th century has been preserved in the author's opinion, the almost fully fossilized frontal moraine rampart of the Great Azau Glacier in the place nearly 2 km below the front of the glacier in the 19th century (Figs. 9 C, 18). Length of this glacier during its maximum extent in the mid 19th century was described and

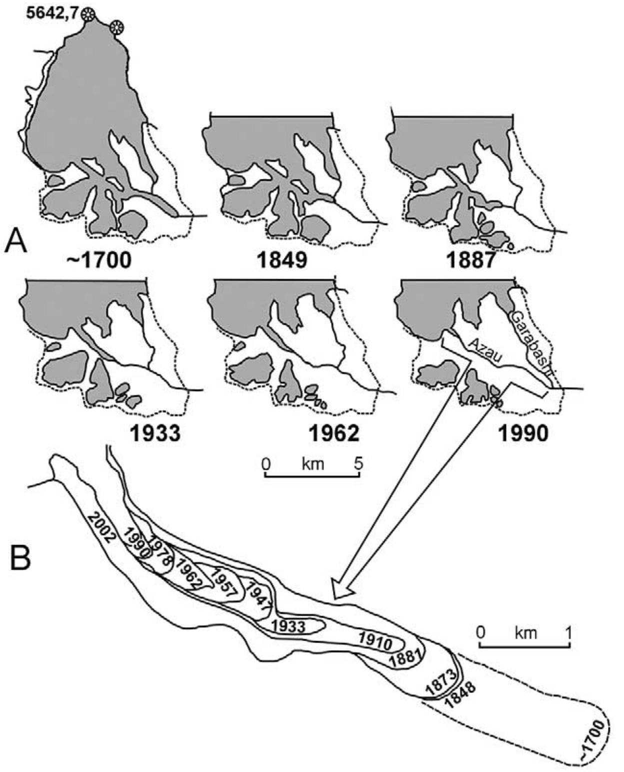

Fig. 18. Changes of glaciers' extent in the study area (on the basis aboundant material mentioned in the paper)
A – in catchment of the Azau Stream, B – changes of the Great Azau Glacier

phographically documented by Abich (1852, 1871), (Fig. 8). The results of my research indicating the further extent of the Great Azau Glacier in about 1700, than in the mid 19th century confirm the results of the research published in Boyarsky's paper (1978), which refer to the Djankuat Glacier in the neighbouring the Adyl-Su Valley in the Little Ice Age.

A dense system of glaciers occupied the study area occurred on the turn of the 17th and 18th centuries in the Azau Valley. The Great Azau Glacier was connected with almost all glaciers in this valley. The Great Azau Glacier occupied 90% of the valley length then, and 80% of the Azau Stream catchment area was covered with ice (Fig. 18). Judging by the size of the visible fragments of the fossilized frontal moraine rampart, the Great Azau Glacier covered the whole width of the valley bottom thus it must have been moving alongside the fluvial fan of the Garabashi Brook. After recession of the glacier the frontal moraine rampart probably played the role of the barrier upstream which there were accumulated sediments transported not only by the Azau Stream but first of all by the Garabashi Brook. This place was the next sedimentary basin (No 3) in the Azau Valley in the analysed time interval, this is after barriers formed by the youngest lava flow (ca. 1100 BP) and the Garabashi Brook fan. The rate of material accumulation in this basin must have been high as the frontal moraine rampart underwent almost total fossilization. Existence of this moraine rampart can be proven only by the presence of large basalt and granite boulders, the tops of which are visible in erosional dissections (Fig. 9 C). To sedimentary basin located upstream of the frontal moraine rampart material was transported by the Garabashi Brook on a large scale, probably during occurring still in the 18th century great floods generated by intensified volcanic activity of Elbrus. After having filled the sedimentary basin with deposits, waters flowing through the frontal moraine rampart cut shallow erosional furrows and since then this rampart has not played the role as the dam retaining material.

If the Great Azau Glacier, during the first transgression in the Little Ice Age reached greater size than in the mid 19th century, then the lateral moraine ramparts must have been higher located on the slopes than preserved till now remnants of such moraines from 19th century. Due to the big inclination of slopes, particularly in the granite area, moraine material was totally eroded. This is why yet in the 18th century must have been taking place further material adding to the bottom of the Azau Valley, at the largest scale upstream the already mentioned morphologic barriers. Dissection of these morphological barriers which began after accumulation of big quantity of deposits led to removal a part of glacifluvial material alongside the Azau Stream channel. Such a direction of geomorphological development of this valley is indicated by the erosional scarp on both sides of the Azau Stream channel, reaching in the break through fossilized frontal moraine rampart of the Great Azau Glacier nearly 20 m height. But the deepest (to 30 m) and widest zone of the erosional dissection was formed in the place where glacifluvial deposits filling sedimentary basin upstream the fan of the Garabashi Brook occur.

