DEBRIS FLOWS:
Disasters, Risk, Forecast, Protection

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Reconstruction of debris floods caused by breach of the prehistoric rockslide dams in Central Asia and their parameters assessment

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Debris and mud flows belong to the most rapid and, thus, hazardous mass wasting natural phenomena. Most powerful and disastrous events are caused by lakes' breach, the glacial lakes mainly (GLOFs). Even more adverse consequences might be caused by the breach of rockslide-dammed lakes formed in large river valleys, when up to several cubic kilometers of stored water can be released in a short time. Outburst floods transport significant amount of debris eroded from the blockages and entrained from the valley slopes and transform into debris floods. Such phenomena can be exemplified by several case studies that occurred in the historical times in different mountainous regions. Traces of the extremely powerful debris floods that occurred in the prehistoric times in different parts of the Central Asia region, in the Kokomeren, Aksu, Sokh, Gunt, Pianj River valleys were identified by analysis of high-resolution space images and during field observations. Analysis of rivers' thalweg profiles, of the specific landforms left by debris floods on river terraces and of the deposits accumulated downstream of the breached dams allow assessing height of the surge wave and peak discharge at some distances from the breached blockages. These events, along with historical outburst floods, can be considered as analogues applicable for assessing possible effects of the outburst of both the existing dammed lakes and those lakes that could originate in future.

debris flow, outburst flood, rock slide, Central Asia

Реконструкция селевых паводков, вызванных прорывами доисторических обвальных дамб в Центральной Азии, и оценка их параметров

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Грязекаменные и грязевые потоки относятся к наиболее быстрым и, следовательно, опасным разрушительным природным явлениям. Самые мощные и катастрофические события вызваны прорывом озер – главным образом, ледниковых (GLOF). Еще более неблагоприятные последствия могут быть вызваны прорывом озёр, образованных в крупных речных долинах вследствие обвалов, когда в течение короткого времени может быть накоплено и спущено до нескольких кубических километров воды. Потоки захватывают значительное количество обломков из завалов, вовлекают материал со склонов долины и превращаются в селевые потоки. К таким явлениям можно отнести несколько исследований событий, которые произошли в исторические времена в разных горных районах. Следы чрезвычайно сильных наводнений, произошедшие в доисторические времена в разных частях Центрально-Азиатского региона, в долинах Кокомерен, Аксу, Сох, Гунт, Пяндж, были идентифицированы путем анализа космических снимков высокого разрешения и во время полевых наблюдений. Анализ продольных профилей рек, рельефа отложений, оставленных наводнениями на речных террасах и отложений, накопленных ниже пробитых плотин, позволяет оценить высоту прорывной волны и пиковый расход на некотором расстоянии от разрушенных завалов. Эти события, наряду с информацией об исторических селях, можно рассматривать как аналоги, применимые для оценки возможных последствий прорыва как существующих подпрудных озёр, так и тех озёр, которые могут возникнуть в будущем.

сель, прорывной паводок, обвал, Центральная Азия

Introduction

Debris and mud flows belong to the most rapid and, thus, hazardous mass wasting phenomena. Most powerful and disastrous of them are caused by lakes' breach, mainly the glacial lakes (GLOFs) [*Vilímek et al., 2013*], or lakes dammed by rockslides in relatively small river valleys. Peak discharge of such floods, releasing up to hundred thousand, rarely few million cubic meters of water, usually reach 500-1000 m^3/s. It can be exemplified by the disastrous outburst flood with peak discharge up to ca. 1000 m^3/s that occurred in 1963 not far from the Almaty City due to catastrophic breach of the Issyk Lake [*Litovchenko, 1964; Strom, 2013*]. However, the consequences that can be even more adverse, might be caused by the outburst floods after breach of rockslide dams that block rather large river valleys, and store tens of million up to several billions cubic meters of water that can be released in a short time. Such outburst floods transport significant amount of debris eroded from the blockages and entrained from the valley slopes and bottoms, but do not reach the flow density typical of the “classical” debris flows (>1800 kg/m^3), and, thus, can be classified as debris floods [*Stepanov, Stepanova, 1991; Stepanov, Yafyazova, 2014*]. Debris floods are included in landslide classification system [*Hungr et al., 2014*] and are characterized by: “Very rapid flow of water, heavily charged with debris, in a steep channel. Peak discharge comparable to that of a water flood”. However, debris floods we are talking about might pass along normally inclined channels of well-developed river valleys.

Their effects can be exemplified by several case studies that occurred in the historical times in different mountainous regions. 1n 1786 earthquake-triggered Dadu rockslide in Sichuan Province in China formed a dam, which subsequent failure caused the lake outburst and flooding that killed about 100,000 people downstream, thus being the most disastrous catastrophe ever reported, caused by the secondary (damming and inundation) and tertiary (outburst) effects of large-scale slope failure [*Dai et al., 2005; Lee & Dai, 2011*].

