International Journal of
Geohazards and Environment
http://ijge.camdemia.ca, ijge@camdemia.ca

IJGE 2016 **2**(**3**): 166-179

Available at http://ojs.library.dal.ca/ijge

Technical Notes

Debris Flows of the Tunkinsky Goltsy Mountains (Tunkinsky District, Republic of Buryatia in Eastern Siberia)

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Abstract: On the night of June 28, 2014, near the village of Arshan in Tunkinsky district, Republic of Buryatia in eastern Siberia, two types of debris flows were formed as a result of intense storm precipitation: 1) debris floods along the river Kyngarga; 2) debris flows along the valleys originating from the cirques of the southern slope of the Tunkinsky Goltsy range, which went in the south-west direction towards the village. A year later, July 14, 2015, in the village of Arshan a debris flood occurred in the river Kyngarga. During the Holocene debris flows have occurred repeatedly, traces of which are seen in the sections of loose deposits. Their age was defined with the help of radiocarbon analysis of buried soil horizons. A historical analysis of debris flow activity on the territory for more than a century was made using published scientific works. Natural factors for the formation of debris flow situation were considered (synoptic and climatic conditions, hydrology, geology and landscape structure were evaluated). Reasons for the most recent debris flows were defined. A detailed analysis was given of the valleys of a number of rivers where results of debris flows were the most destructive. As a result of the debris flow along the river Kharimta, realignment of the river network took place. Consequences of debris flows for the natural environment and infrastructure of the village of Arshan were evaluated. It is considered that the partial destruction of the village of Arshan is a distinct possibility in the near future due to debris flows from cirque #1.

Keywords: debris flow, soil avalanchings, kars (cirques), radiocarbon age, Holocene, Tunkinsky Goltsy Mountains, Arshan village

1 Introduction

The areas of intensive development of debris flows, the main factors of their formation and distribution are presented in the articles of Siberian scientists (USSR Academy of Sciences 1963, Astrakhantsev and Ivanov 1964, Astrakhantsev and Budz 1966, Budz 1969). The most thorough study of debris flows.identified the geological, geomorphological and hydro-meteorological factors and conditions of formation of debris flows (USSR Academy of Sciences 1963). The methodological basis for the study of debris flows in the mountains south of eastern Siberia was established by Astrakhantsev and Budz (1962).

In recent decades, the study of debris flows has focused on the mechanisms of their formation in the conditions of intense torrential rainfall, in particular with the use of instrumental measurements and modeling techniques (Takahashi 1981, Anderson and Sitar 1995, Iverson et al 1997, Berti et al 1999, Jakob and Hungr 2005, Sassa and Wang 2005, Gregoretti

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DOI: 10.15273/ijge.2016.03.016

and Fontana 2008, McCoy et al 2010).

Synoptic situation

Debris flows in the village of Arshan have resulted from the contemporary atmospheric circulation. To analyze the change in the nature of general atmospheric circulation we used classification of Northern Hemisphere atmospheric circulation by Dzerdzeevsky`s method (Dzerdzeevsky et al 1946). Classification criteria are posted on the websites http://igrankononova.narod.ru and www. atmosphericcirculation.ru (Kononova 2007). Debris flow hazardous elementary circulation mechanisms (ECM) were ranked for mountain systems (Malneva and Kononova 2005). In Arshan on July 16-17, 1962, and on June 27-28, 2014, and during the debris flood in the river Kyngarga on July 13-14, 2015, the most hazardous synoptic conditions obtained. In all these cases, synoptic conditions favorable for convective cloudiness and heavy precipitation over the study were: a) surface level diffused trough combined with upper-level low gradient trough (up to 9 km); b) cold front; c) south cyclone from Mongolia; d) blocking ridge over Trans-Baikal territory. The village of Arshan was centrally located in relation to low pressure troughs, and heavy rainfall resulted. Unfortunately, due to the current lack of a meteorological station in the village of Arshan, it is not possible to estimate, even approximately, the amount of precipitation on June 27-28, 2014, and July 13-14, 2015.

The last decade has been identified as an atmospheric circulation transition period in the Northern Hemisphere. This transition is characterized by an increase in extreme precipitation in different sectors of the Northern Hemisphere, including the territory of Russia, which, in turn, is leading to an increase in flooding and related geohazards (Kononova 2014).

2 Climatic Conditions

Climatic peculiarities of the Tunka Basin are formed under the influence of lateral-zonal and altitudinal gradients. Radiation balance is around 1340 MJ/m^2 (Belousov et al 2000). The territory is characterized by significant amplitude of seasonal and daily fluctuations in air temperature with warm but short summer and cold winter with little snow. In summer, cyclonic weather prevails, while in winter the action of the Siberian High results in clear, windless and frosty weather. As early as in September mountains are covered by snow which melts in June. Snow cover depth is usually less than 0.5 m over the valley. Closer to the forest boundary the depth is up to 1-1.5 m. Precipitation is distributed unevenly over the territory, both in area and in seasons of the year. The great bulk of precipitation falls during the summer; the three summer months (June-August) account for up to 72%. Heavy and very heavy precipitation has been increasing in Siberia during the past five decades (Groisman and Gutman 2012).

Location of the Arshan village in the piedmont of the Tunkinsky Goltsy ridge determines the formation of climatic conditions, different from those that characterize climate of the central part of the valley. According to the data of long-term observations (1910-1997), temperature at the weather station Arshan (closed in 1997) is 3-6 °C higher than in the central part of the basin in winter and 2-4 °C lower in the summer months (Vasilenko and Voropai 2015). Mean long-term annual precipitation in Arshan village is around 480 mm, while at the weather station Tunka (center of the basin, 20 km to the south from Arshan) it is 320 mm. Long-term mean precipitation in Arshan was 89 mm in June, 141 mm in July, and 116 mm in August. The following years: 1941, 1942, 1962, 1966 and 1971 in Arshan have monthly amounts, significantly higher (by 250-340 mm) than the average. Daily precipitation amount in Arshan reached maximum in August 1941 – 98 mm, in August 1947 and July 1962 – 88 mm. The high mountain areas at Tunkinsky Goltsy ridge have precipitation about two times higher compared to the Arshan station. In Tunka the daily precipitation is much lower, for instance maximal daily precipitation for the observation period (1888-2015) does not exceed 60 mm. The previous debris flood on July 17-18, 1962, was caused by abundant precipitation. The Arshan weather station recorded 176.6 mm during two days, while the Tunka station only 29.5 mm (Zonov 1962).