On the basis of the presented geomorphological facts it can be presumed that yet in the 18th century there occurred catastrophic floods in the Azau Valley which were generated by activating of volcanism on Elbrus (second rank cone under the Garabashi Glacier). Till the end of the period when such floods occurred the fan of the Garabashi Brook was overbuilt. The consequence of this process was filling with glacifluvial deposit the sedimentary basin (No 2) upstream the Garabashi Brook fan, and upstream the now fosillized frontal moraine rampart of the Great Azau Glacier from about 1700 (sedimentary basin No 3). Most probably after extinction of volcanic phenomena in the region of the Garabashi Glacier, this is in the 18th century, dissection of the thick layer of loose sediments in the Azau Valley could start.

The next stage of glaciers transgression in the Azau Valley began yet at the end of 18th century or at the beginning of 19th century and reached its maximum in the mid 19th century. This is documented by descriptions, drawing and photographs taken by

Abich (1852, 1871) and topographic map from 1887 (Pastukhov's map). At that time glaciation of the Azau Valley, although smaller than 150 years earlier, also was of the dense system glaciers character (Fig. 18). The front of the Great Azau Glacier reached the fan of the Garabashi Brook and covered previously deepened, as well as the non deepened part of the valley bottom. Preserved till that time fragments of the lateral moraine ramparts of the Great Azau Glacier are present on the slopes at the relative height up to 300 m which informs about the size of that glacier at that time. Also lateral moraine ramparts of other glaciers in this area confirm a greater extent of the Azau Valley glaciation in the mid 19th century in comparison to the present state. Frontal moraine ramparts of the glaciers in the analyzed area have not been preserved.

During the second trangression of the Great Azau Glacier in the Little Ice Age a gorge (in Russian *ushkhelye*) was finally formed at the place to which about 1100 years ago the youngest lava flow went down from the southern slope of Elbrus (Figs. 9 B, 13). As the result of the first and the second transgression of this glacier the gorge was widened to 200 m and gained the typical U-shaped transverse profile. During the distant extent range of the Great Azau Glacier only a part of its ice mass found room in the profile of the gorge, its remaining part was moving upstream the lava flow. This indicates the presence of the lateral moraine rampart of this glacier in the lowest section of the lava flow at the height up to 300 m above the valley floor (Fig. 9 B). Also the photograph by Abich from 1871 showing a wide and highly elevated a tongue of the glacier in this part of the valley (Fig. 8) indicated it.

The frontal moraine rampart of the Great Azau Glacier registering its maximum extent in the mid 19th century has not been preserved. Glacifluvial deposits in the sedimentary basin upstream this moraine rampart were deposited in the place where erosional dissection in the floor of the Azau Valley which had began in the 18th century was the deepest. Deposits from this basin underwent the stage erosion. Accumulation of deposits in this sedimentation basin (No 4) in the Azau Valley (in time of investigation) lasted at least since about 1870 when fast recession of the Great Azau Glacier began. Erosion of lateral moraine ramparts of glaciers in the Azau Valley determined quick growth of deposits in this sedimentary basin. This process lasted till the deep dissection and later total disappearance of the frontal moraine rampart near the channel of the Azau Stream. Erosion of this frontal moraine rampart must have begun yet in the second half of the 19th century and was ended not later than in the mid of the 20th century because in the following years this form of landscape was not mentioned in abundant literature concerning the described area.

It is worth to mention the occurrence of a fragment of the lateral moraine rampart of the Great Azau Glacier on the left side of the Azau Stream above 30 m high scarp. On this moraine rampart which is not reached by snow avalanches is located the Moscow State University Station on the Azau Clearing. On the investigated area only on the inner part of this fragment of the lateral moraine rampart above and below the high scarp lies ground moraine with numerous dead-ice forms (Fig. 9 B).

The Great Azau Glacier has not only been undergone, sice 1873 quick shortening and narrowing but also its thickness has been diminishing. Initially till 1881 during the glaciers' recession its width was not diminishing, but after 1910 it also started narrowing especially in the place of already mentioned gorge. As a result during the 20th century the difference in heights between highly situated lateral moraine ramparts and the Great Azau Glacier began to grow fast. Because of high inclination of the slopes these moraine ramparts were and still are quickly eroding. Upstream the gorge the Azau Valley is widening, but its slopes are still very steep. During the last 60 years the front of the Great Azau Glacier recessed in this section of the valley by about 2 km. At this time in the area moraine material was eroded almost totally.