Two catastrophic floods in Punjab in 1841 and 1858, caused by failure of rockslide dams that had blocked the Indus River and its large tributary, the Hunza River, correspondingly, resulted in 20-25 m rise of water in Indus River more than 400 km downstream from the breached rockslide dams [*Drew, 1875; Mason, 1929; Burbank, 1983; Delaney & Evans, 2011; Ahmed et al., 2014*].

The 1914 breach of the Rio Barrancos rockslide dam in Argentina resulted in the outburst flood that devastated the entire 900 km-long Rio Colorado valley up to its fall into Atlantic Ocean [*Groeber, 1916; Gonzalez Diaz et al., 2001; Hermanns et al., 2011*].

Breach of the ca. 200 m high Bairaman rockslide dam in Papua New Guinea about 180×106m3 in volume that released about 50 million cubic meters of water produced debris flow with an estimated volume of 120×106m^3 and average velocity of 20 km/h [*King et al., 1989*]. It was observed by eyewitness who reported that surge wave just downstream of the breached dam was up to 100 m high. 39 km down the Bairaman River, at its mouth, this flood was 8 m above normal river level.

One of the most recent events occurred in 2000 in the Yigong and Brahmaputra river valleys [*Shang et al., 2003; Evans & Delaney, 2011*]. Catastrophic breach of the about 50 m high dam and release of up to ca. 2.0 km^3 of water in Tibet in China produced flood wave with 120,000 m^3/s peak discharge recoded about 17 km downstream and 44,200 m^3/s peak discharge about 500 km downstream, in India [*Evans & Delaney, 2011*].

These examples demonstrate the level of hazard that can be associated with the breach of rockslide blockages in large river valleys. Since such phenomena are rare, it complicates compilation of the empirical relationships between various parameters that can be used for reliable assessment of characteristics of outburst floods that will occur in future inevitably, due to breach of the existing and newly formed large rockslide dams. That is why identification of the traces of similar prehistoric events and quantification of outburst floods is of high interest. Several such events have been identified in Central Asia region.

Prehistoric debris floods in Central Asia region

Traces of the extremely powerful debris floods that occurred in the prehistoric times were found in different parts of the Central Asia region, in the Kokomeren, Aksu, Sokh, Gunt, Piandj River valleys [*Strom, Abdrakhmatov, 2018*]. They were identified on high-resolution space images and, in some cases, as in the Kokomeren River valley in Central Tien Shan, during field observations [*Strom, Zhirkevich, 2013*].

Geomorphic and sedimentological evidence allowing identification of the prehistoric debris floods

Traces of the extremely powerful debris floods that occurred in the prehistoric times in different parts of the Central Asia region could be identified on high-resolution space images. The most informative evidence of such past phenomena is the amygdaliform ravines left on river terraces by powerful and, most likely, debris enriched flows, which level exceeded these terraces' level. One of the best examples was found in the Aksu River valley in Xinjiang (Fig. 1 and 2) [*Strom, Abdrakhmatov, in press*]. In its upper reaches, in Kyrgyzstan, this river is named Sarydjaz.

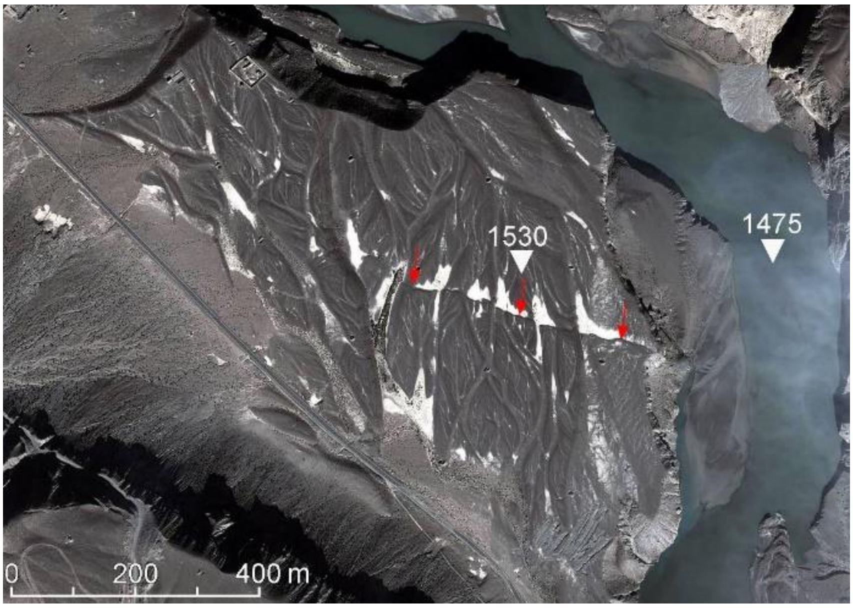

Fig. 1. The amygdaliform ravines left by powerful flow on the 50-m high river terrace of the Aksu River, about 16 km downstream from the breached dam. Terrace was ruptured by a small fault (marked by red arrows). Google Earth image.

