MOUNTAIN DISASTERS

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Summary

Mountains and high ground occupy about 20% of the land, and approximately 10% of the Earth's population live in mountains. Great differences in altitude and significant energy potential of gravity, along with the important role of water in both liquid and solid phases, means that natural disasters are common phenomena in mountains. First of all, there are landfalls (faults) and landslides, mudflows and snow avalanches, glacier surges and floods. Landfalls and landslides are genetically and spatially interconnected. Significant differential in height and the high potential energy of the relief, together with the steepness of slopes, all play important roles in creating these events. The moving force of the gravity processes are the huge weight of mountain rocks under displacement, and the water contained inside them. To stop or slow down a landslide processes, the coefficient of slope stability must be increased, and the amplitude of its seasonal fluctuations should be decreased. Prediction of landslide processes is possible for a limited part of a slope (local forecast), or for a vast territory with identification of sites having high stability of slopes (regional forecast).

Mudflows are rapid channel flows consisting of a mixture of water and rock fragments, suddenly appearing in basins of small mountain rivers. Rainstorms, snow and ice melting, and, more rarely, breakthroughs of lake dams, volcanic eruptions, heavy earthquakes, and consequence of economic activity, can all cause mudflows. The motion of a mudflow differs from other channel processes in the greater saturation of solid material, amounting to 10-15 to 60-70% or more of its volume. Rather often, mudflows arise at a breakthrough of a near-glacier or glacier-dammed lake. By their structure mudflows are divided into two types, cohesive and uncohesive ones. Cohesive flow follows hydraulic laws, while an uncohesive one observes the laws of plastic-viscous medium flows. The mudflow activity of a territory is expressed through the

occurrence (frequency of falls). This can be estimated for an individual mudflow basin or region.

A snow avalanche is a snow mass rushing down with great velocity. Avalanches can arise in every place where the average thickness of snow cover exceeds 30-40 *cm* on slopes with a steepness greater than 15° and a relative height differential greater than 40-50 *m*. The main cause of avalanche initiation is loss of snow stability on a slope due to overload of the slope following heavy snowfalls and snowstorms, and formation of weakened horizons within the snow thickness. Avalanches move with a speed of 40-50 $m \cdot s^{-1}$. Powder avalanches which are mixtures of dry snow and air of very low density are particularly dangerous as they are often accompanied by a destructive air wave. The distance traveled by an avalanche outburst varies from just tens of meters to 10-20 *km*. In a zone of avalanche deposition, snow deposits of from 5 to 30 *m* thick may be formed. Great effort is expended in preventing and combating avalanches, and predicting avalanches.

Natural disasters in mountains are also caused by glacier surges, the most typical feature of which is an unstable regime. The frequency of surges in such glaciers varies from several years to a century or even longer. During surges glacier tongues can advance over a distance of some kilometers. The most dangerous phenomena associated with glacier surges are the formation of dammed lakes in lateral valleys, marginal depressions, and at places where glaciers merge. When the level of the lake has reached 0.8-0.9 of the height of an ice dam, generally, the dam is breached and the lake breaks through. Sometimes, liquid water breaks through when cavities within the body of an advancing glacier are filled and the ice begins to float. Efficient systems of information support with data on natural phenomena should be based on new information technologies, computer processing of satellite data and automated cartography.

1. Introduction

Mountains and high ground occupy about 20% of the land on planet Earth, and about 10% of the human population inhabit these areas. However, at least half of the total population directly or indirectly use the resources of mountains. People living in mountains, usually in small ethnic groups, live under extreme natural conditions, outside the more economically developed plain territories. Natural disasters, of various sorts, are common in mountains.

Mountain landscapes are extremely dynamic, and there are three main reasons for this. First, tectonic elevation of mountains accumulated enormous energy potential of the Earth gravitation. Second, they have been elevated to significant altitudes, and thus created great orogenic energy. Third, it is a typical characteristic of high mountains that they create an interruption in atmospheric water circulation with a significant part of the water accumulating in glaciers, snow cover, and in loose deposits, where they have the potential of contributing to landslides and mudflow processes. Dynamism of mountain landscapes is further exacerbated by human activity such as deforestation, heavy grazing by livestock, road construction, development of mining industry, etc.