Erosion of the lateral moraine ramparts till their total disappearance took part in the upper part of the Azau Valey, this is upstream the gorge, in the second half of the 20th century faster on the steep granite slope than on the slope is made of volcanic rocks facing south (Fig. 19). It can be concluded that the speed of erosion of these formations depends a greater degree on the inclination of slopes rather than their exposition. At the advanced stage of lateral moraine rampart disappearance on the slopes are only singularconical mounds of debris, which up till now have been preserved only on the slope made of volcanic rocks (Figs. 10, 12).

Faster erosion of moraines on the granite slope than on the volcanic one results in duality of glacifluvial deposits found in the Azau Valley upstream the gorge. On the layer of granite boulders in the bottom of the valley there is the material of a darker colour made of varigrained volcanic clasts (Fig. 20). Such composition of glacifluvial deposits in this part of the Azau Valley can be observed in every erosional dissection.

Transport of vast amount of material from the slopes to the bottom of the valley causes fossilization of granite roche moutonnees which cropp out when the Great Azau Glacier front is recessing (Fig. 21). The lower glacial polished rock is situated the greater the glacifluvial deposits cover is till they are fully burried. In front of the glacier burrying glacial polished rocks is connected with a local bases determind by culminations of these forms of the

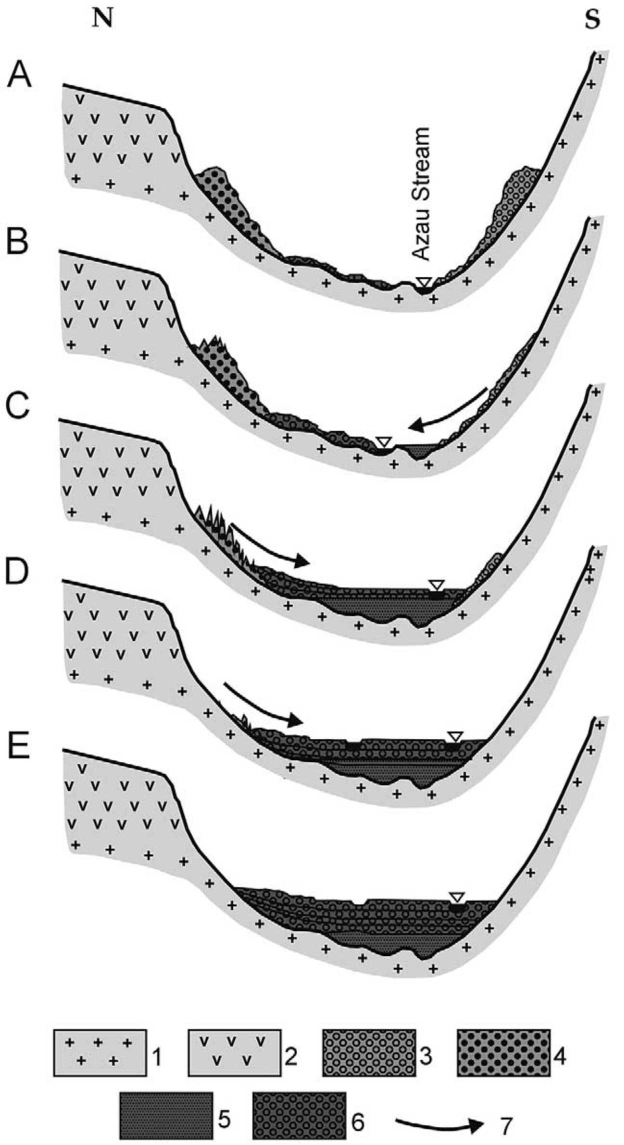

Fig. 19. Scheme illustrating the course of lateral moraine rampart erosion on the northern and southern slopes of the upper part of the Azau Valley and the course of glacifluvial material deposition in the bottom of the valley

A–E – phases of changes in the relief of the valley, 1 – granite bedrock, 2 – volcanic rocks, 3 – lateral moraine rampart on granite slope, 4 – on volcanic slope, 5 – glacifluvial deposits transported from granite slope, 6 – from volcanic slope, 7 – debris transfer from slopes to a bottom of valley

Fig. 20. Twofold formation of glacifluvial sediments covering the floor of the upper part of the Azau Valley

The bottom layer of light coloured sediments is the granite deposit, the upper dark coloured layer is the volcanic material

area. Nevertheless with the course of the valley, the differences in the height of burrying succeeding glacial polished rocks are diminishing with concurrent thickness growth of glacifluvial material burden. Therefore the longitudinal profile of the Azau Valley between the Great Azau Glacier front and the gorge is staircase and at the same time more and more levelled with its course. This segment of the Azau Valley can be considered the next sedimentation basin (No 5) in the investigated area in which presently are being formed gradually situated outwash fans of dual formation, formed as a result of the thick-grained material deposition covering the granite glacial polished rocks.

