SLUSHFLOWS: BASIC PROPERTIES AND SPREADING

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ABSTRACT. The article presents results of an analytical review of factual data and scientific studies concerning slushflows. The basic conditions and gears of origin, parameters and typology of flows are considered, as well as the impact slushflows have upon topography and vegetation, spreading and seasonal distribution, dangerous consequences of snowslides. Slushflows are regarded as zonal paragenic mudflow phenomena typical of the subarctic climate zone. The area of territories with slushflows predominance accounts for 20 per cent of the total land subject to mudflow phenomena. Recurrence intervals of snowslides average one in 5 to 10 years.

THE NATURE AND BASIC PROPERTIES.

The article by A.Washburn and R.Goldthwait [65] was the first to define a slushflow as a specific natural phenomenon. The authors described a slushflow as a mud-similar flow consisting of water-saturated snow moving within a stream channel.

Slushflows emerge in springtime, during deep thaws, when generation of snow melt water exceeds the snow's infiltrating capacity. Its existence lasts from a few seconds to several hours. The dynamics is characterized by the following components: formation of side ridges 0.5-2.0 metres high; changes in the composition towards the final stage of the slide when it becomes almost similar to a waterflow.

Numerous subsequent articles, published in English, referred to the aforementioned study as to the primary source and, thus, consolidated the use of the term "slushflow". In Russian the phenomen was given the name: "water-snow flow".

The term "slush avalanche" has emerged and established later [53]. The Russian equivalent in word to word translation sounds as an "avalanche consisting of water-saturated or melted snow". Nevertheless, preference has been given to the first term [40].

The first reports on slusflows were published in Russian in the late fifties - early sixties as well [26; 62; 41; 42; 17]. In most cases they defined a slushflow as a snow / water-rock flow. Later the definition: "snowbroth flow" emerged, and then - the term "slushflow" itself [3; 31; others]. The latter definition has become conventional, as well as "snowbroth flow", its synonim [16; 47].

Slushflows belong to the class of exodynamic phenomena usually characterized by high flow velocities: a slushflow is rapid and its surface is wavy even upon an ice dome with inclinations of 1° [63]. In shallow valleys slushflows produce hollow sounds resembling athunderstorm or a running train [17; 45; 22]. The flow slides in the form of a steep-fronted wave, characteristic of mud and water-rock flows. The flow's inertness manifests itself in misalignments of the surface at the turns of the valley. At those points traces of corrasion and accumulation can be seen up to 20 m above the flow bed.

Abundance of free water within the moving substance is proved by traces of its activities in the flow's tail. Such "muddy water floods" accompanied slushflow slides in the northern Sweden [53]. After a series of avalanches in the Khibini Mountains (May 1977) accumulations of sorted sediments of various sizes could be seen upon the surface of removed snow mass even a few hundred meters downstream.

The substance of a slushflow is actually a mixture of grains and snow-water balls. Flows retain their two-component structure within ice domes, but in case of mountain slopes they absorb rock debris, fine earth, soil particles and pieces of plants. Content of mineral inclusions vary - according to field tests - from 5% (in the Khibinis) to 10-11% (in the Tyan-Shan) [47]. The per cent content of free water accounts for 35 to 50% [34; 3; 38]. Density of a slushflow under the aforesaid conditions is about 900 kg/m^3 or, with inclusions, 1000-1100 kg/m^3.

Velocity of a snowbroth flow varies, depending on inclination: from 1.5 metre per second on flat ice domes to 4-8 metres per second in mountain valleys [17; 57; 22] with estimated maximum of 15-20 metres per second. The study [36] divides slushflows, according to their velocities, into two groups: fast (x10 m) generated in steep denudational slopes; and slow (x 1 m) formed within river valleys and gentle slopes.

As reported by investigations made in the mountainareas of the northern Russia, the volumes of slushflow detrital mass vary from 20,000 to 50,000 cubic metres, with maximum volume of 500,000 m^3 registered in the Circumpolar Urals.

BASIC CONDITIONS AND GEARS OF FORMATION.

The main factors of slushflow generation are: considerable thickness of snow; an ice layer upon the snow; orographic conditions providing for damming of thaw water; rapid snow melting [12].