Perennial snow and ice typically accumulate in high mountains. Glaciers are confined to zones of high precipitation, which are usually receiving several times more than the surrounding lowlands and foothills. Within glaciers themselves, additional snow concentration results from snow-storms and avalanches. This is why the nival-glacial zone contains the greatest moisture storage in mountains, sometimes much more than climatologists and hydrologists believe. This fact adds to the scale of natural disasters in mountains.

Disastrous processes have been a feature of nature throughout its evolution, and certainly throughout the history of humankind. Disastrous events occur suddenly, without any evident regularity, and they leave indelible marks in nature, sometimes for decades or centuries. In the history of natural environments they always played a revolutionary role, transforming individual territories or landscapes into new qualitative states. Today they are greatly complicated by anthropogenic impacts, causing very harmful and frequently catastrophic effects.

People are increasingly frequently becoming victims of natural disasters, and damage from them increases. This happens for two reasons. First, with development of scientific-technical progress, human activity penetrates farther and deeper into high-mountain and polar regions, where the power and occurrence of manifestations of disasters are greater than that on developed territories. Secondly, by interacting more with nature, we often cause disturbance of established relationships, as well intensifying undesirable dangerous phenomena. As a result of this a paradox arises, i.e. with the progress of science and engineering, human society becomes more and more vulnerable and dependent on nature; although the number of victims of individual natural catastrophes is decreasing, the total damage from them is increasing.

In principle, natural disasters are not catastrophic events, they become so when they impact the human economy. The definition of “catastrophic” always contains a socio-economic element, so this cannot be used to describe a purely natural process. Studying of natural processes has its own specific objectives. The main purpose is to develop methods and means for predicting the time and scale of an event. But, to achieve this, the mechanism and processes causing the event must be studied first, along with the geographic distribution of the processes and their components.

The most important characteristic of natural processes is their aperiodicity, arising at unequal and usually unpredictable time intervals: more than once a year (snow and stone falls, sudden floods), every few years (floods, mudflows), and after intervals of many years (glacier surges, earthquakes, volcanic eruptions). It is precisely the aperiodicity of their manifestation which makes people perceive such events as disastrous, unexpected and terrifying.

The human memory has a unique capacity to idealize the past and to overestimate the importance of the present time. One can often hear and read that the present climate is much more variable, extreme events happening more frequently, and this emphasizes the unusualness of the present epoch and forebodes serious natural changes. However, if one compares the recent time with some past period which is known from documents, nothing specific except cyclic fluctuations of natural phenomena are revealed. Both the twentieth century and earlier periods have similar manifestations of the threatening forces of nature.

Let us take avalanches as an example. In the winter of 1986/87, the situation in the Caucasus became critical as mountains overloaded with snow threatened landslides, mudflows, and floods. The total thickness of snow exceeded the climatic norm by a factor of two to three, creating a really dramatic situation and creating a great flow of emotional information in mass media. Though many hundred of houses were destroyed in the Svanetia area, none of 320 famous svan towers were damaged. They were built in the twelfth to thirteenth centuries, which were characterized by a cool and moist climate with abundant snow falls. Buildings, located close to the towers, also survived, experiencing only minor damage.

Clearly, ancient builders chose sites above which no avalanche catchment was present. In these sites snow never accumulated sufficiently to reach a critical mass; when it fell into the valley it dropped in relatively small and safe quantities. The svan towers are so accurately built with respect to local slope features that the snow mass pressure always come to a corner of the construction, and, thus, they act like anti-avalanche wedges.

At the present time, the approach, called the “environmental” one, is pre-eminent. It is based on the idea that the risk and scale of consequences are exclusively determined by natural parameters such as degree of seismicity, occurrence and magnitude of floods, slope stability, etc. This is why natural disasters, i.e. rock falls and landslides, mudflows and snow avalanches, glacier surges and floods in mountains, are being actively studied.