3 Hydrologic Characteristics of the River Kyngarga

The river Kyngarga runs from the southern slopes of the Tunkinsky Goltsy at an altitude of 2260 m and flows into the river Tunka at the left, twelve kilometers from its mouth. The length of the river is 26 km. Area of catchment is 231 km^2 and average slope is 5.95%. Average flow velocity changes from about 1.5 m/s in the upper part to 0.02 m/s near the mouth. In the upper reaches of the river there are three waterfalls. The bottom of the river-bed in the upper part is rocky, at the waterfalls composed of crystalline rocks, in the lower reaches it is of sand, gravel, and peat (Surface Water Resources 1972). On the left bank of the river Kyngarga mostly ephemeral streams descend from the cirques. The main tributaries of the river Kyngarga are the rivers: Malyj Kharimta, Kharimta, and Ulyamkhai. On both sides of the Kyngarga river valley there are a number of small, ephemeral channels. During heavy precipitation they flow to the piedmont as debris flows and can cause significant damage to the village of Arshan and its surrounding areas.

With respect to hydrology the territory is underexplored. There was one hydrological station at the river Kyngarga: Kyngarga – Arshan, which operated between 1972 and 1987. Currently there are no instrumental observations of the levels and rates of flow in the watercourses of the river Kyngarga basin. Most annual runoff takes place in the warm period; the river's regime is characterized by spring-summer inundation and floods. In summer there can be observed several short-term (3-7 days) rain floods, the height of rise of which is considerably higher than that of spring and is about 1.5 m in the upper part, 0.5-0.7 m in the lower reaches, in some years debris flows occur. As a rule, from July to September, floods come one after another. Rate of streamflow in the river is high during this period. There is possibility of flooding of low-lying infrastructure objects and the village of Arshan. Maximum rates of stream flow and water levels are most often in July and August. The greatest rises (up to 3-4 m) were observed in 1912, 1938, 1941 and 1971 (Surface Water Resources 1972). The greatest flow of significant rain flood of July 26, 1971, defined by the flood marks (State Water Cadaster 1978) was 94.8 m^3/s. According to rough estimates, on July 28, 2014 water level in the river Kyngarga rose by 2.5-3 m, relative to pre-flood level, average stream flow rate could be 4.5-5.5 m^3/s. Abundance of mud and stone material in the river flow caused high destructive potential of the flood.

4 Geologic Aspects

The southern slopes of the Tunkinsky Goltsy are underlain by a 1-2.5 km East-West band, composed of Archaean – lower Proterozoic complex: gneisses, plagiogneisses, crystalline schists, and thin intercalated marbles (Samburg 1971). To the North, closer to the divide, are intrusions formed by foliated paleogranites and gneiss-granites. Then there are strata of rocks (lower-middle-upper Proterozoic complexes), composed of limestone, gneisses, schists, and dolomites. Along the foot of the Tunkinsky Goltsy Mountains a sloping foothill plain (a piedmont) has been formed by wide and large fans of proluvial-alluvial material and glacial formations represented by boulder deposits with pebble-gravel-sand filling. At the bottom of the slope of the Tunkinsky Goltsy there is the active Tunkinsky Fault. The village of Arshan is located in seismic zone with earthquake grade of 10 points on the MSK-64 scale.

5 Landscape Structure and Debris Flows

The modern landscape structure of the surroundings of the village of Arshan is characterized by the proliferation of high-mountain goltsy (tundra) and subgoltsy (open woodland), mountain-taiga high- and middle-mountain, as well as piedmont and intermountain depressions of taiga geosystems. Main changes in landscape structure due to the descent of debris flows are observed in the valleys of the river Kyngarga and its main tributaries. Geosystems of the river Kyngarga's valley within the study area before the disaster were characterized by the proliferation of pine, with a touch of birch and larch, sometimes with willow and spruce, herb-moss forests. In the valleys of the left tributaries of the river Kyngarga, flowing from the slopes of the Tunkinsky Goltsy, common were larch, sometimes spruce-larch forests. Within the borders of the basin the valley complexes were represented by larch-spruce-pine, sometimes larch-birch-pine green moss-shrub-herb forests. Large blocky complexes remain in the valleys of the left tributaries of the river Kyngarga.

Holocene debris flows activity

The first reliable information about debris flows in the study area refers to the late 19th – early 20th centuries – the period of numerous scientific expeditions to study geological and geographical conditions of the Lake Baikal region. The first descriptions of debris flows which occurred in the river Kyngarga in 1897 were made by L'vov and Kropachev (1909). The next debris flow event took place as a result of heavy rainfall over the Tunka Basin on August 2 (Old Style), 1903. Then debris flows, which occurred in the rivers Kharimta and Khurai-Khobok, covered large areas of arable land near the Ulus Ulyabory. The "Chronicle of the City of Irkutsk for 1902 – 1924" compiled by Romanov (1994) gives information about debris flows on June 25 and 27, 1912, near the village of Arshan. As a result of debris flow in 1952, thick deposits accumulated in the valley bottom of river Bugutoi, having descended from its left tributary, and Kyngarga river water level rose by more than three meters (Zonov 1962).

Next time debris flows in Tunkinsky Goltsy took place on the night of July 17-18, 1962. Kyngarga river water level reached up to three meters which threatened the bridge over the river in the village of Arshan, but no severe damage of the banks or big volumes of mass transport were observed in the whole mountain area. The amount of mud and stone material carried from the mountains was defined as 25-30 thousands m^3 per 1 km^2 of catchment basin, i.e. mean thickness of the layer scoured from the surface was a few centimeters (Zonov 1962).