Evaluation of the size of deposition and erosion of material in distinguished sections of the valley during the last ca. 1100 years

On the basis of reconstructed changes in the relief of the Azau Valley in investigated period, there was elaborated the scheme presenting relative differences between intensification of erosional and accumulative phenomena in the result of which present-day relief of the distinguished sections of the valley was formed (Fig. 22). The size of erosion and material deposition in the period of functioning of the sedimentary basin upstream the lava flow was greater than in other sections of the valley beyond the comparison. Erosion used to be very intensive both on the slope of Elbrus at the moment of flow of a great amount of water and later as well, when loose material was being removed from the valley. The development of the fluvial fan of the Garabashi Brook taking place due to activation of volcanic phenom-

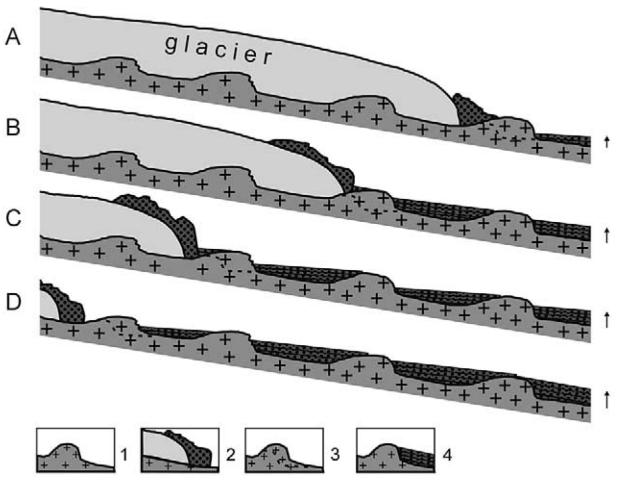

Fig. 21. Scheme illustrating the course of aggradation of granite glacial polished rocks cropping out from under the Great Azau Glacier by glacifluvial deposits
A–D – phases of changes in the relief of the valley, 1 – roche moutonnees, 2 – front of glacier, frontal moraine and dead ice, 3 – glacially polished granite rocks dissected by proglacial stream forming a small gorge, 4 – increasing thickness of glacifluvial deposits in front of granite rocks

ena and which had begun much earlier before the lava flow went down to the Azau Valley represents lesser intensification of erosional and accumulative phenomena in the valley as compared to the earlier mentioned situation. Similarly lesser intensification of erosion and accumulation was taking part in the valley in the sedimentary basin upstream this fan although the scale of these processes in this section of the valley was much greater than in the remaining part of the valley. In the sections of the Azau Valley upstream the frontal moraines the amount of deposited glacifluvial material and the scale of its further erosion is even smaller. Minimum sizes of these processes in the scale of the whole valley was stated in the youngest sedimentary basin on the foreland of the Great Azau Glacier.

Discussion and conclusions

The greatest intensification of erosion on the slopes of the Azau Valley, of material deposition on its floor and of the further removal of material was in the analysed period connected with the direct influence of volcanic phenomena, i. e. with temporary damming the valley by the lava flow. So far this aspect of the investigated area modelling has not been mentioned in literature. Although indirect influence of intensified volcanic activity of Elbrus on modelling the Azau Valley and upper sections of the Kuban and the Malka valleys has already been noticed (Tushinsky 1968, Bashenina et al. 1974 a, b, Koronovsky 1985), this process sporadically delivers vast amounts of water from the melting ice cap on this volcano – into the already lesser degree is responsible for intensification of erosion and deposition in the valleys. This is why the rate of remodelling of the Garabashi Valley and the neighbouring section of the Azau Valley under the excessively intensified flows of *jökulhlaup* was in the investigated period smaller than this of the section of the Azau Valley upstream the youngest lava flow. This also concerns the scale of deepening these valleys after the period of their greatest filling with glacifluvial material. Dissection of the Azau Valley floor near the Garabashi Brook fan is now much more shallow than of the upper section of the Azau Valley because of unclogging of the valley after preceeding erosion of the lava flow front. But because of incomparably longer time of modelling of the Garabashi Valley and the neighbouring section of the Azau Valley by the great flows (effect of numerous concurrent episodes of *jökulhlaup* type) the contemporery relief of these valleys gives the impression of a greater impact of indirect volcano effect. This impression is now intensified by the almost total lack of traces of previous much greater filling the upper part of the Azau Valley upstream the youngest lava flow with glacifluvial material.

