MUDFLOWS

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Summary

Mudflows are swift channeled streams, consisting of a mixture of water and fragmental rock material and arising suddenly in basins of small mountain rivers. They are formed in conditions of a contrasting mountain relief, accumulation of weathering rock material and a water pulse which provides the necessary volume for a runoff. Direct reasons for the origin of mudflows are showers, intensive snow and ice melting, and more rarely, outbursts of the mountain lake dams, volcanic eruptions, and strong earthquakes, as well as sometimes it can be the result of human activity. Mudflows are characterized by a pulsating motion and significant erosion-accumulation and destructive effect. Their typical features are a short-term action and absence of a strict periodicity of occurrence. By their structure, the mudflows are subdivided into two types which are unbounded and bounded ones. In unbounded mudflow, the main water mass is in a free state and serves as the transporting medium for the solid component of the mudflow. A bounded mudflow actually does not contain any free water, it is held between fine-dispersed (clayey) particles in a form of hydrate films and pinched water. The bounded mudflow follows the hydraulic laws, while the unbounded one follows the laws of flow of viscous-plastic media. In terms of mudflow mass composition they are subdivided into water-stone, mud-stone, water-snow, and water-ice flows. There are different mechanisms of the mudflow origin: erosion, outbursts, and failure-sliding. As a rule the mudflow movement has the character of an avalanche. A mudflow activity of a territory is expressed through occurrence (frequency of events) of mudflows; it can be determined for both individual mudflow basin, or some region. Multi-factor character of the mudflow phenomena creates great difficulties for a long-term forecasting of such phenomena. There is a background forecast that mean a prediction of mudflow situations over significant territory, and also a local forecast that is made for an

individual basin. It is known that there are general conditions under which one can wait for mudflows of different genesis. For shower mudflows these are periods of intensive and long-lasting rains, for the glacier ones it is hot months of intensive ablation, and for mudflows of spring snow melt it is the last snow-melt period in combination with warm rains.

1. Conditions of the mudflow formation

A mudflow is a mountain channel stream that consists of a mixture of water and rock debris. It is characterized by pulsation (wave) movement and significant erosion-accumulation and destructive effects. The specific features of the mudflows are short life-time (1-3 hours, as a rule) and an absence of a strict periodicity of manifestation.

The direct original causes of mudflow formation are showers, intensive melting of snow and ice, more seldom - earthquakes, eruptions of volcanoes, outbursts of lake water through dams, and economic activity. Mudflows arise during especially intensive rains or due to outbursts of water from moraine lakes and other glacial water bodies. In both cases, mudflows result from interaction between water and loose-detrital material in hollows and canyons having big steep gradients.

The ratio between the amounts of solid and liquid substances, which can be expressed by the value of density of the mixture, is the principal and determinant feature of any mudflow. The water density is 1000 $kg{\cdot}m^{-3}$, and the rock density is in most cases about 2700 $kg{\cdot}m^{-3}$; thus, the density of mudflows varies in a wide range - from 1100 to 2500 $kg{\cdot}m^{-3}$. Besides, the properties of the mudflow mass depend on its composition, i.e., the relative masses of fractions of different size.

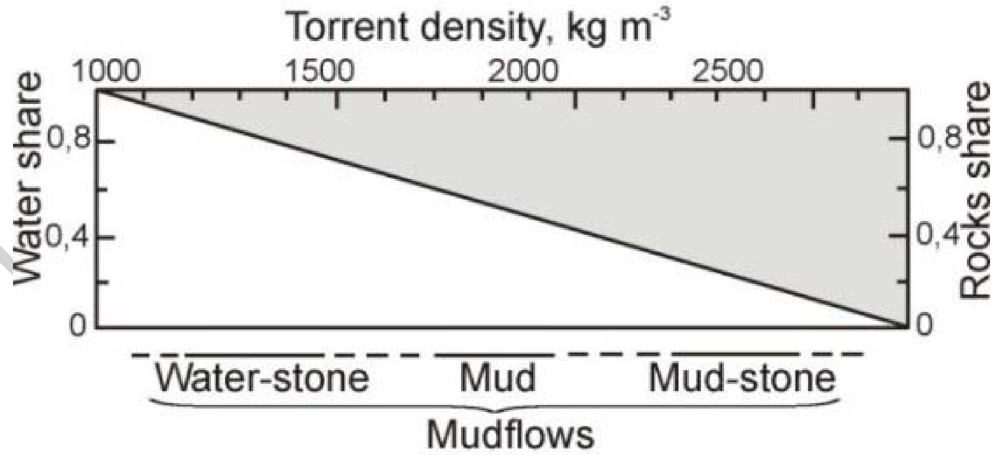

Figure 1. Three types of mudflows singled out by their mud mass density, which depends on the relation between water and rock

Depending on the composition and density of the mudflow mass, three types of mudflows are singled out: water-stone, mud, and mud-stone ones (Figure 1). The density of the water-stone flows varies within the limits of 1100-1500 $kg{\cdot}m^{-3}$. They originate in high floods, tear off large-sized detrital material lying in the channel, and carry a large amount of suspended and dragged sediments. The density of mudflows is within 1600-2000 $kg{\cdot}m^{-3}$; they consist of mud with increments of rock fragments. And at last, the mud-stone flows have a density of 2100-2500 $kg{\cdot}m^{-3}$ and consist of the rock debris, whose intervals are filled with mud.