Similar features were found in the Sokh River basin in Southern Tien Shan, Kyrgyzstan, just downstream of the confluence of Ak-Terek and the Khodja-Achkan Rivers, where it had been dammed by, likely, two-stage Korgon rock avalanche (Fig. 3).

Another geomorphic evidence of powerful, debris-enriched outburst floods that could be identified far away from the breached blockage is the shape of the alluvial fans of large rivers where they left rugged mountainous terrain (Fig. 4). Usually both floodplain and river terraces of large rivers are flat, planar, dissected by active and abandoned channels. It can be exemplified by cross-section C-D of the Pianj River valley, about 20 km off its outlet from the Darvaz

Range, shown in Fig. 5. However, cross-section A-B at the head part of this alluvial fan is quite different. Its axial portion is about 20 m higher than side parts recalling alluvial fans formed at the mouths of small temporary creeks formed by individual or recurrent debris flows.

Detailed analysis of the microrelief and topography of this fan reveals some evidence of its two-stage formation (see dashed envelopes on the profile A-B on Fig. 5). We anticipate that at least the most recent one could be formed by the catastrophic debris flood caused by the breach of Shidz rockslide dam that had blocked Pianj River valley about 350 km upstream forming a lake that could store up to 31 km^3 of water [*Strom*, *Abdrakhmatov*, *2018*].

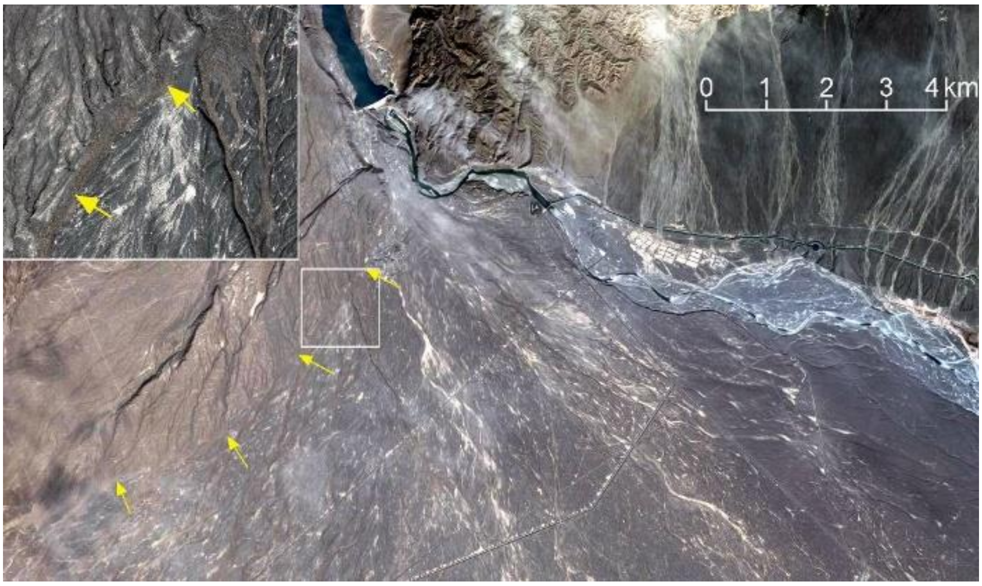

Fig. 2. The dendritic amygdaliform micro relief of the alluvial fan formed by the catastrophic outburst flood contrasting from the landforms of the older alluvial fan. The HPP dam in the upper part of the image is about 27 km downstream from the breached rockslide dam. Boundary between two generations of the alluvial fan landforms is marked by yellow arrows. Outlined area is shown in the inset. Google Earth image

Fig. 3. Possible two generations of the Korgon rock avalanche body and evidence of the outburst flood from upstream. 1 – older generation of debris with smooth surface composed of finer material; 2 – younger generation with much coarser material; F – the specific landforms on the terrace surface left by outburst flood; aQ – fluvial deposits. Google Earth image

Fig. 4. Google Earth satellite image of the Pianj River alluvial fan near Moskovskyi town (M) and its dendritic amygdaliform micro relief shown in the zoomed inset. Lines A-B and C-D mark position of the profiles shown on fig. 5.