Slushflows form under various orographic conditions: from gently inclined ice domes to steep slopes of mountains. Two basic morhological types of drainage basins are specified in mountainous areas: slope/ valley catchment; and riverbed catchment [31; 12]. Slope catchment results from gentle depressions and denudational cuts; valley catchment is executed by drainage basins of water streams. (Some basic parameters ov valley-type catchment in several mountain lands are presented in Table 1. Available data concerning other regions conform to those given in the Table.)

The most favourable orographic conditions are characteristic of river basins with heads lying within surfaces of plateaus or bottoms of vast ancient kars (cirques). Snowmelt water concentrates upon a gently inclined rolling surface and snow-ice dams emerge easily in rock bars (steps), especially in gorges filled with snow. Such orographic conditions further formation of vigorous streams, reported to exist in Spitsbergen (Svalbard) [20], the Kyrgyz Range [51; 28], northern Finland [12]. Attempts have been taken to develop a morphologic classification of drainage basins in the Khibini Mountains [3; 58; 66].

Inclinations within waterheads of drainage basins are: 10-15° in the northern Sweden [39], 8-20° in the Khibinis, 4.5° to 40.5° in Norway [11], 2° to 15-20° in Alaska [38]. Both ice domes with inclinations of 1-5° and heads of shallow valleys with inclinations of 10-20° should be specified as most characteristic.

Formation of slushflows is regulated by general climate background and meteorological preconditions within the conception period. The said preconditions must favour saturation of snow layers and generation of free water. Usually this situation results from sharp temperature increases or heavy rains. According to various sources a slushflow is preceded by 3° to 10°C temperature raise within 2-5 days period. For example, such increases can be viewed in the Khibinis during advective spring thaws [35] and the Brooks Range (Alaska) in case of combined effect of warm continental air and sunshine [37].

In Norway, slushflow formation is effected mainly by heavy raining. Only one flow of 24 examined resulted from intense snow melting without rain. The measured values of rains which resulted in the slushflow slide of January, 27-28th, 1981, was 40 and 115 mm/day respectively [18; 22].

Eleven slushflows in the Russian North have been studied. The analysis carried out has made it possible to differentiate significances of several indices with regard for flow origin: shift or breakthrough mechanism. Average values of temperature gradient (after transition through 0°C) are 3.8° / day for shift-resulting slushflows and 1.6° /day for break-resulting ones. Estimated values of overall water supply during the last 5 days before the slide are about 60 mm and 150 mm respectively. Precipitation contributes not more than 10% in the total water supply.

One of the first publications concerning slushflows [53] has indicated three main preconditions required for formation, namely: saturation of a snow layer before water emerges under it; step-like sloping of the rock-bed, providing for subsidence and cracking of snow being melted from the bottom.

The process of slushflow generation on gently inclined slopes of ice domed was described in the studies [63; 36]. When snowmelting is intensive, seasonal snow covering a glacier is so saturated with water that it becomes slushy and tends to acquire the properties of water. The snow covering areas with wedging-out waters and bottoms of shallow valleys in the ice loses its cohesive potential and suddenly starts to flow, involving the snow lying downhill. Similarly, soaking and suspension of a snow layer upon a river bed causes formation of slushflows in middle and lower sections of gently inclined valleys [32; 33].

Formation of a slushflow on a mountain slope is sometimes enforced by pressure in drainge channels under snow [2]. The author specifies such flows as pressure avalanches. Comparison studies of conditions leading to formation of flows on ice domes and on mountain slopes have revealed two basic types of formation mechanism: (1) percolation, performed by percolating free water; and (2) pressure, i.e. caused by hydraulic pressure in undersnow drainage channels [55].

V. F. Perov [16; 51] defines two basic types of formation: shift (a snow layer in a riverbed or a slopebeing torn off) and break (in snow dams). In this classification percolation and pressure are varities of a shift.

V. N. Sapunov [58] considers five independent types of flow formation: (1) percolation; (2) pressure; (3) break; (4) suffosion; (5) gravitation (impact of snow avalanches).

The data concerningNorway [18] tend to specify three types: (1) sudden cut-off in the area formation start-up; (2) sliding of water-saturated snow fields (with snow dams crossing drainage channels); (3) rapid regressive growth speading from the point of initial origination. Evidently, the first type correlates with percolation, while the second - with a break.