2. Rock Falls and Landslides

Among the relief-forming processes on land, landslides and rockfalls play the role of musical percussion instruments. Their impact is short and efficient and they achieve an obvious result. Major natural and natural-anthropogenic catastrophes are associated with them. The consequences of landslides and rockfalls are particularly great during strong earthquakes. The seismic process is one of the mechanisms forming high mountains. At different stages in the Earth’s history, there have always been areas of mountain formation with high seismicity, where landslides and rockfalls repeatedly took place.

Rockfalls and landslides are genetically and spatially inter-related. They dam rivers, form temporary dammed lakes with a subsequent potentially drastic water discharge, and so on. The basic difference between them is that, when moving, rockfalls lose contact with the slope, while landslides never do so.

Rockfalls and landslides can occur in any mountains and sometimes in plain areas too. They can be on a huge scale and their effects may leave prominent scars in the terrain. Several immense faults and landslides are known in the history of the Tien Shan. For instance, in 1911, a landslide of 2.2 km^3 volume, caused by an earthquake, dammed the large River Murgab in the Pamirs mountains. Lakes Sarez and Yashil-Kul', also in the Pamirs, were formed by great faults.

Great height difference together with a high relief energy, and great steepness of valley slopes and talvegs play significant roles in the formation of faults. The landslide processes depend on the thickness and composition of covering sediments and on the dynamics of their wettability. Slopes with negative tilts can be formed in only young non-weathered rocks. Rock weathering along with formation of crevasses promote fault processes, but immediately after a small-fragment zone of weathering begins to form, the talus processes manifest themselves. Crumbling continues until the slope angle reaches a value equal to the slope of repose of the crumbling material. After the completion of crumbling, a zone of crushing of fragmental material arises, forming a deluvium which is a perfect medium for landslide development.

Most of the area of any mountain range consists of slopes with different steepness and extension. There are natural slopes and those created artificially. Stability of slopes varies and often gives rise to slope processes, i.e. rock displacement down the slope, sometimes not just due to the gravity, but also under the action of water running down the slope (surface wash-off, deluvium processes). The moving force of the gravity processes is the weight of displaced rock and underground waters contained therein. Sometimes these motions are exacerbated by seismic shocks or hydrodynamic pressure of water, running through the mountain rocks.

The progress of landslides and other gravitational processes, including stone falls, is conditioned by the relationship of slope steepness to thickness and composition of the weathering crust and other covering structures on the slope. The stability of slopes of homogeneous geological structure depends on the strength and density of the rocks, the height of the slope and its geometry, in particular, by its steepness.

The stability of a slope is broken when the support in its foot is removed. The cause of this can be erosive activity of rivers and glaciers, coastal waves, tidal currents, subaerial weathering of rocks, along with their wetting, drying and frost impact. Creating excavations, quarries, pits and channels, removal of supporting walls and sheet pilling, creation of water reservoirs, and change of their level, can lead to the same results.

Landslides occur on part of a slope due to disturbance of the rock equilibrium, caused by increase of slope steepness, resulting from water wash-down, weakening of the rock strength by weathering or over-moistening with rains and underground waters, effect of seismic shocks, building and economic activity carried out without taking into account the geologic structure of the region. Most often, landslides occur on slopes composed of alternating layers of clayey and water-bearing rocks. The landslide progress is also exacerbated by an arrangement of strata where the layers lie with their inclination towards the slope, or they are cut across by crevasses in the same direction. In strongly wetted clayey rocks, a landslide takes a form of a torrent.

The word “landslide” (like the word “avalanche”) means both the process leading to the event as well as the event itself. A landslide is a displacement of some of the rock on a slope, down to a lower level in a form of sliding motion, generally without loss of contact between moving and motionless rocks. A landslide starts as a result of breakdown of the slope stability and lasts until a new state of equilibrium has been reached. Any landslide process is irreversible. After the displacement a slope assumes new geometry and internal structure, and any repetition of a landslide cycle takes place in other rock mass in a new place.

Mountain rocks underlying the sliding surface of a landslide as well as the resulting relief are called the landslide “bed”. The lower part of a landslide body, adjacent to the sliding surface, as well as the surface limiting it from below is called the landslide “foot”. Isolated parts of a landslide have different names: the “head” is the upper part of a landslide body; the “tongue” is part of the sliding mass moving over a surface of separation, generally in the lower part of the landslide body (Figure 1).