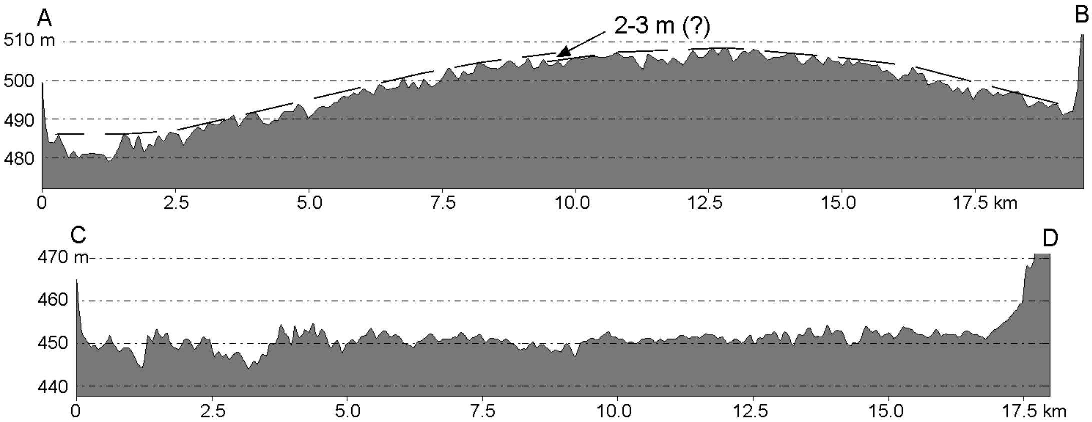

Fig. 5. Topographic profiles of the Pianj River floodplain (see their position in Fig. 4). It can be assumed that giant alluvial fan with convex profile A-B could be formed by successive debris floods

Similar shape characterizes fresh alluvial fan of the Muzart River valley that drains southern slopes of the Tien Shan east of the Victory Peak in Xinjiang (Fig. 6), most likely formed by the breach of one of large blockages identified in the mountainous part of this river valley 30-50 kilometers upstream.

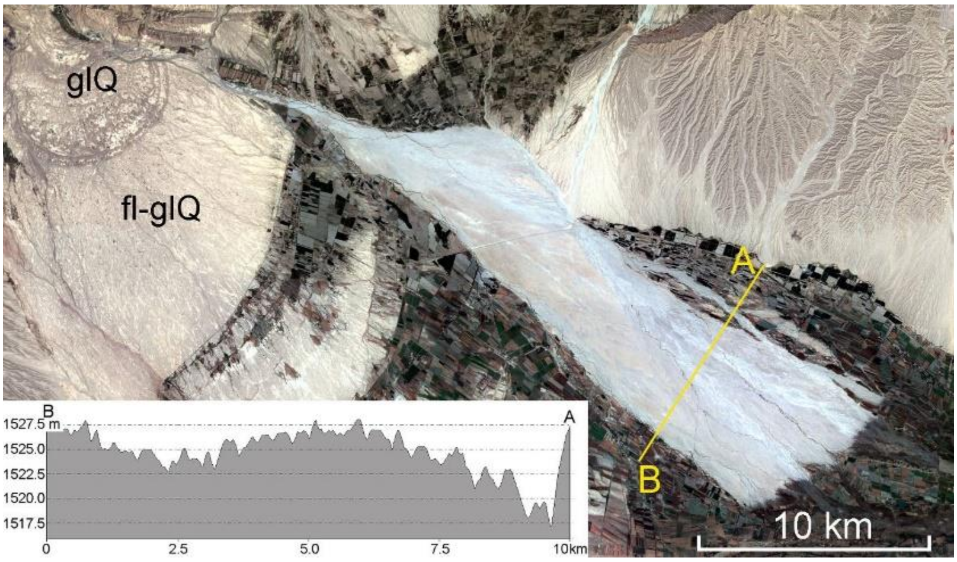

Fig. 6. Abnormally large fresh alluvial fan of the Muzart River. glQ – end moraine of the Muzart valley glacier; fl-glQ – fluvial-glacial deposits. Google Earth image. Profile A-B across the alluvial fan is shown in the inset

Identification of past debris floods caused by breach of voluminous rockslide-dammed lakes can be based also on careful study of sediments downstream of large blockages. Excellent example can be found in the Kokomeren River valley, Central Tien Shan, Kyrgyzstan, downstream of the breached Lower Aral Rockslide dam [*Strom, Zhirkevich, 2013*]. Rock avalanche that originated on top of the ridge composed of Paleozoic granites at 41.798º N, 74.288º E split into two parts upper of which (A on Fig. 7) had formed a 70-80 m high dam with a lake that could impound about 250×106 m3 of water. The lower body (B on Fig. 7) caused only partial blockage that was eroded by the outburst from the breached lake.

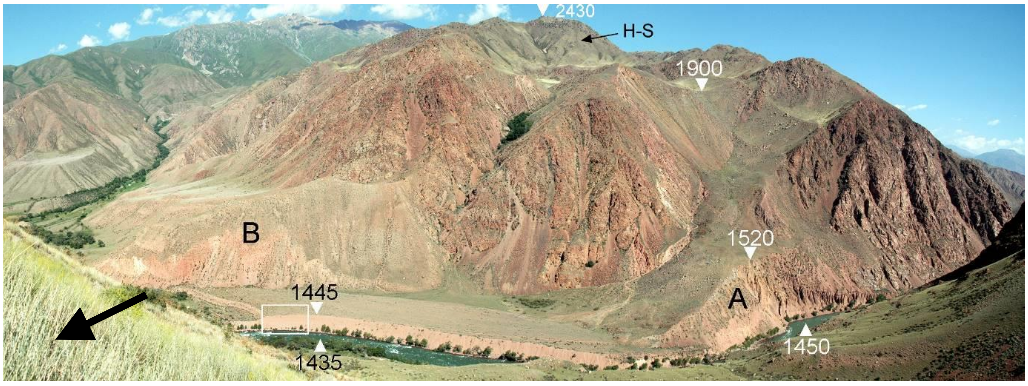

Fig. 7. Lower Aral rockslide. A and B – the upstream and the downstream pats of the deposits; H-S – the head scarp area. Bold black arrow marks the position of outcrop shown in Fig. 8. Outlined outcrop of the terrace-like surface left by the outburst flood is shown on Fig. 9