Laboratory flume trials and modeling of a percolation-type formation under the conditions similar to tjose in the Khibini Mountains have shown that all the basic parameters studied (slope morphology, amount of snow accumulated, physical and mechanical properties of snow cover) make contributions of the same order to the value of maximum tensile and shear stress in a snow layer [5]. The breaking-down point of riverbed snowbanks (ratio between solid and liquid phases) is 0.80-0.95 g/cm^3.

GEOMORHOLOGICAL EFFECT AND IMPACT UPON VEGETATION.

The first studies of geomorhological signs of slushflow sliding were carried out in north Sweden [53; 54].

The author emphasized such minor surface landforms as depletion furrows and struck depressions typical for transit zones. Later chippings were described, found on sides of large stones,as well as fine earth layers on large boulders and traces of misalignments of flow surface at the turns of thre riverbed [12]. Three generations of flows can be specified within the alluvial cone [20].

The first description of geomorhological signs of slushflow sliding in the Russian North (the Khibinis) was made by V. F. Perov [41; 42]. In transit zones they manifest themselves in corrasion and valley slopes "littered" with debris. The accumulation zone exists in the form of an alluvial cone or a narrow scroll strip (length up to 1 km) consisting of detrital rocks. Sediments consist of unsorted mixture of boulders and large-size debris, with considerable share of wood debris; their structure is porous and mellow. Surfaces of the most large detrital rocks are covered with fine earth, left by snowmelt. Downstream the main acumulation area branches of small-size debris formed by water streams can be found. Same characteristics describe traces left by the most recent mass slushflows in the Khibinis (May 1997).

On-site inspections have revealed similar geomorhological signs in other areas of the Russian North, namely: the Putorana plateau and the mountains of the Kolyma river basin [44; 45]. Thickness of sediments reaches 0.5-1.0 m. Cuttings and knockings can be seen on large detrital rocks within the valley slopes.

Similar traces of slushflows were found by the author in mountain lands of the temperate belt: the northern slope of the Stanovoy Range, and the Udokan Range (Stanovoye Highland). General appropriateness has been reflected in publications concerning mudflow phenomena [14; 46].

Slushflow sliding causes compositional changes, various types of oppression and damage of trees. These signs are used for identification of the phenomenon and determination of its age applying dendro-chronological method. In most cases knockings on trunks and young growth in the places of destroyed trees are examined. First examinations were made in the Khibinis [42; 43; 7], later - in Siberia [44; 45]. Data for the Brooks Range (Alaska) received through geomorphological signs comply to those for the northen Eurasia [36; 38; 39].

Summing up the aformentioned facts, we conclude that:

1. Traces and results of geomorphological activity of slushflows is uniform for various regions of the Earth. This is an additional reason for their separation into a special category of natural phenomena.
2. A slushflow is an important agent of denudation, predominantly in the mountains of the Subarctics. Volumes of detrital materials they carry considerbly exceeds those carried by snow avalanches. In some cases they elongate the profiles of slope feet by re-destributing debris brought by screes.
3. Deformation of trees by slushflows serves as an indicator of certain parameters and helpes to determine frequency of slidings. In scarcely populated areas dendro-chronological method is the only reliable way to define the present schedule of avalanches.

SPREADING AND RECURRENCE.

There have been carried out investigations describing formation of slushflows on: Baffin Island [63]; Antarctic Peninsula [24]; north-western and north-eastern sections of Greenland [65; 34]; Banks Island (Canadian Arctics) [64]; Spitsbergen (Svalbard) [20]. Slushflows on mountain ranges, formed in small valleys have been described both for continental and maritime climate conditions. Continental climate influences slushflows of the Brooks Range [36; 39], while maritime climate - northern and middle sections of the Scandinavian Mts. [53; 54; 19; 12]. In both cases slushflows are widespread and slide frequently enough.

As for mountain ranges outside glacial zones, slushflows in Scandinavia [53; 54; 19; 12] and Alaska [36; 39] have been studied both for continental and maritime climate conditions.

The first phase of investigations in Russia (1950-1960) embraced slushflow slides near Norilsk [26], the Polar Urals [21; 62; 17], and the Khibinis [41; 42].