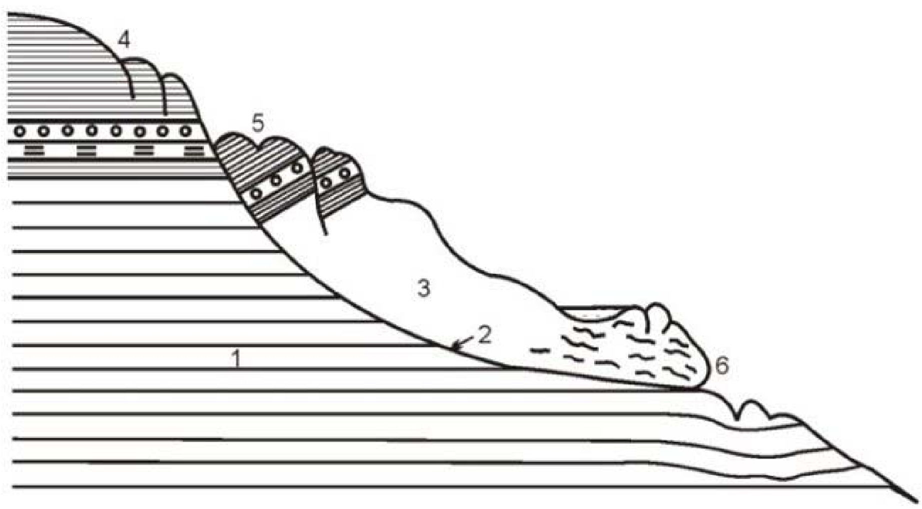

Figure 1. Longitudinal cross-section of a landslide:
1 is a bedrock massif; *2* is the landslide bed; *3* is the landslide body; *4* is edge (crest) of a separation; *5* is the head; *6* is the tongue; *7* is the foot

Classification of landslides is based on types of mountain rock movements. These are landfalls, overturn, landslides of slipping, extrusion, and streams (flows):

- under landfalls, a quantity of rock, of any size, is broken off from a steep slope or a scarp and falls down, bumping and jumping;

- overturn is the detaching, inclination and rotation of a rock block under the effect of gravity or the effect of water where there is a steep bedding of layers; their center of rotation is located below that of the center of gravity;

- landslides of slipping are characterized by shearing deformations and dislocations along one or several surfaces, and within the limits of a relatively low-power zone. The massif dislocated can be moved outside the limits of the initial surface of the break into the relief elements which become the boundary of the landslide foot;

- in landslide-extrusions a loosening, caused by a shear and cracks of expansion, takes place. As a result, various movements take place in a general spreading but no visible and well-pronounced basic surface of the displacement or zone of plastic deformations is observed. Overlying blocks of compact rocks can subside, slide, rotate, and break down, and become transformed into landslide-flows under water encroachment;

- landslide-flows in solid rocks are deformations scattered among many large and small cracks, or even micro-crevasses without a concentration of the displacement along one extensive break. These movements proceed extremely slowly and, obviously, at more or less the same speed. Landslide-flows can form folds, bends and other manifestations of plastic deformations. The speed distribution reminds a flow of a viscous liquid.

Continuous transition from sliding to avalanching of fragments takes place as the movement accelerates, being caused by the decrease of cohesion or increase of the water content and steepness of slopes. Landslides of fragmental mass sliding, and more rarely fragmental avalanches, can contain rotating landslide blocks in their frontal parts. When the fragmental masses slide down to the slope foot, the landslide separates into smaller parts, and the movement itself usually remains slow. In fragmental avalanches the progressing movement is fast, the displacing masses are diluted, and, at the least, they are partially transformed into a flow which rushes down a creek channel and can spread far from the slope foot.