Mudflows move along the stream channels of mountain rivers. Mudflow motion differs from other channel flows by the high degree of their saturation with solid material, which consists of 10-70% or greater of the mudflow volume. The amount of solid suspended matter in mountain rivers, which seldom exceeds 1-2%, affects insignificantly the regime of water streams: they are governed by the channels given to them and the flow around obstacles, and they behave just as liquids. When the water stream is highly saturated with solid material, the character of the stream movement drastically changes, particularly when the stream encounters some obstacles. The mudflow tends to keep the straight-line movement and produces a head-on impact with obstacles. The consequence of these impacts is the destruction of weak obstacles, as well as rafts and jams near insurmountable obstacles, at steep turns and the channel narrowing. Thus, when the mudflows under the unchanged channel conditions, its fluid properties, i.e. fluidity and continuity, dominate, and properties of its solid component begin to dominate with changing channel conditions. On the whole, the mudflow is an intermediate medium between liquids and solid bodies, and it possesses the properties of both of them. It is capable to move along a rather steep channel; when the channel is smoothed out, the movement of the mudflow ceases.

All the above specific features that distinguish the mudflow from other water streams are due to their high content of solid material. This precludes the formation of mudflows in mountain rivers abounding in water. In this instance, where the saturation of water with solid material within a sufficiently long section needed to impart the properties of the mud stream to the river, is virtually impossible. Large mountain rivers can assume the mudflow character only within limited sections downstream of the influx of torrentially active water streams. However, the concentration of the mudflow material rapidly decreases farther downstream. Therefore, mudflows are generally characteristic of small perennial and ephemeral mountain water streams.

The major cause of the formation of mudflows is floods which are sufficiently strong to set in a motion a considerable amount of loose detrital material located on slopes and in channels. The second prerequisite to the formation of mudflows is the existence of sufficient storage of this material capable to come into motion. For this, the third condition is necessary, which is the presence of significant gradients of slopes and channels within the limits of the basin. This is the reason that mudflows typically occur in mountain rivers and do not occur in flat and hilly areas.

The natural factors governing the formation of mudflows are hydrometeorological, geologic, geomorphologic, and soil and vegetation. The duration and intensity of atmospheric heavy precipitation play the major roles in the formation of rainstorm mudflows. During heavy showers, rock debris (which is the main source of the solid component of mudflows) progressively accumulate in the form of gravity clusters, detritus, massifs of rock slides, and matter that has a tendency to floating. They become super-wetted, loose the balance, become eroded, and get into the water stream.

How rapidly the mudflow arises in this case depends on the lithology and degree of destruction of the rocks which compose the slopes and channels of the mud flow basin, also the existence of the rock slide and talus areas, and the degree of rock erosion. Examples are known when after a long drought, the first intensive and long shower has caused the mudflow; or heavy showers have not led to the formation of any mudflow, whereas ordinary rains caused a mudflow. The point is whether loose detrital material suitable to be washed out is available.

The temperature regime during mud-forming precipitation is of great importance. Snowing does not cause mudflows. It is rather common that less significant warm shower rains cause mudflows, whereas stronger cold rains do not. The mudflows associated with snow melting in spring depend on the snow pack of the preceding winter and the character of weather in spring. Mudflows are often arise due to the combination of intensive snow-melt and warm spring shower rains. The principal factor of the formation of the glacial mudflows is the air temperature during the period of the most intensive melting of glaciers, particularly the twenty-four-hour periods of positive temperatures in the zones of intensive ablation.

The principal hydrologic factor is the glacial lake breakthroughs. They produce strong floods and with them catastrophic mudflows. The additional factor is breakthroughs of water bodies formed by stone concentrations or cofferdams in the channel. These breakthroughs are particularly dangerous in the cases when the groundwater aquifers are located along the sliding surfaces of littoral massifs. This contributes to the disturbance of their balance state and their fall down into the channel.

The geologic factors are the lithologic composition and condition of rocks composing the upper layers of the weathering crust. The main exogenous processes that form the solid component of mudflows are disintegration of bed-rocks, accumulation of loose detrital material, and its transport downward along the slopes and channels of mountain water catchments. Mudflows can also be associated with the erosion of banks and channel bottoms, which leads to the formation of clusters and taluses. The sources of mudflows in glacial basins are frontal and lateral moraines that contain many millions of cubic meters of detrital material.

The geomorphologic factors manifest themselves through the effect of the relief of mountain basins on the mudflow processes at all stages of the mudflow formation, movement, and deposition. The higher are the gradients of the basin and the degree of the relief ruggedness, the quicker is the disturbance of the balance of unstable massifs and blocks, the smaller amount of water energy is needed for it, and the higher is the speed of the mudflow and its ability to capture new and new masses of solid material. The dynamic characteristics of the mudflow directly depend on the lengthwise gradient of the channel, which determines the speed and destructive impact of the mudflow. Therefore, it is not the casual fact that the mudflows (mostly glacial ones) formed in high mountains are the most catastrophic. They produce much greater volumes of the debris cone than the rain shower mudflows do.