The fact of recognition of slushflows as a specific type of natural phenomena found its reflection in the first general map of mudflow phenomena in the USSR supplied with a special study [29; 31], comprising the mountainous regions of the Subarctics and Arctic islands into a zone of slushflow prevalence.

New data on locations and dates of slushflow slides, recurrences and types of spreading in various areas of the Subarctics were collected during the following years. The said data concerned, in particulatar, the Khibini Mts. [6; 43; 60; 14], the Polar Urals [52; 22], the Putorana Plateau [44], the Kolyma basin [45] and the watershed between the Kolyma and the Sea of Okhotsk [32; 33]. In the temperate zone slushflow phenomena in the Stanovoye Highland [23; 47; 50], Kamchatka Peninsula [8; 9], Sakhalin [10] were studied. Slushflows were also registered in Transcaucasia [1; 13] and the Tyan-Shan Mts. [61].

The main results of the studies of spreading and time distribution of slushflows have been reflected in the works of the author [46; 47] and could be brought together into the following statements:

1. The zonal nature of spreading has been proved completely. Prevalence of rain mudflows in the subtropical and temperate belts gradually gives place to prevalence of slushflows in subarctic and arctic climate zones. Slushflows in the Arctics can form at low elevated (starting at the sea level) and gently sloping surfaces. In the Subarctics they tend to form in low and middle highlands and combination (paragenesis) with mud floods and snow avalanches, often within the same drainage basins, is characteristic. In the north section of the temperate zone slushflows are widely spread in middle mountains, in permafrost and mountain tundras only; they subordinate to rain mudflows. South of that belt, local manifestations of the phenomenon favoured by specific topography or climate anomalies are the only possible.
2. Slushflows tend to slide down in June-July in the arctic zone, and in May-June in the subarctic and northern section of temperate belts. In the rest of the temperate belt and in the subtropical zone seldom slushflows slide in March-May, sometimes in February.
3. Average recurrence of slushflows in areas of wide spreading is: each 10 years in the Khibinis; each 5 years in Siberia. Higher recurrences in continental Siberia are caused by rapid-thawing springs and homogeneous structure of snow cover.

In the summary study by A. L. Washburn [64] the Arctics and mountainous areas of the Subarctics are specified as the most subject to slushflows. The results of the questionnaire [40] prove their spreading in the temperate belt as well.

The differences in seasonal distribution in different regions are caused mainly by the degree of climate "continentness".

The principal spreading and seasonal distribution peculiarities on a world scale are given in the chart [47] and Table 2. They should be considered as the first draft zoning of slushflows (on the present level of knowledge). The territories with slushflows prevalence make 20% of the total mudflow endangered area of the world [30].

SLUSHFLOWS AMONG EXOGENOUS PROCESSES. TYPOLOGY.

First articles concerning slushflows defined them as mudflow-like phenomena, characeristic of areas with cold climate conditions [65]. The study [34] specifies slushflows as an interim phenomena between floods and dust avalanches (as well as mudflows - between floods and landslides). Such an analogy is rightful only if comparison is limited to contents of flowing masses.

Similarity between slushflows and mudflows (mud and water-rock) is emphasized in the typology of mudflow and mudfow-like phenomena of the world [46; 48]. The author specifies a group of paragenic mudflow phenomena., including both slush- and water-ice flows. The principal difference between paragenic and genuine mudflows is that snow and ice in paragenic phenomena act as the solid component. From the viewpoint of mudflow geography, a paragenic mudflow is a zonal (subarctic or subnival) version of a mudhlow. Paragenic phenomena are a component of nival-glacial systems (along with glaciers, snowbanks, avalanches, glacial mudflows, aufeis etc.) and are characterized with the paramount importance of snow cover and ice for substantial composition and basic development processes [16].

Development of a slushflow typology is in its initial stage. There are two basic approaches to the problem. One of them uses formation time and gear, and flow size as main criteria [27]. It is proposed, on the base of investigations in the Khibinis, to specify two types of flows - those generated before an undersnow drainage channel is formed, and those emerging when the channel is existing already. The first type includes two kinds of flows: (1) surface (i.e. the top layer of snow moves) and (2) comprehensive (i.e. the entire mass of snow within a streambed moves). A similar classification has been proposed for the Polar Urals: (1) small flows (slide in early spring and frequently); (2) large (slide in early summer) [14].