In July 1971, as a result of debris flow, the waters of the river Kyngarga overflowed its banks and flooded part of Arshan village on the left bank.

Thus, analysis of historical data on debris flows indicates multiplicity and frequency of debris flows in the studied area for the last 100 years. In the loose deposits of debris flows accumulation zone we repeatedly noticed traces of their activity of Holocene age (Makarov et al 2014). The river Malyj Kharimta dissected debris flow horizons divided by buried underdeveloped soils six times during the last 600 calendar years (Figs. 1 & 2, point 853 – 51°53'50.7", 102°30'34.4", WGS-84). Within these soil-sedimentary strata a sharp change in granulometric composition of deposits is observed (from sandy loam and sand to gravel-pebble). Maximum thickness of accumulated debris flow deposits was 64 cm.

Debris flow deposits of different ages, separated by humus layers and underdeveloped soils were found in profile of loose deposits (Figs. 3 & 1, point 183 – 51°52'40.05", 102°21'17.37") in the middle of the piedmont sloping plain.

The age of the first debris flow event is determined by dating of buried soil located at the bottom part of the section, with an age of c.4,000 calendar years (LU-7787). The presence of humus layer of the same age at the depth of 55 cm indicates that the debris flow caused soil erosion and its accumulation on the surface. Then the soil surface was covered again with debris flow deposits of sandy loam composition, with thickness of 50 cm, in the stratum of which modern soil was formed, with not more than 600 years of calendar age (LU-7857).

In some places at fans, forming a piedmont sloping plain, traces of ancient as well as of modern debris flows are left as frontal lobes of slightly rounded material and fresh erosional gullies (Figs. 4 & 1).

6 Debris Flows near the Village of Arshan on June 28, 2014

Place of origin of debris flows is in the cirques (Fig. 5). First, storm precipitation has formed streams that have begun to erode the underlying loose deposits and brought boulders, pebbles,

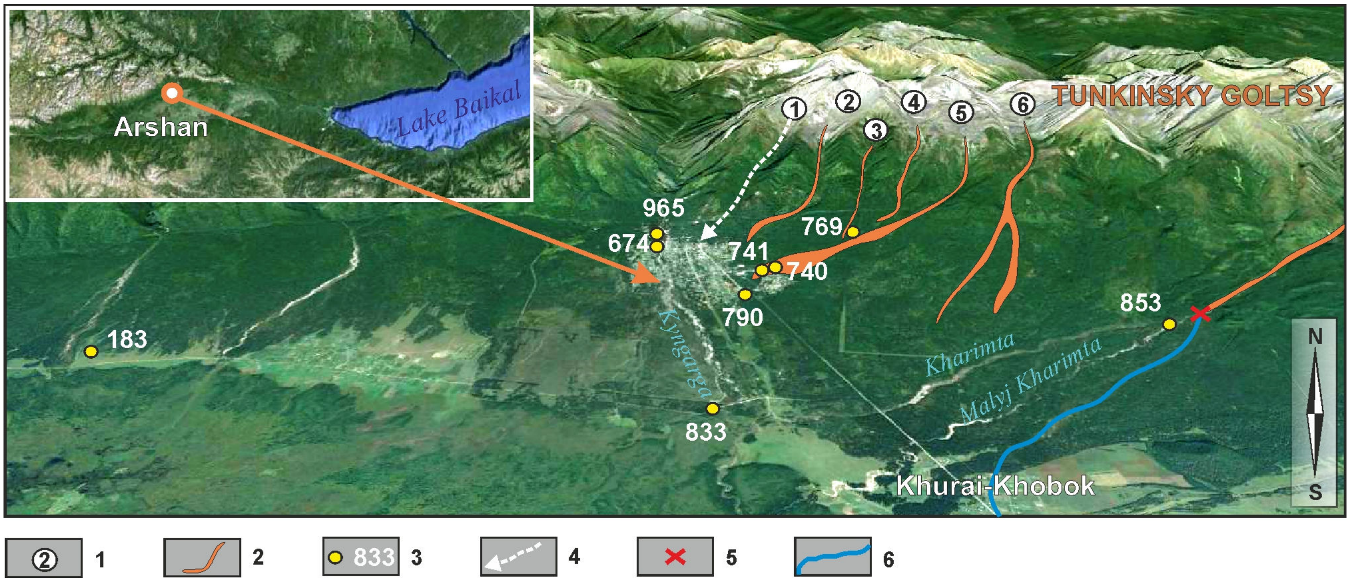

Figure 1. Location of the study objects and debris flows descended June 28, 2014, from Tunkinsky Goltsy Mountains. 1 – number of cirques (kar); 2 – debris flows; 3 – observation point and its number; 4 – anticipated direction of debris flow; 5 – blockage of river beds with debris flow; 6 – new Kharimta river bed