The mountain watersheds, whose slopes are covered with high thick forests having thick root systems, seldom occur to be mudflow-dangerous. Forests act as if it cements soil with its roots and preserves soil from disaggregation. The tree's canopy, bushes, herbal cover, and forest litter defend bed-rocks from being washed out and affected by the sun rays, and thus markedly depress the processes of erosion and physical weathering. Tree crowns intercept a considerable portion of precipitation and in doing so they reduce the runoff and contribute to its dispersing in time; forest litter is favorable for water penetration into soils and bed-rocks. And lastly, tree trunks act as a thick wall, block the way for taluses, avalanches, and rock falls. Forests on slopes serve as the most reliable means to prevent mudflows and provide the safety for the downstream areas.

Among the anthropogenic factors initiating mudflows are unsystematic deforestation on the slopes and degradation of the surface and soil cover because of unregulated pasturing. These result in a soil loss and bed-rock outcrop, make bed-rocks vulnerable to the mechanical effect of precipitation, reduce infiltration, and increase the coefficient of the surface runoff. All this contributes to the development of mudflows. The longitudinal plowing of slopes also aggravates the mudflow processes: the furrows and hollows, which result from plowing, become the centers of mountain erosion.

Other forms of economic activities can also initiate mudflows: improperly organized mine heaps of processed rocks at mining enterprises; numerous explosions of rocks when building railways, highways, and other constructions; the lack of recultivation of land in places of constructing and stripping in open pits when extracting ores; overflow and unregulated discharge of water from irrigation channels located on steep slopes; excessive air pollution with emissions from industrial plants, which destructively affect the soil-and-vegetation cover.

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Bibliography

Costa J. Physical geomorphology of debris flows. Developments and applications of geomorphology. Berlin-Heidelberg, New York, Tokyo: Springer-Verlag, 1984, p. 268-317 [Causes of mudflows origin, their types and characteristics, differences from other types of flows, methods of study and ways of protection are considered].

Debris-Flow Hazard Mitigation: Mechanics, Prediction and Assessment. Proc. of First Intern. Confer. San Francisco, California, August 7-9, 1997. Ed. Ch. Cheng-Lung. New York, 1997, 817 pp. [In 75 report processes of origin, mechanics and parameters of mudflows, methods of study, assessment of mudflow danger and prediction, measures of protection are considered].

Debris-Flow Hazard Mitigation: Mechanics, Prediction and Assessment. Proc. of Second Intern. Confer. Taipei, Taiwan, August 16-18, 2000. Rotterdam, Brookfield: Balkema, 2000, 608 pp. [In 71 reports processes of origin and mechanics of mudflows, assessment of mudflow danger and prediction, measures of protection are considered].

Fleishman S.M. Mudflows. 2nd edition. Leningrad: Gidrometeoizdat, 1978, 312 pp. (Russian). [Processes of origin, movement, deposition of mudflows, methods of their study, forecast and calculation of parameters, measures of protection].

Innes J.L. Debris flows. Progress in physical geography, v. 7, December, 1983, p. 469-501 [Matters of terminology, classification, distribution and in more detail – mechanics and characteristic features of mudflows and deposits are considered].

Stepanov B.S., Stepanova T.S. Mechanics of mudflows. Moscow: Gidrometeoizdat, 1991, 379 pp. (Russian) [Physical-mechanical properties of mudflow-formating grounds and their models, mechanism of origin and movement of mudflows, methods of their calculation are considered].

Takahashi T. Debris flow. Rotterdam: Balkema, 1991 [Mechanics of origin, movement and deposition of mudflows].

Biographical Sketch

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

V.M. Kotlyakov participated in many expeditions. He worked and wintered in the Arctic, the Antarctica, at the slope of the highest summit of Europe, the Elbrus, headed the high mountain glaciological expeditions to the Pamirs.

The main theoretical results of V.M. Kotlyakov`s works consist in elucidation of laws of snow and ice accumulation of the Antarctic ice sheet as well as ice sheets in general (1961), snow cover of the Earth and its fluctuations within time and space (1968), the tasks and abilities of 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 for four glacial-interglacial cycles (1985 and further on). During the last years, V.M. Kotlyakov dealt with the global changes of the environment, geographical aspects of global and regional ecological problems, and the problems of interaction between the Nature and society.

V.M. Kotlyakov is the honorary president of the Russian Geographical Society and the President of the Glaciological Association. In 1987-91, V.M. Kotlyakov was elected the President of the International Commission of Snow and Ice, in 1987–93, he was the member of the Special, and later Scientific, ICSU Committee of the International Geosphere-Biosphere Programme, in 1988–96, the vice-president of the International Geographical Union. Now he is a member of the Earth Council.

V.M. Kotlyakov is elected a member of the Academia Europaea and the Academies of Sciences of France and Georgia, a honorary member of the American, Mexican, Italian, Georgian, and Estonian Geographical Societies.