These remarks may refer to the results of studies of the valleys close to other glaciated volcanoes where investigation was concentrated most often on transformation of the area relief due to such events *jökulhlaup* and also lahars and pyroclastic flows (Thorarinsson 1957, Einarsson et al. 1980, Flink et al. 1981, Jónsson 1982, Russell et al. 2002, Gudmundsson 2005, Karasiewicz 2005, Russell 2005). Underestimating in literature the role of direct influence of volcanism in modelling neighbouring valleys results from the effect that damming valley by lava flows is more rare than formation of excessively intensified flow which may also transport vast amounts of loose volcanic material.

In earlier studies focussed on changes in the relief of valleys neighbouring with glaciated active volcanoes there was no opinion of a greater influence on a morphology of the area – volcanic phenomena or oscillation of glaciers and concurrent processes. In the case of the Azau Valley there is visible the lesser role of glaciers' oscillation in the transformation in these valleys relief than even indiret influence of volcanism (Łajczak 2006). Changes in the relief of the Azau Valley under the influence of moraine material deposition and of material transport alongside the slopes as well as in the result of later erosion of this material may be considered secondary when compared to changes caused by volcanic and concurrent phenomena. At the same time the earlier part of the valley was cropped out from under the glacier, the greater is the scale of hitherto changes in its relief which means the transport of loose material from the slopes to the bottom of the valley. This is why in this respect minimum changes are observed in the high-