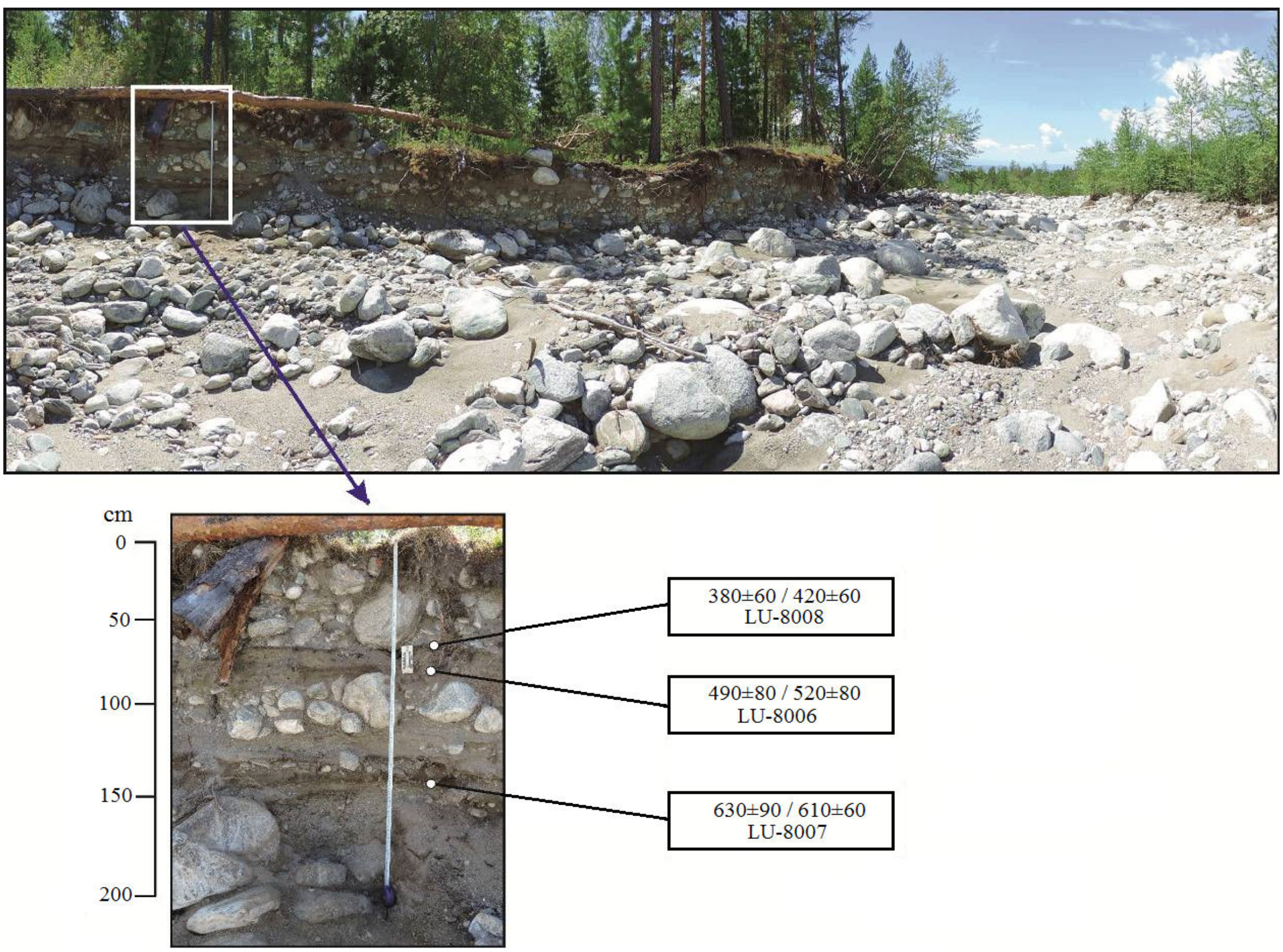

Figure 2. Soil-lithological stratum represented by a number of buried immature soils covered with debris flood deposits. Left bank of the river Malyj Kharimta (point 853). In boxes: radiocarbon / calendar (cal BP) age of the sample and its number

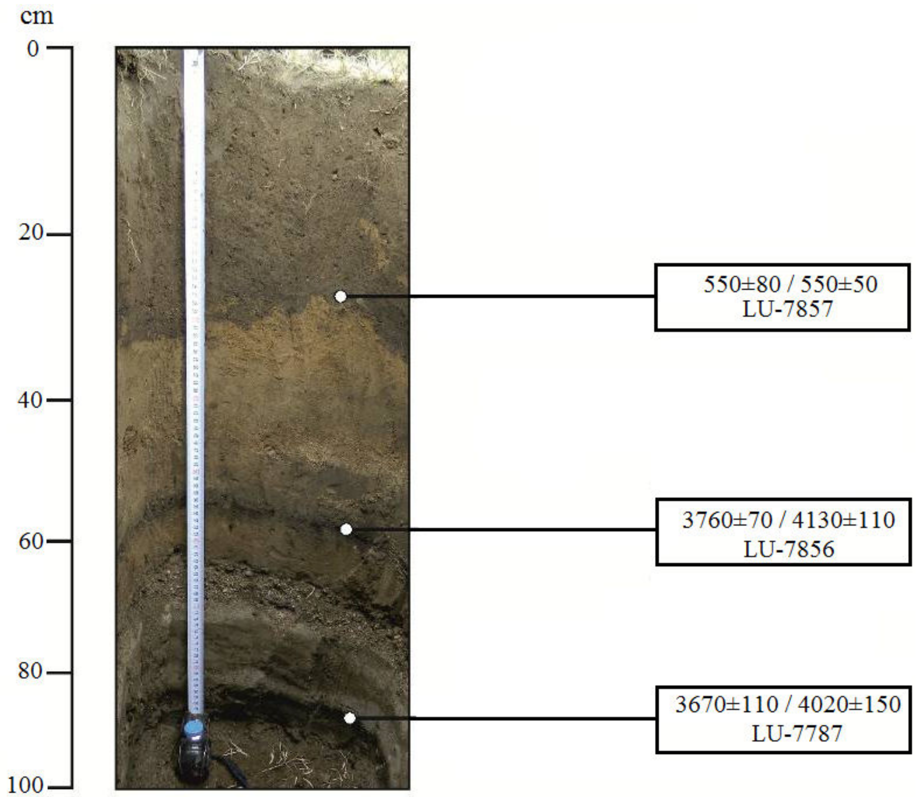

Figure 3. Soil-lithological stratum represented by a number of buried immature soils covered with debris flood deposits. The terrace above the floodplain of unnamed stream (point 183)