The other approach is given in [57; 12]. B. N. Rzhevsky and V. D. Panov [57] specify the following phenomena within the group of "avalanche/ mudflow processes": dust avalanches, ground avalanches, extra-moist ground avalanches, avalanche-mudflows and slush avalanches (slushflows). V. N. Sapunov [59] specifies the types of slushflows as follows: avalanche-like, mudflow-like, floodlike.

DAMAGE. CONTROL MEASURES.

Slides of slushflows, especially in newly developed areas, tend to lead to destruction and human casualties. Unfortunately, the risks of those disasters are taken into account rarely. According to the data obtained through the international questionnaire [40], the objects most often destroyed by slushflows include highways, railways, buildings, communication and power supply lines. Here is a short list of notable catastrophes (with human losses) caused by slushflow slides:

North Europe: Svalbard, June 1953 [38], North Norway, January 1981 [38]; Russia: near Norilsk, May 1955, Ognevka settlement in West Altai, March 1997, geologists settlement on the Kekurnaya river (90 km NW of Pevek), Magadan Province, June 1991. All of them included destruction of houses or temporary structures.

The existing variety and scale of control measures are limited. One of the oldest measures is digging of drainage canals in snow before it begins to melt. It was applied in the Scandinavian North in 1930s-1940s. But, according to practical experience, it could not always prevent from formation of flows [53]. In Norway, after the 1981 disaster, it was decided to remove 18 buildings, protect 1 building with a dam, and control traffic on the endangered highway during risk periods [19].

In Russia, protection against slushflows was implied at the "Apatit" group of mines in the Khibinis: a stone rubble dam (implying extracted rock material) was constructed in 1970s to protect the Koashvinsky mine. A similar dam was erected on the Gakmana r. after the 1989 spring snowbroth flow, to protect the Yuksporsky mine.

The most essential considerations to be regarded in order to avoid slushflow-caused disasters are: (1) preliminary appraisal of areas of future development is required within the regions of slushflow spreading; (2) construction of stone rubble dams is the most efficient engineering measure against slushflows as such dams are reliable, easy in construction and render durable service.

Table 1. Slushflows: drainage parameters and recurrence intervals - average and extremum values

Region	Drainage parameters			Recurrence (time betw. slides), years	Data source
	Area, sq.km	Stream length, km	Average inclin., pro mille		
Khibinis	5.8	3.3	122	10	"Mudflow danger areas...", 1976
	1.0 - 17.2	*.9 - 5.5*	*60 - 300*	*7 - 14*	
Putorana	5.0	3.2	241	5	Perov, 1981
	.6 - 12.8	*1.3 - 5.8*	*95 - 418*	*2 - 10*	
Kolyma basin	3.4	3.2	129	5	Perov, 1984
	1.2 - 8.5	*1.7 - 5.1*	*50 - 206*	*3- 10*	
Brooks Range	2.9	2.2	206	7	Onesti, 1983
	.7 - 12.6	*1.0 - 5.5*	*90 - 340*	*3 - 11*	

Table 2. Speading and seasonal distribution of slushflows in view of climate conditions.

climate zone	type of climate	region	spreading and seasonal distribution
I. Arctic	I.1.Transitional from maritime to continental	Spitsbergen (Svalbard), Franz Josef Land, Novaya Zemlya, Taimyr Peninsula, Canadian Arctic Arch., Greenland	Spreading - limited with surfaces and peripheria of ice shields and domes. Slide season -June-July
II. Sub-arctic	II.1. Transitional from maritime to continental	Mts. of Kola Penins., Circumpolar and Polar Urals	Spreading - everywhere. Slide season -May-June Recurrence period -10 years
	II.2. Continental	Mts. of NE Eurasia, NW North America, Putorana Plateau, Verkhoyansk Rg., Chersky, Kolyma and Chukchi highlands, Brooks Rg., Mackenzie Mts.	Spreading - everywhere. Slide season -May-June Recurrence period -5 (4 to 7) years
III. Tem-perate	III.1. Maritime of west coasts and islands	a) Scandinavian Mts., Iceland	Spreading - wide. Main slide season -May-June (sometimes - in January)
		b) Coast Mts., Chugach (Alaska and W.Canada)	No data available. Evidently, speading is more limited than in Scandinavia due to lower temperatures
	III.2. Continental	Stanovoye Highland, Stanovoy Rg., Skalisty Rg.	Spreading - limited;subordinate to water-rock mudflow of rain genesis. Slide season -May-June (in Siberia). Average recurrence period -6 years

REFERENCE.