About 2 km downstream of the dam there is a small 37 m high cliff on the right bank of the river covered by an apron of angular granite clasts and with accumulation of large angular boulders of granite up to 1 m in size at its downstream side (Fig. 8). First, most powerful surge wave carrying meter-size boulders eroded from the dams' carapace was so large that it could not pass just through the existing stream and overrode this cliff. Those boulders that passed along the stream were brought far away, but those that pass just above the cliff were deposited in the 'shadow' behind it (see left inset in Fig. 8). The following portions of the outburst debris flow left smaller fragments on top of the cliff with imbricated flattened fragments nearly 40 m above the riverbed level (see upper inset in Fig. 8).

Fig. 8. Debris left by outburst flood after breach of the Lower-Aral rock avalanche dam on the isolated 37 m high cliff. See explanations in the text.

Deposits left by the final stages of this catastrophic outburst form the terrace-like surface about 10-14 m above the modern riverbed level on the right bank of the Kokomeren River between two bodies of the Lower-Aral rock avalanche. While morphologically it looks similar to the alluvial river terrace, it is composed of alternating layers of fines and of unrounded angular clasts (Fig. 8). The latter correspond to the episodes of more powerful flow caused by temporal blocking of the erosional canal in the blockage.

Fig. 9. Typical section of the outburst flood deposits about 14 m thick forming terrace-like surface just downstream of the Lower-Aral breached dam.

Analyses of valleys cross-sections, rivers' thalweg profiles with due regard to the specific landforms left by debris floods on river terraces and of the deposits accumulated downstream of the breached dams allows assessing their parameters such as height of the surge wave and peak discharge at some distances from the breached blockages.

Debris floods parameters assessment

Rough calculations have been performed to estimate peak discharge of the debris flow that left deposits shown on Fig. 8 and 9. Presence of imbricated clasts on top of the ca. 37 m high cliff shows that this flow had passed over it. One-meter size of largest angular boulders carried by this flow and preserved “in the shadow” of this cliff allows estimating flow velocity to be about 10 m/sec at least. Area of the Kokomeren valley section at the level reached by the flood wave was calculated as ~3000 m^2 that gave peak discharge value of ca. 30,000 m^3/sec (Strom & Zhirkevich, 2013) – almost 50 times more than the maximum value ever recorded here (~600 m^3/sec according to the State Water Inventory (1987).

Peak discharge estimate of the debris flood that formed the dendritic amygdaliform ravines on the 30-40 m high river terrace of the Sokh River downstream from the confluence of the Ak-Terek and the Khodja-Achkan Rivers shown on Fig. 3 is controversial. The most reliable source of this outburst was the breach of the ~150 m high rock avalanche dam about 40 Mm^3 in volume ~4.5 km upstream, in the Ak-Terek River valley. The area of the valley section up to the level slightly exceeding that of the curved terrace is about 8000 m2. Considering high velocity of the outburst flood wave, corresponding peak discharge should reach several tens thousands cubic meters per second. However, unlike the Lower Aral and the Aksu outburst floods that had emptied dammed lakes almost completely, the Ak-Terek dammed lake had been silted practically up to the dam's crest level (see Fig. 10). Thus, this rockslide dam breach could not release amount of water large enough to produce so high surge wave.

This discrepancy could be explained if we assume that flood occurred when the Sokh River valley was blocked by the second generation of the Korgon rockslide (marked by ‘2’ on Fig. 3). This dam could fill the river canyon almost up to the terrace level so that outburst flood had entered the inundated valley. Thus, the discharge of the surge wave that curved the amygdaliform ravines could be much lower than if it had to pass through the empty valley. Besides, this wave could trigger the breach of the blockage formed by the second Korgon rockslide.