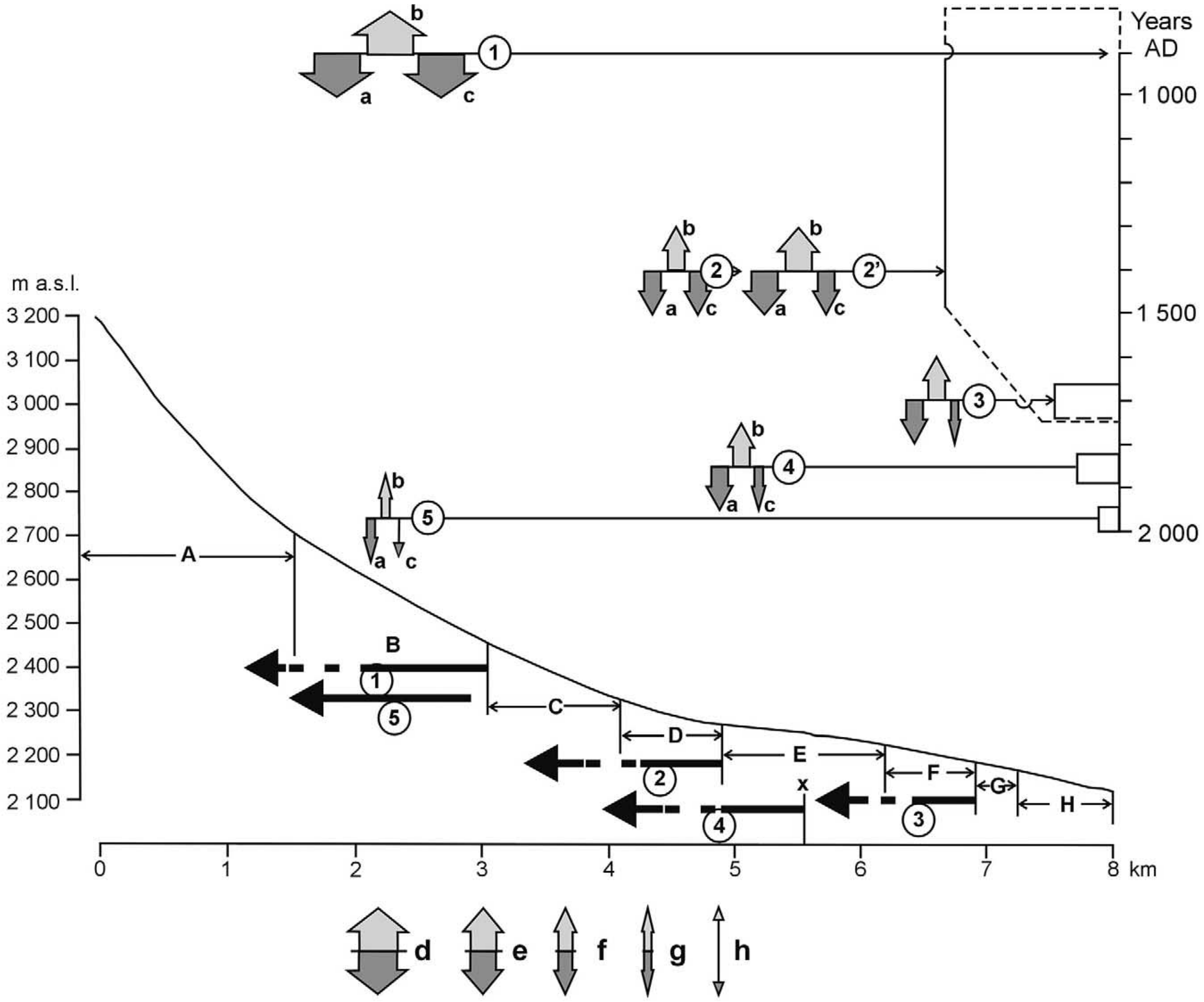

Fig. 22. Relative changes of deposit erosion and accumulation in the Azau Valley in the period studied

On the background of the longitudinal profile of the valley, the main morphological sections are marked: A – section with the tongue of the Great Azau Glacier, B – section between the front of the glacier tongue and the youngest lava stream, C – section occupied by the front of the lava stream, where the gorge is developed, D – section between the lava stream and the upper limit of the Garabashi Brook fan, E – section with the fan of the Garabashi Brook, F – section between the lower limit of the Garabashi Brook fan and the rampart of frontal moraine of the Great Azau Glacier from about 1700, G – section with the rampart of this frontal moraine, H – section between the rampart of frontal moraine and the end of the side valley of the Terskol Brook. X – position of the furthest limit of the frontal moraine of the Great Azau Glacier from about 1850. Thick arrows show the limit of sedimentation basins in the valley bottom: 1 – upstream of lava stream, 2 – upstream of fan of the Garabashi Brook, 3 – upstream of rampart of frontal moraine from ca. 1700, 4 – upstream of rampart of frontal moraine from ca. 1850, 5 – within the modern direct foreland of the Great Azau Glacier. Additionally, sedimentation basin 2' is marked, which is now the fan of the Garabashi Brook. The dotted line shows the probable further limit of the sedimentation basins. The numbering of the basins is according to the order of the description in the text. The longitudinal profile of the valley starts at the outflow of the tongue of the Great Azau Glacier from the ice cap of the Elbrus. a – relative intensity of erosion on the valley slopes when the material was supplied to individual basins, b – relative intensity of sedimentation in the basins, c – further intensity of deposit erosion in sedimentation basins. The numbers next to the arrows refer to individual basins. The location of the arrows (a, b, c) refers to a given sedimentation basins at the time when these processes occurred (time axis) and the location in the valley. Relative intensity of erosion and accumulation processes: d – very large, e – large, f – medium, g – small, h – minimal

est part of the Azau Valley, released from under the ice only in the last 60 years (see Fig. 18).

The rate of changes in the Azau Valley relief during the last 150 years, documented on the basis of the rich factographic material distinguishes this area from neighbouring valleys within the main ridge of the Caucasus, for example the Adyl-Su Valley where eroded lateral moraine ramparts have been preserved to a small extent (Łajczak 2006). It cannot be excluded that quick degradation of lateral moraine ramparts in the Azau Valley, just after the recession of the Great Azau Glacier front containing yet a dead ice (ice-cored moraine) the flow of volcanic heating may be partly responsible, as under the volcano up to the 2,000 m a.s.l. there is the magma reservoir (Tushinsky 1968, Koronovsky 1985).

In the research work of the Russian geomorphologists (for example: Tushinsky 1968, Bashenina et al. 1974a, b, Zolotariev & Seinova 1997, Seinova & Zolotariev 2001) the stress is on leading role of debris flows in modelling slopes and valley floors in the Caucasus. The Baksan Valley and particularly its highest part called the Azau Valley is the most significant in this respect. Although the listed authors do not always directly specify what the source of the material transported in the form of debris flow is, we should keep in mind that it originates from being degraded lateral moraine ramparts and in the case of high hanging glaciers on the slopes of the valley also from the frontal moraine ramparts. A significant fragment of the Garabashi Brook alluvial fan not covered with birch-pine forest and with braided channels of the Garabashi Brook is considered to be the active debris flow with a volume of over 100,000 m^3, one of the greater in the Baksan river catchment and the greatest in the Azau Valley (Zolotariev & Seinova 1997, Seinova & Zolotariev 2001). The remnant fragments of this fan covered with boulders mainly of basalt with diameter of 3 m, are included by the cited authors to the older debris flows. The main source of this material are not degraded moraines but being deepened floor of the Garabashi Valley. In the present hydrologic conditions in this valley the mention debris flow becomes active every 20 years, on average, and the course of this process has been controlled exclusively by climatic factors for at least 200 years.