Figure 4. New debris flow gully (on the left in the photo) and ancient debris flow deposits (on the right in the photo) at debris flow fan of the river Pervaja Shikhtolayka (point 769 – 51˚55'03.5", 102˚27'45.0")

gravel, and sand into movement. After a short time, storm precipitation filled slope deposits with water, and, having lost traction, they began to move. On the cirque's slopes soil avalanches of detrital material began to form, represented predominantly by boulder, gravel, debris, and sand. Soil avalanches, descended to the sloping cirques' bottoms, brought glacial deposits to movement. Mud and stone mass began to descend along the valleys of rivers and streams, eroding proluvial-alluvial deposits on its way. Having cut the stratum of these deposits by at least 5 meters, debris flow mass ran into rock weathering crust. Soil avalanchings along the cirque slopes, probably, happened not simultaneously, but with short intervals, thus causing impulsive movement of debris flow. On its way, mud and stone mass brought vegetation, mostly pine-larch forests with a touch of birch and aspen, to movement. With deep erosion, there was complete destruction of soil cover. From the cirque no 1, mostly debris floods descended, run into the bottom of the stream and flew along its bed towards another unnamed stream, originating from the cirque no 2. The total length of the debris flow passage along the valley of the unnamed stream, coming from the cirque no 2, is 5.5 km. Of this distance, the origin zone was 71%, transit – 11% and accumulation – 18%. After some time, at the entrance of the first cirque another, middle-scale debris flow had formed and moved towards the village of Arshan. The debris flow stopped 500 m north of the village. Probably, trees played an important role, serving as a barrier to the passage of the debris flow.

Debris floods deposited boulder-gravel-pebbles in the "Arshan" resort, where they accumulated. At the same time, the flow of water with high concentration of suspended sand and loamy material went to the Traktovaya street near the bus terminal of the village of Arshan, destroyed sidewalks and lawns on both sides of the main street, in some places eroding loose gravel-pebble-sand deposits at a depth of up to 1.5 m.

The greatest erosion damage was observed in the lower part of the village, where debris flows of mud and stone went from the unnamed stream, originating from the cirque no 2, and the river Vtoraja Shikhtolaika to the Traktovaya street (Figs. 6 & 1). Within the fences of the houses a layer of debris flow deposits up to 1 m had formed. Some houses were pelted with mud and stone material up to windows. Some of them were destroyed. Drainage channel in the middle part of the village was also covered with debris flow deposits.

During the passage of the debris flow to the fan, the debris flow mass buried trees growing on its way. On the perimeter of the debris flow

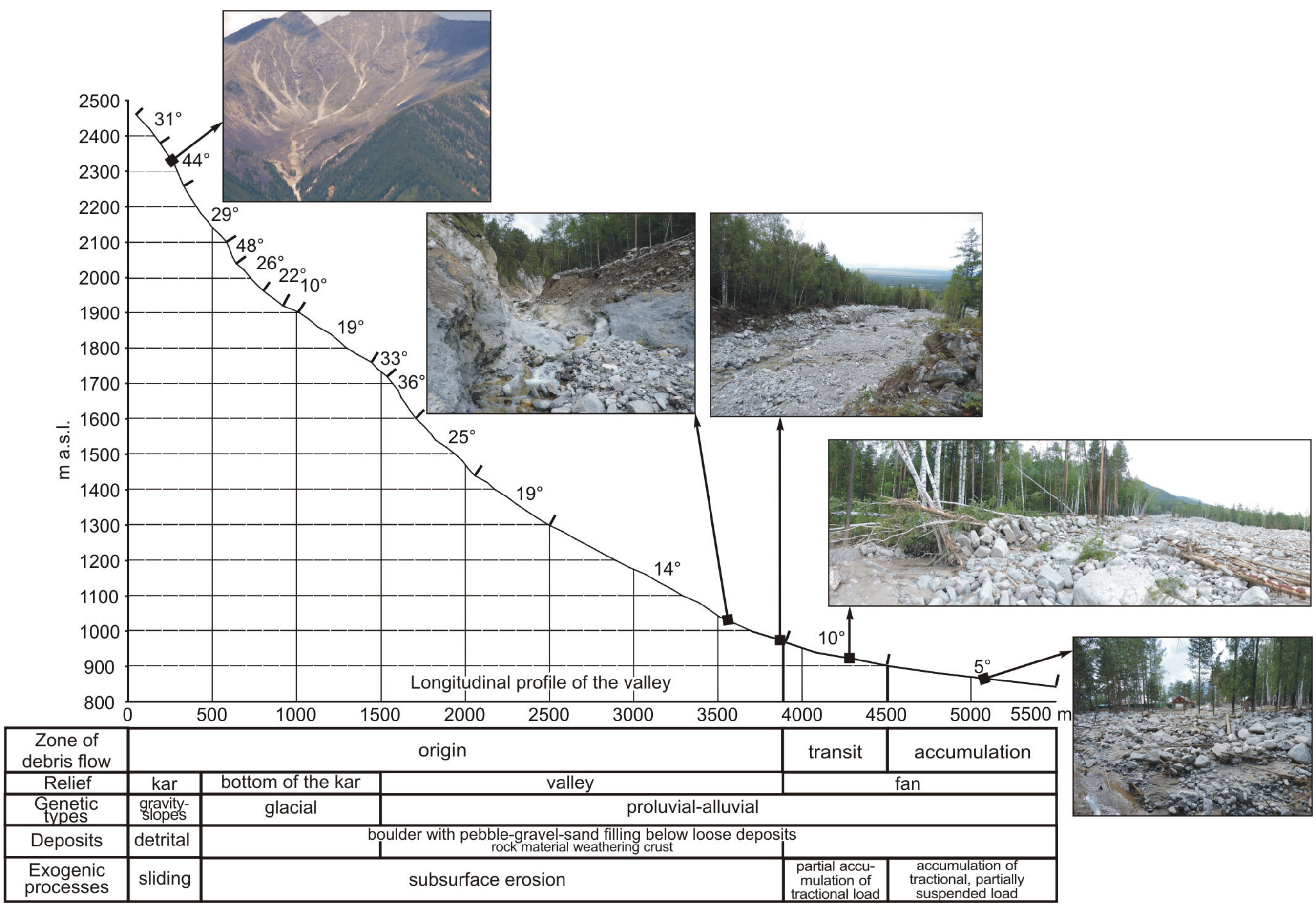

Figure 5. Schematic diagram of debris flow formation on June 28, 2014 (exemplified by the unnamed stream descending from the cirque no 2)