1. Akifyeva K. V. et al. Peculiarities of avalanche formation processes in the mountains of moist subtropical zone of West Trancaucasia (Adzharia). Vestnik Moskovskogo Universiteta, 1997. No.2, p.78-85. *(in Russian)*
2. Akkuratov V. N. Meteorological preconditions of avalanche formation in the Khibinis. MGI, vol.12, 1966, p.232-238. *(in Russian)*
3. Blagoveshchensky V. P. Slushflows in the Khibinis. L. Gidrometeoizdat publ., 1975, p.88-96. *(in Russian)*
4. Bozhinsky A.N., Freidlin V. S. A model of slushflow formation. MGI, v.46, 1983, p. 65-71. *(in Russian)*
5. Boyarsky I. Ya.,Karger I. L., Laptev M. N. Experimental study of qualitative characteristics of slushflow formation. - Mudflows in the mountain regions of the USSR. Moscow State University publ., 1979, p.88-95. *(in Russian)*
6. Boyarsky I. Ya., Perov V. F., Sapunov V. N., Freidlin V. S. Mass slide of slushflows in the Khibinis, May 1977 - Mudflows in the mountain regions of the USSR. Moscow State University publ., 1979, p.96-99. *(in Russian)*
7. Budarina O. I., Leontovich A. M., Freidlin V. S. Results of dendrochronological investigations in basins - sources of slushflows. - Problems of slushflow control, Alma-Ata, Kazakhstan publ., 1981, p.220-233. *(in Russian)*
8. Budarina O. I., Perov V. F. On appraisal of mudflow risks in the mountain areas of Kamchatka. - Problems of slushflow control, Alma-Ata, Kazakhstan publ., 1981, p.201-212. *(in Russian)*
9. Budarina O. I., Perov V. F. Map mudflow endangered areas of Kamchatka. Vestnik Moskovskogo Universiteta, ser. Geography, 1984, No.1 p.86-88. *(in Russian)*
10. Budarina O. I. ., Perov V. F., Sidorova T. L. Mudflows on the Sakhalin I. Vestnik Moskovskogo Universiteta, ser. Geography, 1987, No.3 p.76-81. *(in Russian)*
11. Caine Nel. A model for Alpine talus slope development by slush avalanching. Journ. Geology, 1969, v. 77, No. 1, p. 92-100.
12. Clark M.I. and Seppala M. Slushflows in subarctic environment, Kilpisjarvi, Finnish Lapland. Arctic and alpine Research, 1988, v.20, No.1, p. 97-105.
13. Dzyuba V. V. Physical-mechanical properties of snow and avalanches in Adzharia. Slope processes. Moscow State University publ., 1980, p.57-63. *(in Russian)*
14. Fleishman S. M., Perov V. F. Mudflows. Moscow State Univrersity publishers, 1986, 127 pages. *(in Russian)*
15. Freidlin V. S. Hydrometeorological preconditions of slusflow formation. MGI, v.35, 1979, p.198-200. *(in Russian)*
16. Glaciology Dictionary , under Kotlyakov V. M., Leningrad, Gidrometeoizdat, 1984 (528 p.). *(in Russian)*
17. Guskov A. S. Mudflow of 21 June 1965 in the Polar Urals, MGI , v.14, 1968, p.320-322. *(in Russian)*
18. Hestnes E. A contribution to prediction of slush avalanches. Annals of Glaciology, 1985, v.6, p. 1-4.