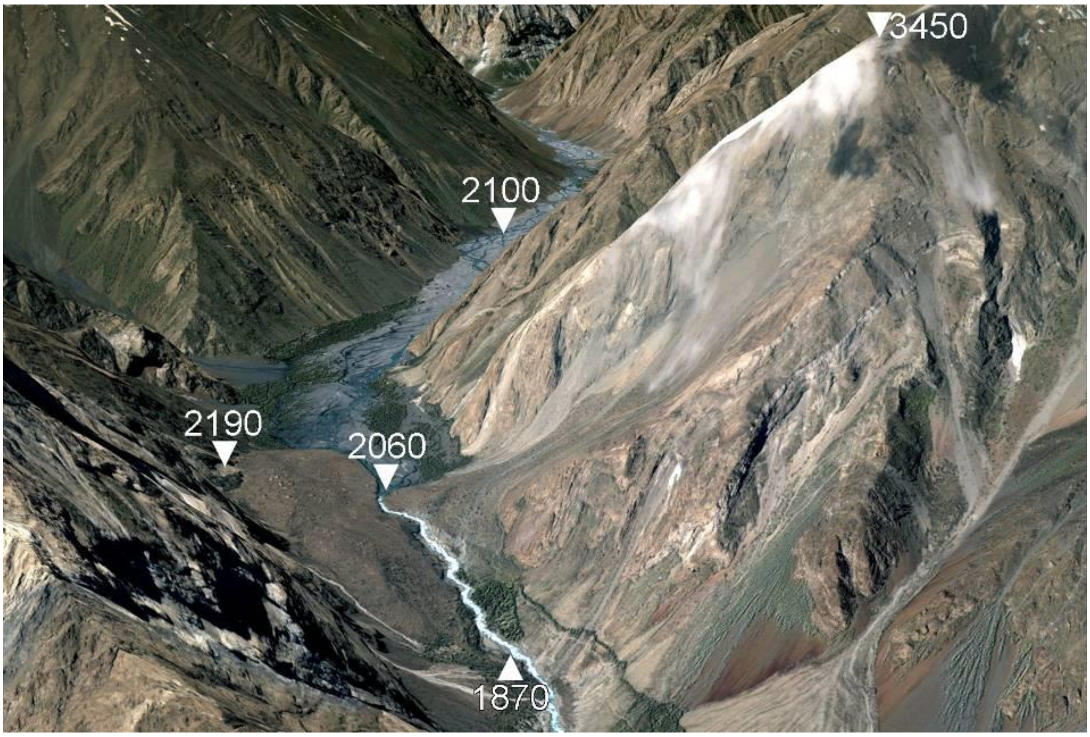

Fig. 10. Almost completely silted dammed lake in the Ak-Terek River valley. 3D Google Earth view

Much more powerful debris flood that curved terraces shown in Fig. 1 and 2 was associated with the breach of the Sarydjaz-Aksu blockage formed by the ca. 300 m high rockslide about 900 Mm^3 in volume at 41.764° N, 79.526° E. The 31 km long dammed lake could store up to 2.2 – 2.5 km^3 of water. This slope failure occurred on a slope composed of the dark grey Carboniferous metasediments, while area downstream is composed of pink and reddish Paleozoic and Cenozoic sedimentary rocks (Fig. 11).

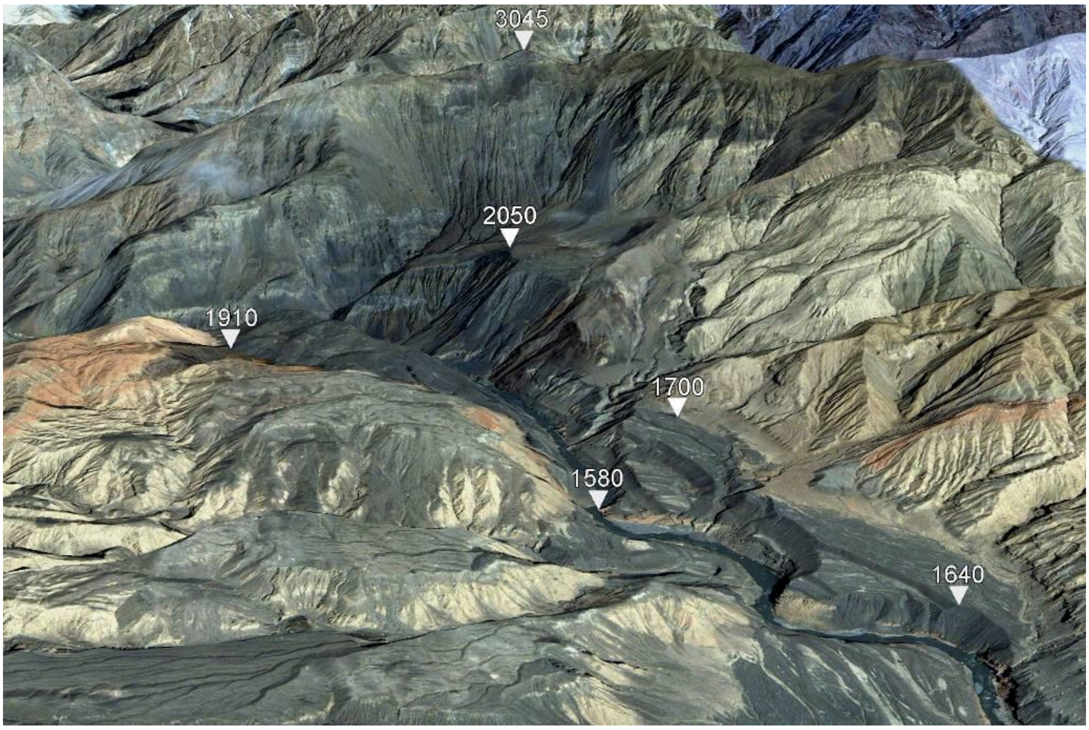

Fig. 11. Evidence of the catastrophic outburst flood caused by the Sarydjaz-Aksu rockslide dam breach – terraces up to 120 m high "painted" by dark-grey debris eroded from the dam's body. 3D Google Earth view