Figure 6. Ravine formed by water flow along the Traktovaya street near the "Sayany" resort. Picture of June 28, 2014. Local time 18:30 (point 790 – 51˚54'03.5", 102˚26'43.3")

Figure 7. Obstruction of wood and stone material in the form of a "fence" near the medical rehabilitation center "Sagaan Dali" (point 740 – 51˚54'29.0", 102˚26'45.2")

Figure 8. Front part of debris flow descended along the river Vtoraja Shikhtolaika. Picture of July 9, 2014 (point 741 – 51˚54'32.4", 102˚26'53.2")

boulder material accumulated in the form of debris flow levees. Perpendicular to the debris flows movement among the trees there appeared numerous obstructions of wood and stone material up to two meters in height, resembling a fence (Figs. 7 & 1). In transit zone sporadic shifts of slightly rounded boulders of 2 to 3 m were recorded.

To estimate the extent of debris flow mass from the cirques of the Tunkinsky Goltsy southern slope, the scope of activated deposits was evaluated to about 2 million m^3. It should be noted that this figure is not final.

Below the origin and transit zones there is the zone of accumulation, namely a debris flow fan. In this particular case, it would be practical to divide it into three sub-zones: 1 – basic (accumulation of solid phase of debris flow with filling), 2 – intermediate (accumulation of solid phase of debris flow with filling of suspended loads), 3 – final (accumulation of suspended loads only). In the second and third sub-zones debris material is deposited in the form of radial splays, predominantly in depressions. The largest zone is the third one where suspended material can be carried by water flows several kilometers away.

In the upper part of accumulation zone mainly tractional loads were deposited. Along the valley of the river Vtoraja Shikhtolaika their thickness was 3-3.5 m. Width of the debris flow front part in this zone was 325 m (Figs. 8 & 1). Moving along the perimeter of fan, boulder material destroyed wooden houses on its way. In the vicinity of the medical rehabilitation center “Sagaan Dali” boulder deposits reached the second floor (Figs. 9 & 1).

It should be noted that the zone of origin, transit and accumulation of debris flows are well interpreted in satellite images at sites of mass destruction of vegetation cover. However, during the field studies it was revealed that under the forest canopy along the debris flows there also can be observed zones of accumulation and transit of disperse suspended loads, which cannot be seen in satellite images. Their width amounts to tens and hundreds of meters. In the direction of movement debris flows were delimited by strong water flows, at first advancing the moving debris flow mass. As a result of this, in the middle and lower parts of the piedmont sloping plain temporary and permanent watercourses, overflowing the banks, formed nonhomogeneous in structure and granulometric composition deposits up to 2 m (Fig. 10). Having descended from the piedmont sloping plain, water flows with high concentration of suspended loads reduced their speed, thus being deposited. In conditions of stagnation, sedimentation of powdery-sandy-clay fraction took place, at a higher flow speed – of sandy fraction. Covered were pine, spruce and mixed coniferous and small leaved forests, as well as wetlands and pastures. According to preliminary estimates, the area covered by deposits can be as large as tens of square kilometers.

Almost at the same time with formation of debris flows along the river Kyngarga a debris flood began its movement. On the left bank of the river, on the territory of medical buildings of the “Arshan” resort, water flow from the river caused massive development of erosion. The movement involved boulders with diameter up to 74 cm. In some places loamy material up to 45 cm was deposited. Mineral water wells located near the river bed were covered with boulders and pebbles. Powerful water flow caused abrasion of the banks and bottom of the river valley, due to the movement of incorporated trees and shrubs twisted with roots in large amounts, which formed blockages. During the first hours of flood in the village of Arshan a bridge over the river Kyngarga built in late 2013 was destroyed (Figs. 11 & 12). Below the bridge, because of the river’s left bank collapse, the road was damaged and a stone building was partially demolished.

During the first hours after the beginning of debris flow formation, mud and stone mass blocked the bed of the rivers Kharimta and Malyj Kharimta in the point of their branching, as a result of which the water flow with suspended loads went along the old bed of the river Kharimta towards the village Khurai-Khobok, where it flooded depressions along the roadside (see Fig. 1).

Simultaneously with the passage of debris flows from the territory of the village of Arshan and its surroundings, together with tractional loads, a great amount of solid domestic wastes were carried, which, together with woody debris,

Figure 9. Building of medical rehabilitation center “Sagaan Dali” obstructed with debris flow deposits descended along the river Vtoraja Shikhtolaika. Picture of July 9, 2014 (point 740 – 51˚54'29.0", 102˚26'45.2")