Landslide-flows in loess, usually caused by seismic shocks, kill more victims than any other type of slope motions. Landslides resulting from the earthquake of 1920 in the Kansu province of China, killed about one hundred thousand victims. The normal and sufficiently cohesive internal structure of a porous sandy loam was destroyed in this case by a seismic shock, so that the loess was actually transformed into a dust which flowed into valleys, filling them and burying settlements. As noted, these landslide-flows were mainly dry. Vast loess landslide-flows, caused by the Khait earthquake on 10 June 1949 in Tadjikistan, filled valleys with a layer several tens of meters thick over a distance of many kilometers, burying or destroying 33 settlements.

The problem of landslide control consists of provision of slope stability, i.e. one must prevent a landslide on a still static slope or stop the dislocation of sliding masses. It is possible to achieve this by the following measures: 1) to stop or to moderate the processes causing irreversible reduction in the coefficient of stability of a slope; 2) to raise the existing average coefficient of stability of the slope; or 3) to decrease the amplitude of seasonal fluctuations in the coefficient of stability, limiting the possible temporal decrease of the coefficient of stability under the most favorable combination of factors exerting effect on the slope.

Landslide control can last for many centuries. In ancient times, anti-landslide measures were used for different purposes. In the nineteenth and early twentieth centuries the idea was widely accepted that the main cause of landslides was water, and the main measure to control them was drainage and water-discharging trenches. Since development of landslides depends not just on underground water and they can take place even in the absence of water, it is not surprising that efforts to stabilize landslide slopes by means of only a drainage and water-discharge were often unsuccessful. In practice a complex of anti-landslide measures should provide a reserve of coefficient of slope stability, no less than that assigned for a certain time period with a prescribed probability.

Forecast of landslide processes is of great importance. The kind of prediction depends on the size of the area for which a prediction is made. It can be for a limited part of a slope, in which case the degree of stability and conditions of its disturbance must be determined (local forecast), or it can be for a vast territory within which certain parts can be identified where contemporary stability of slopes is least and where the effect of deteriorating conditions of slope stability is most intensive (regional forecast). For a static slope or scarp, it is necessary to find out if there is any possibility of the slope equilibrium being broken, and the type, boundaries and scale of any future landslide, as well as the mechanism, time, maximum speed and amplitude of its displacement.

There are numerous methods for the calculation of the value of the coefficient of slope stability, and its variability, In addition to experimental methods for measuring the stresses, physical modeling, historical-geological and analogue methods can be used. Future development of the landslide process on a slope where it has already started, or where there have been multiple repetitions, is predicted on the basis of observations of the landslide process itself as well as different changes taking place on the slope.

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Biographical Sketch

Vladimir Mikhailovich Kotlyakov was born in 1931. He is a member of the Russian Academy of Sciences (elected in 1991), and Director of the Institute of Geography, RAS. With particular interest in glaciology and the physical geography of polar and mountain regions, he directed the twenty-year project resulting in the World Atlas of Snow and Ice Resources (published in 1997).

He has participated in many expeditions. He worked and wintered in the Arctic, Antarctica, on the slope of the highest summit of Europe, the Elbrus, and he headed high mountain glaciological expeditions to the Pamirs.

The main theoretical results of his works consist in elucidation of laws of snow and ice accumulation on the Antarctic ice sheet as well as ice sheets in general (1961), the snowiness of the Earth and its fluctuations in time and space (1968), the tasks and abilities of the space glaciology (1973), the application of isotope and geochemical methods to the study of the environment and its evolution (1982), the study of the past four glacial-interglacial cycles (1985 and further on). In recent years, V.M. Kotlyakov has dealt with global changes of the environment, geographical aspects of global and regional ecological problems, and the problems of interaction between Nature and society.

V.M. Kotlyakov is vice-president of the Russian Geographical Society and President of the Glaciological Association. In 1983–87 he was President of the International Commission on Snow and Ice; from 1987 to 1993, he was a member of the Special, and later Scientific, ICSU Committee of the International Geosphere-Biosphere Programme, and from 1988 to 1996, Vice-president of the International Geographical Union. Currently, he is a member of the Earth Council.

V.M. Kotlyakov has been elected a member of Academia Europaea and the Academy of Sciences of Georgia, and an honorary member of the American, Mexican, Italian, Georgian, and Estonian Geographical Societies.