Thickness of glacifluvial deposits in the Azau Valley grows alongside its course up to 200 m in the section between fans of the Garabashi and the Terskol brooks. This result based on the analysis of the transverse profiles of the valley corresponds to the numbers given by Tushinsky (1968) and Koronovsky (1985) resulting from the geophysical research. The cited authors report that such thickness is gained by deposits in the Baksan Valley up to the mouth of the last tributary fed by the glacier on Elbrus, this is to the Irik Brook (see Fig. 18). Such space distribution of deposit thickness in the bottoms of the Baksan and the Azau valleys may be only partly explained by impact of now fossilized frontal moraine ramparts, which were formed during the Little Ice Age and earlier in the last glaciation. The main role in such variety of glacifluvial sediments thickness in this set of valleys must have been played by the intensified supply of material during floods *jökulhlaup* type, which "were born" not only under the Garabashi Glacier, but also under the Terskol and the Irik glaciers on Elbrus. Accumulation of consecutive "waves" of intensified transport of material in the Azau Stream and the Baksan River gave the effect of clearly enlarged thickness of sediments up to the vicinities of the Irik Brook mouth. This also indicates the short transport of such a great amount of material, which is quicly deposited on the floor of the valley causing its gradual superposition. Dissection of these sediments by the main stream/river in the valley later is limited to a narrow zone only. Given facts and interpretation are contrary to the opinion of Bashenina et al. (1974a, b), according to whom convex sections of the Azau Valley floor and further of the Baksan Valley have tectonic foundation only.

Another confirmation of the dominating influence of volcanism on Elbrus on the modelling the Azau Valley and further the Baksan Valley, may be diminishing upwards the valley relative height of four distinguished in this area planation surfaces: upper Pliocene, lower Pleistocene, mid-Pleistocene and upper Pleistocene especially upwards from the Irik Brook mouth (Tushinsky 1968). The youngest of these planation surfaces "fades away" in the zone of the mouth of this tributary and higher, in the neighbourhood of the Garabashi Brook fan in the Azau Valley is already situated over a 100 m below the floor of the valley. These facts may be indicating advanced alluviation of the Azau Valley and the upper part of the Baksan Valley during Quaternary glaciations of the Caucasus. It may be concluded that the formed glacial through of these rivers was up to a considerable height filled with glacifluvial sediments at the time, when quickly growing volcanic cone of Elbrus was in to higher degree covered with the ice cap and when the frequency of events of *jökulhlaup* type was growing. This process is still in progress although for at least 200 years has not been registered.

The Azau Valley represents a typical lay-out of the slope-valley system with cascade shift of weathered material, on the granite and volcanic slopes. On the slopes above preserved fragments of lateral moraine ramparts and in hanging valleys above the frontal moraine ramparts there is temporarily deposited material which is moved when the continuity of ramparts is broken, mainly in the form of debris flows. Next it is temporarily retained on paraglacial fans and above low situated moraine ramparts. Frontal moraine ramparts on the floor of the main valley, except the rampart from about 1700, were quickly eroded. Similarly even greater amounts of material were temporarily retained by the lava flow which had blocked the valley and to lesser degree the Garabashi Brook fan. Removal of glacifluvial material from these sedimentary basins caused further superposition of the valley floor in its further course, particularly a section of the valley upstream now fossilized frontal moraine rampart from about 1700.

Hanging tributary valleys on both slopes of the Azau Valley play the role of exporting accumulated earlier weathered material (in Russian *syeleformiruyushkhaye doliny*). The same role is played by sedimentary traps above the lateral moraine ramparts on slopes. However the floor of the Azau Valley functions as the area retaining genetically varied material transported from the slopes as a result of geomorphological processes, most of it is glacifluvial material. So this area functions as the valley importing waste material, in Russian *syeleprinimayushchaya dolina*. High thickness of the deposited glacifluvial sediments on its relatively long section on the southern foreland of Elbrus proves effectiveness of this function of the valley. Retention of material on the floor of this section of the valley reaches various intensity and was or still is the greatest in distinguished sedimentary basins. Material from the majority of distinguished sections of the valley was during the analysed period removed to various degree, only the section of the valley floor which cropp out from under the glacier the latest is still undergoing aggradation.

In the period of lack of visible activity of Elbrus volcano, the example of which are at least the last 200 years, the greatest and the fastest changes in the Azau Valley relief take place during the recession of valley and niche glaciers and during concurrent shrinking of the extent of tongues flowing from the ice cap on this volcano. Therefore I confirm the opinion of Maizels (1979) that the size of material aggradation in the valley of a proglacial river depends on: firstly on the amount of moraine material which due to favourable morphologic features of the area may quickly erode and can be transported to the stream channel and secondly on the amount of easily accessible weathered material derived from marginal ice-free areas, and thirdly on the amount of melt water available to transport the sediment.