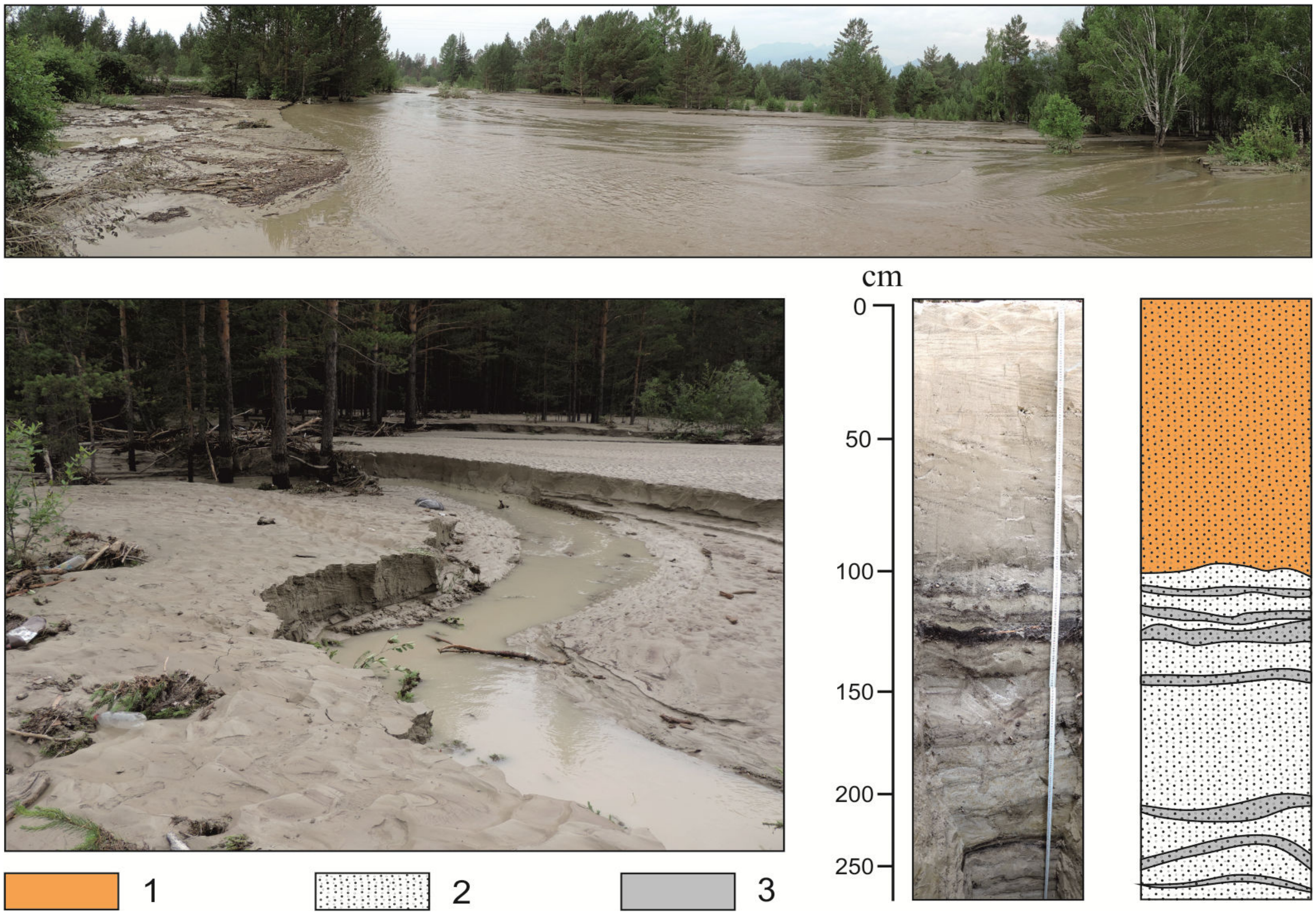

Figure 10. Fine sandy deposits formed as a result of debris flow on June 28, 2014. Right bank of the river Kyngarga, neighborhood of the village Tagarkhai (point 833 – 51°52'32,6", 102°26'41,1"). 1 – debris flow deposits accumulated in the first part of the day on June 28, 2014; 2 – fine sand; 3 – humus layers (immature humus soil horizons)

Figure 11. Bridge over the river Kyngarga on March 26, 2014

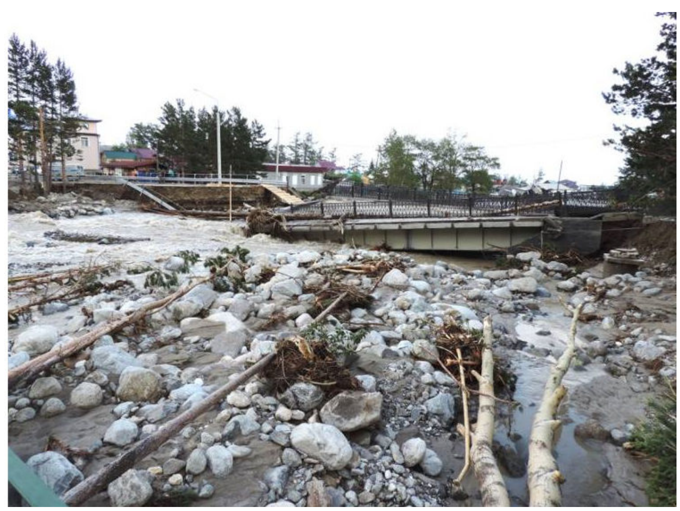

Figure 12. Bridge over the river Kyngarga on June 28, 2014, after the passage of debris flood along the river. Local time 19:18. Photo from the right bank of the river (point 674 – 51˚54'51.7", 102˚25'36.4")

formed numerous blockages. Among them were bulk wastes (used domestic appliances). These effects can be classified as environmental pollution of the territory.

7 Debris flood on the River Kyngarga in the Village of Arshan on July 14, 2015

After the destruction of bridge due to debris flood in 2014, in order to resume the passage of water, three tubes were put and a false fill was made. Then, in autumn of 2014, a wooden bridge on metal bearing structures was mounted below the embankment. On June 14, 2015 after a short rainfall there formed a flood in the river. Pipe culverts got blocked with stone material and water went out of the river to the left bank of the village of Arshan. The consequences were eliminated in quite a brief period by constructing a temporary dam and a channel was made by removing one of the pipes.

A year after the disastrous debris flows, on the night of July 13-14, 2015, there had been precipitation in the village of Arshan during the whole night. As a result, early in the morning there was a flood in the river Kyngarga, which transformed into a debris flow, which, in turn, gradually transformed into a debris flood. Having reached the maximum force by 11 o'clock (Fig. 13), the water began to splash onto the road bridge. In the morning of July 14, 2015, a powerful water flow washed the temporary embankment, and the remaining pipe was carried under the bridge, thus having partially blocked the passage. By this time precipitation began to stop and water level was gradually decreasing at a rate of not higher than 10 cm/h at the peak of water rise.