19. Hestnes E. and Sandersen F. Slushflow activity in the Rana district, North Norway. Avalanche formation, movement and effects. IAHS Publ. No.162, 1987, p. 317-330.
20. Jahn A. Some features of mass movement on Spitsbergen slopes. Geografiska Annaler, 1967, 49A, No. 2-4, p. 213-225.
21. Kemmerikh A.O. Mud floods in the Circumpolar and Polar Urals. Meteorol. i Gidrol., 1961, No.3, p.126-127. *(in Russian)*
22. Khodakov V G., Ilyina E. A. Snow/ ice phenomena in the Polar Urals. MGI, v.65, 1989, p.110-118. *(in Russian)*
23. Kirichenko A.V., Ilnitsky P. I. Preconditions of mudflow formation in the mountains of northern Transbaikalia. - Rational exploitation and environmental protection in the BAM zone. Irkutsk, 1978, p. 54-58. *(in Russian)*
24. Koerner R. M. Glaciological observations in Trinity Peninsular, Graham Land, Antarctica. Journ. Glaciology, 1961, v.3 No.30, p.1063-1074.
25. Kolesnikov E. I., Popov V. I. Information concerning slushflows in low mountains of W. Altai. Leningrad, Gidrometeoizdat publ., 1981, p.43-49. *(in Russian)*
26. Komlev A. M. Mud floods in the Polar North. Meteorol. i Gidrol., 1957, No.12, p. 31-32. *(in Russian)*
27. Laptev M. N., Sapunov V. N., Freindlin V. S. Preconditions and gear of slushflow formation. MGI. v.32, 1978, p.43-49. *(in Russian)*
28. Maksimov N. V. Preconditions of pressure avalanche formation and prediction. Meteorol. i Gidrol., 1973, No.3, p.66-72. *(in Russian)*
29. Map of mudflow endangered areas of the USSR (scale 1:8,000,000). Under V.F. Perov, S.M. Freidlin, Moscow GUGK, 1976. *(in Russian)*
30. Map of World Mudflow Phenomena. V. F. Perov, I. S. Artyukhova, O. I. Budarina, T. G. Glazovskaya, T. L. Sidorova, Debris-flow Hazards Mitigation: Mechanics, prediction, and assessment. Proceedings of first international conference, New-York, 1997, p.322-331.
31. Mudflow endangered areas of the Soviet Union, under Fleishman S. M.and Perov V. F., Moscow State Univrersity publishers, 1976,308 pages. *(in Russian)*
32. Nefedov V. N. Formation of mudflows under snowmelt in Magadan province. Kolyma, 1982, No.12, p.28-31. *(in Russian)*
33. Nefedov V. N., Kuznetsov K. L. Slushflows in Magadan province. - Mudflows, compil., Moscow, Gidrometeoizdat publ., 1983, p.106-112. *(in Russian)*
34. Nobles L.H. Slush avalanches in northern Greenland and the classification of rapid mass movements. Internat. Assoc. Sci. Hydrol., pub.69, 1966, p.267-272.
35. Okolov V. F., Freidlin V. S. Meteorological conditions of slushflow formation. Problems of slushflow control, Alma-Ata, Kazakhstan publ., 1981, p.234-250. *(in Russian)*
36. Onesti L. J. Slushflow activity in the Atigun Pass area. Permafrost and related features. Guidebook