Immediately downstream from the dam the surge wave had painted river terraces by black debris eroded from the dam's body up to 120 m above the riverbed and ~700 m wide. About 2 km downstream outburst flood wave became wider – nearly up to 1000 m and affected river banks up to 80 m high. Considering generally triangular cross-section of the river valley and ~10 m3/sec velocity of the outburst flow (in fact it could be even higher), the peak discharge could reach 400,000 – 500,000 m3/sec – about 4 times more than that of the 2000 Yigong outburst flood [*Wang, 2008; Xu et al., 2008; Evans, Delaney, 2011*]. The dam was breached almost completely and do not form any distinct knickpoint.

Cascade breach of rockslide dams

Interesting observations were made in the middle reaches of the Pianj and the Gunt River valleys. Both valleys had been dammed by two large rockslide dams hundreds million cubic meters in volume each at a distance of ~12 and ~6 km correspondingly [*Strom, Abdrakhmatov, 2018*] (Fig. 12, 13). Judging from thalweg profiles both upper dams have not been incised up to its base, unlike completely breached dam in the Aksu River. Both thalweg profiles between breached dams are much steeper than up- and downstream.

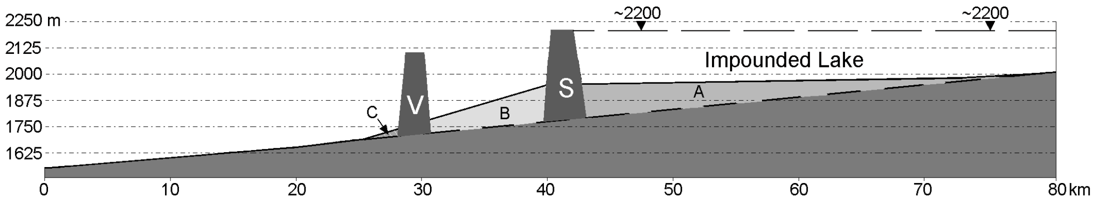

Fig. 12. Thalweg profile of the Pianj River between the Bartang and Yazgulem River mouths. A – sediments accumulated in the dammed lake; B – deposits eroded from the Shidz blockage; C – deposits accumulated downstream of the Voznavd rockslide dam. 2200 m a.s.l. – assumed level of inundation

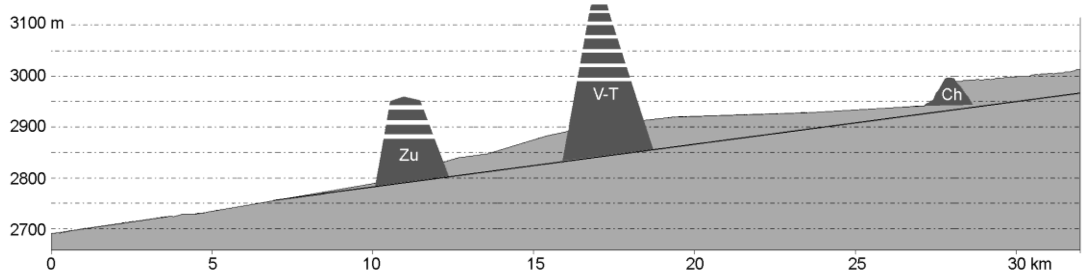

Fig. 13. The longitudinal profile along Gunt River between the Pathur River and Vuzhdara River mouths. Blockages: Ch – the Chartym; V-T – the Vir-Tangiv; Zu – the Zuvor. Black line – the assumed original thalweg

We hypothesize that in both cases both dams had originated simultaneously. Such conclusion is based on following considerations. When the upper dams breached, large amount of debris had been eroded from their bodies. This material accumulated in the trap between two blockages (see unit B on Fig. 12) and protected the lowermost part of the upper blockage from further erosion so that the siltation of the remaining part of the dammed lake could continue for a rather long time. Further breach of the lower dam, whose outburst flood was not confined by any obstacle, did not leave so thick accumulations. If the lower rockslides would block valleys earlier or later than the upper ones, the valleys upstream them should be silted in the same way upstream of the upper blockages with nearly horizontal thalweg, which is not observed. Such conclusion provides additional argumentation in favor of seismic triggering of the rockslide described in this section.