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References

Abich H.W., 1852. Explanations to geological studies on the northern slope of Caucasus range from Elbrus Mt. to Beshtau. *Caucasian Calendar*, Tbilisi (*in Russian*).

Abich H.W., 1871. Study of glaciers in the Caucasus Mts. *Review of Investigations of Caucasus Mts* 1, Tbilisi (*in Russian*).

Bashenina N.V., Bronnikova V.K. & Rubina E.A., 1974a. Routes in the Elbrus area in the Region of Moscow State University Station. *Studia Geographica*, Brno, 44: 87–119.

Bashenina N.V., Tushinsky G.K., Golubev G.N. & Miagkov S.M., 1974b. Geomorphology of Elbrus Mt area. *Studia Geographica*, Brno, 44: 9–86.

Boyarsky L.Y. (ed.), 1978. *The Djankuat Glacier*. Proc. Gidrometeoizdat: 124 pp. (*in Russian*).

Einarsson E.H., Thorarinsson S. & Larsen G., 1980. The Solheimar tephra layer and the Katla eruption of 1357. *Acta Naturalia Islandica*, 28: 3–20.

Flink J.H., Molin M., Dolli R.E. & Greeley R., 1981. Rheological properties of mudflows associated with the Spring 1980 eruption of Mount St. Helens Volcano, Washington. *Geophys. Res. Lett.*, 8: 43–46.

Gerasimov I.P. (ed.), 1974. *Mountainous areas of European part of Soviet Union and the Caucasus Mts.* Proc. "Science", Moscow: 360 pp. (*in Russian*).

Gerasimov I.P. (ed.), 1980. *Alps – Caucasus Mts.* Proc. "Science", Moscow: 325 pp. (*in Russian*).

Gudmundsson M.T., 2005. Characteristics and morphological impact of subglacial volcanic activity in Iceland. *Proc. of the Intern. Conf. Reconstruction of glacial processes in the chosen marginal zones of the Islandic glaciers – forms and deposits*, Iceland: 13–19.

Jónsson J., 1982. Notes of the Katla volcanoglacial Debris Flows. *Jökull*, 32: 61–68.

Karasiewicz M.T., 2005. Dynamics of Sólheimajökull and jökulhlaups events on its forefield. *Proc. of the Intern. Conf. Reconstruction of glacial processes in the chosen marginal zones of the Islandic glaciers – forms and deposits*, Iceland: 57–62.

Koronovsky N.W., 1985. Is Elbrus the active volcano? *Priroda*, 8: 42–52 (*in Russian*).

Łajczak A., 2006. Erosion and accumulation processes in the Azau Valley in Central Caucasus Mts during the last thousand years. *Proc. of the ICCE IAHS Intern. Conf. on Sediment Dynamics and the Hydromorphology of Fluvial Systems*, Dundee, Scotland, UK: 21–28.

Maizels J.K., 1979. Proglacial aggradation and changes in braided channel patterns during a period of glacier advance: an alpine example. *Geogr. Annlr.,* 61 A: 87–101.

Russell A.J., Tweed F.S., Knudsen O., Roberts M.J., Harris T.D. & Marren P.M., 2002. Impact of the July 1999 jökulhlaup on the proximal river Jökulsa a Sólheimasandi, Myrdalsjökull glacier, southern Iceland. *IAHS Publ*., 271: 249–254.

Russell A.J., 2005. The geomorphological and sedimentary impact of jökulhlaups Skeiðarársandur. *Proc. of the Intern. Conf. Reconstruction of glacial processes in the chosen marginal zones of the Islandic glaciers – forms and deposits*, Iceland: 73–96.

Seinova I.B. & Zolotariev E.A., 2001. *Glaciers and Debris Flows in Surroundings of Elbrus Mt.* Proc. Univ. of Moscow, Dept. of Geography: 220 pp. (*in Russian*).

Thorarinsson S., 1957. The jökulhlaup from the Katla area 1955. *Jökull*, 27: 20–25.

Tushinsky G.K. (ed.), 1968. *Glaciation of Elbrus Mt.* Proc. Univ. of Moscow: 345 pp. (*in Russian*).

Zolotariev E.A. & Seinova I.B., 1997. Catastrophic debris flows in surroundings of Elbrus Mt during the last two thousand years. *Proc. MGI*, 82: 184–188 (*in Russian*).