Intern. Conf. on Permafrost. Fairbanks, Alaska, 1983.

37. Onesti L. J. Meteorological conditions that initiate slushflows in the Central Brooks Range, Alaska. Annals of Glaciology, v.6, 1985, p.23-25.
38. Onesti L. J. Slushflow release mechanism: a first approximation. Avalanche formation, movement and effects. IAHS Publ., No.162, 1987, p.331-336.
39. Onesti L. J. Depositional environment and morphology of slush avalanche deposits, Central Brooks Range, Alaska. Geol. Soc. of Amer., 1989 Annual Meeting, Abstracts with program.
40. Onesti L. J., Hestnes E. Slush-flow questionnaire. Ann. Glaciol. v.13 Cambridge, 1989, p.226-230.
41. Perov V. F. Materials concerning snow-banks, glaciers and permafrost topography of the Khibini Mts. Moscow, 1965, 190 pages. *(in Russian)*
42. Perov V. F. Mudflows of the Khibini mountain land, Vestnik Moskovskogo Universiteta, ser. Geography, 1966, No.1, p.106-110. *(in Russian)*
43. Perov V. F. Experience in dendro-chronological investigations in determina-tion of mudflow recurrence in the Khibinis.- Phytoindication methods in glaciology. Moscow, 1971, p.42-49. *(in Russian)*
44. Perov V. F. Mudflow phenomena in the western part of the Putorana Plateau. Problems of slushflow control, Alma-Ata, Kazakhstan publ., 1981, p.212-219. *(in Russian)*
45. Perov V. F. Concerning mudflow danger in the SW section of Magadan Province. Problems of slushflow control, Alma-Ata, Kazakhstan publ., 1981, p.191-197. *(in Russian)*
46. Perov V. F. Mudflow phenomena in the territory of the USSR. Moscow, 1989, -149 pages. *(in Russian)*
47. Perov V. F. Slushflows: materials of glaciological studies, v.79, Moscow, 1995, p.177-185. *(in Russian)*
48. Perov V. F. Mudflow phenomena, dictionary. Moscow, Moscow State Univrersity publishers,1996, 45 pages. *(in Russian)*
49. Perov V. F., Gailit I. T., Budarina O. I., Tretyakova R. V. Estimate of mudflow risks in the Udokan Range (BAM zone).15th All-Union Conference on mudflow control, v.1, Moscow, 1978, p.69-72. *(in Russian)*
50. Perov V. F., Kirichenko A. V., Laptev M. E. Estimate of avalanche and mudflow risks in the BAM zone. - Man and Nature in BAM zone. Irkutsk, 1984, p.59-68. *(in Russian)*
51. Perov V. F., Sidorova T. L. Meteorological preconditions of slushflow formation. MGI, v.64, 1988, p.41-47. *(in Russian)*
52. Poznanin V. L. Mudflows in the northern sectrion of the Polar Urals. -Research and protection of hydrosphere. Moscow, 1975, p.10-11. *(in Russian)*
53. Rapp A. Recent development of mountain slopes in Karkevagge and surroundings, Northern Scandinavia. Geografiska annaler, 1960, v.42, No.2-3, p. 65-200.
54. Rapp A. Solifluction and avalanches in the Scandinavian Mountains. Permafrost International Conference, 11-15 Nov. 1963. Lafayette, Ind. Proceedings. Washington D.C., Natl. Academy of Sciences - Natl. Research Council, 1966, p.150-154.
55. Runich A. V. Snowbroth avalanches - difference from snow avalanches. - Engineer glaciology. (1st All-Union Conference on engineer glaciology. Apatity, 1973, p.96-101. *(in Russian)*
56. Rzhevsky B. N. Pressure avalanches and actuality of their study. MGI, v.16, 1970, p.107-111. *(in Russian)*
57. Rzhevsky B. N., Panov V. D. Avalanche/ mudflow processes in mountains during the snowmelt period. Natural conditions and economy of the North, v.11, Murmansk publ.,1983, p.37-48. *(in Russian)*
58. Sapunov V. N. Slushflows among similar destructive phenomena. Vestnik Moskov-skogo Universiteta, ser. Geography, 1985, No.6, p.31-37. *(in Russian)*
59. Sapunov V. N. Slushflows in the Khibinis. MGI, v.71, 1991, p.94-99. *(in Russian)*
60. Sapunova G. G., Sapunov V. N. Traces of slushflows, MGI, v.35, 1979, p.201-202. *(in Russian)*
61. Seversky I. V. Snow avalanches in Trans-Ili and Djunghar Alatau. Alma-Ata, Nauka publ., 1978, 256 pages. *(in Russian)*
62. Venieri R. Yu. Mudflows in the Circumpolar and Polar Urals.- Investigations of glaciers and glacial areas, v.3, Moscow, Academy of Sciences publ., 1963, p.152-158. *(in Russian)*
63. Ward W. H. and Orvig S. The glaciological studies of the Buffin Island Expedition, 1950. Part IV: The heat exchange at the surface of the Barnes Ice Cap during the ablation period. Journ. Glaciology, 1953, v.2 No.13, p.158-168.
64. Washburn A. L. The world of frost. A geocryological study. Moscow, Progress publ., 1988, 382 pages. *(in Russian)*
65. Wasburn A.L. and Goldthwait R. P. Slushflows (abs.). Geol. Soc. America Bull., 1958, v.69, No.12, p.1657-1658.
66. Yevteev A.O. Morphological classification of slushflow sources in the Khibinis. MGI, v.72, 1991, p.155-160. *(in Russian*