At the maximum of debris flood passage on the river Kyngarga there was mainly bottom erosion, as for the bank erosion – it was not large and the movement began to involve small-diameter pine. Water flow rate approximately did not exceed 4 m/s.

Since on the right bank near the Arshan resort bank backfilling was made under the hanging bridge in autumn 2014, thereby reducing natural cross-section of the river, during the flood of 2015 water went spontaneously along the left bank, threatening a market located along the river.

From the morning of July 14, 2015, streams of all cirques began to flow to the left bank territory of the village of Arshan. A stream of cirque no 1 began descending along the Traktovaya Street. As the rain stopped, it dried up by the evening. Only traces of suspended loads were left. Watercourses from the cirques no 1, 2 and 3 discharged into the drainage channel.

Figure 13. Debris flood in the river Kyngarga at the peak maximum. Local time 11:25, July, 14, 2015 (point 965 – 51˚55'00.0", 102˚25'33.9")

Like a year ago, water flow with suspended loads went along the new bed of the river Kharimta towards the village Khurai-Khobok where it flooded depressions along the roadside again (Fig. 1).

To define the amount of suspended loads and their parameters in the watercourses, water samples were collected. At the peak of water-rock-flow passage turbidity of water in the river Kyngarga was 7.017 kg/m^3. A sharp increase in turbidity is recorded at the peak and a smooth recession during the day. Concentration of suspended loads decreased by 13 times during this time.

At present time there is no hydrological station on the river Kyngarga. To estimate the amount of carried suspended material at the peak of the debris flood passage, the discharge was taken approximately equal to 90 m^3/s. This is water discharge indicator which is lower than the one recorded at the river Kyngarga during the passage of debris floods in 1962 and 1971 (Surface Water Resource 1972, State Water Cadaster 1978). Turbidity was taken as 7.017 kg/m^3. Approximately 2300 tons of suspended material was carried per hour.

8 Effect of Debris Flow on July 28, 2014

As a result of precipitation on June 28, 2014, debris flows were formed in the vicinity of the village of Arshan. Due to the sharp rise of water level in the rivers flowing from the slopes of the Tunkinsky Goltsy Mountains, the streets and roads were flooded, houses and utility buildings were destroyed, and new bridge over the river Kyngarga collapsed. The greatest damage to the village was caused by the debris flows formed in cirques of the Tunkinsky Goltsy. After their descent the territories of residential neighborhood, the “Sayany” sanatorium, medical rehabilitation center “Sagaan Dali”, lyceum-boarding school, and Traktovaya Street were flooded and destroyed (News Report 2014). Overall, as a result of this event, 9 houses were completely demolished, 52 buildings silted, road bridge destroyed; 119 children had been evacuated, 212 residents (including 71 children) were settled by relatives, 1 person died (RIA News 2014).

Within a few hours during the passage of debris flows there had been massive destruction and damage of vegetation:

1. Along the valleys of the rivers and streams on the slopes of the Tunkinsky Goltsy mountain range tree vegetation was ground by the stone material on its way and became part of debris flow mass in the process of bed incision into loose deposits and their involvement in the movement.
2. During their movement, debris flow deposits were crushing trees.
3. Water flows were carried along the perimeter of debris flows, carrying the torn trees on the surface. They were leaving large-scale scars on the trees growing along the river bed, at the height of water level.
4. Small tractional load was stripping bark from the fallen trees.
5. Boulders rolling along the bottom of the stream were leaving scars or stripping bark when hitting a tree close to the roots. Particularly strong damages were caused to birch trunks where bark was peeled off with a single boulder blow to a height of up to two meters.
6. Along the perimeter of debris flows the torn tree trunks formed a “wooden fence”, sometimes “wooden-stone”.
7. As a result of burst release of material, large areas in the vicinity of the village of Arshan appeared blocked by thick layers of suspended loads. Due to this reason, birch and aspen are most likely to die off. The big question is whether spruce and larch-pine forests would remain?
8. Along the valley of the river Kyngarga, lateral and bottom erosion caused destruction of banks and floodplain erosion. Tree root system was eroded, water flows incorporated trunks into movement, in many places blockages were formed out of them.

This disaster also affected the fauna near the village of Arshan, mainly mesofauna. Some insect families and ant hills were disturbed. In sand accumulations, ant hills began to recover in a few days after the debris flows descent. In places where sandy loam and loam were deposited, ants could not make passages even through thin layer of deposits. It is interesting to note that after a month and a half when a buried ant hill was uncovered, the insects were alive. Currently the process of mesofauna recovery is taking place, however, it is possible that new insect communities will emerge.

9 Conclusions

With all the catastrophic character of the debris flow processes near the village of Arshan, it should be noted that there was some good luck for the village that time. Despite the significant scale of damage, consequences for the residents and vacationers of the village were relatively light. Devastating consequences of natural calamity of June 28, 2014, took place at a large scale in the north-eastern and eastern parts of the village of Arshan and affected utility and residential facilities mainly in the zone of debris flows accumulation. At the same time, if the storm front shifted a few hundred meters to the west, then a debris flow would descend from the first cirque, "hanging over the village", cross the territory of the "Arshan" resort and reach the central part of the village. In this case, probably, the fifth part of it would have been affected. Human losses would also have occurred, as chances to escape, due to the specificity of position, would have been minimal.

Currently the debris flow formation situation in the cirque no 1 is quite hazardous, since storm precipitation may cause loose deposits to move (see Fig. 1). This is possible with a further increase in duration of the northern meridional circulation, which would increase the number of storm debris flows as happened in 1960-1970.

A question arises: in what direction will debris flows move in the future? Where they have occurred, that is the unnamed stream originating from the cirque no 2, there is now a convexo-plain surface, the height of several meters. Therefore, it should be expected that future debris flows would pass to the left or the right of the deposited mass. But in any scenario of probable consequences of debris flow activity on the east side of the village of Arshan destruction of houses and massive accumulation of tractional and suspended loads are possible.

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