Conclusions

Case studies described above demonstrate possibility of qualitative and quantitative reconstruction of debris floods caused by breach of large dammed lakes formed by rockslides in major rivers. These data, along with observations made during historical outburst floods that occurred in last 200 years, can be considered as analogues applicable for assessing possible effects of the outburst of both the existing dammed lakes and those lakes that could originate in future. They can be used to test numerical models and codes elaborated to simulate such phenomena. Careful analysis of morphological and sedimentological evidence allows not only reconstruction of hydrological effects of outburst floods, but also conclusions on nature of other related phenomena such as on timing of the cascaded blockages. Further search of similar evidence both in Central Asia and in other mountainous regions of the World will provide more data about this hazardous natural phenomenon – breach of large rockslide-dammed lakes.

References

Ahmed M.F., Rogers J.D., Ismail E.H. (2014). Historic Landslide Dams along the Upper Indus River, Northern Pakistan. Natural Hazards Review, ASCE, doi: 10.1061/(ASCE)NH.1527-6996.0000165.

Burbank D.W. (1983). Multiple episodes of catastrophic flooding in the Peshawar basin during the past 700,000 years. Geol. Bull. Uniu. Peshawar, 16: 43-49.

Dai F.C., Lee C.F., Deng J.H., Tham L.G. (2005). The 1786 earthquake-triggered landslide dam and subsequent dam-break flood on the Dadu River, southwestern China. Geomorphology, 65: 205–221.

Delaney, K.B., and Evans, S.G. (2011). Rockslide dams in the northwest Himalayas (Pakistan, India) and the adjacent Pamir mountains (Afghanistan, Tajikistan), Central Asia. In: Evans, S.G., Hermanns, R., Strom, A.L., and Scarascia-Mugnozza, G. (eds) Natural and artificial rockslide dams. Lecture Notes in Earth Sciences, Springer, Heidelberg, 133: 205–242.

Delaney K.B., Evans S.G. (2015). The 2000 Yigong landslide (Tibetan Plateau), rockslide-dammed lake and outburst flood: review, remote sensing analysis, and process modelling. Geomorphology, 246: 377-393.

Drew F. (1875). The Jummoo and Kashmir Territories; A Geographical Account. Edward Stanford, London, 568 p.

González Diaz E.F., Giaccardi A.D., Costa C.H. (2001). La avalancha de rocas del rio Barrancas (Cerro Pelan), norte del Neuquen; su relacion con la catastrofe del Rio Colorado (29/12/1914), Revista de la Asociación Geologica Argentina, 56: 466–480.

Groeber P. (1916). Informe sobre las causas que han producido las crecientes del Rio Colorado (Territorios del Neuquen y La Pampa) en 1914, Direccion General de Minas, Geologia e Hidrologia, 11 (Serie B, Geologia), Buenos Aires, 29 p.

Hermanns R.L., Folguera A., Penna I., Fauqué L., Niedermann S. (2011). Landslide dams in the Central Andes of Argentina (Northern Patagonia and the Argentine Northwest). In: Evans S.G., Hermanns R., Strom A.L., Scarascia-Mugnozza G. (eds). Natural and artificial rockslide dams. Lecture Notes in Earth Sciences, Springer, Heidelberg, 133: 147-176.

Hungr O., Leroueil S., Picarelli L. (2014). Varnes classification of landslide types, an update. Landslides, 11: 167-194.

King J., Loveday I., Schuster R.L. (1989). The 1985 Bairaman landslide dam and resulting debris flow Papua New Guinea. Q. Journal of Engineering Geology, 22: 257–270.

Lee C.F., Dai F.C. (2011). The1786 Dadu River Landslide Dam, Sichuan, China. In: Evans S.G., Hermanns R., Scarascia-Mugnozza G., Strom A.L. (eds.) Natural and artificial rockslide dams. Lecture notes in Earth Sciences, 133: 369-388.

Litovchenko A.F. (1964). Catastrophic debris flow along the Issyk River. Meteorology and Hydrology, 4: 39-42 (in Russian).

Mason K. (1929). Indus Floods and Shyok Glaciers. Himalayan Journal, 1: 10–29.

Shang Y., Yang Z., Li L., Liu D., Liao Q., Wang Y. (2003). A super-large landslide in Tibet in 2000: background, occurrence, disaster, and origin. Geomorphology, 54: 225–243.

Stepanov B.S., Stepanova T.S. (1991). Mechanics of debris flows. Moscow, Gidrometeoizdat, 379 p. (in Russian).

Stepanov B.S., Yafyazova R.K. (2014). Debris flows of the Southeastern Kazakhstan. vol. 3. Debris flow processes and countermeasures from Debris flows hazards. Almaty, 2014, 433 p. (in Russian).

Strom A. (2013). Geological prerequisites for landslide dams' disaster assessment and mitigation in Central Asia. In: Wang F., Miyajima M., Li T., Fathani T.F. (eds) Progress of Geo-Disaster Mitigation Technology in Asia, Springer-Verlag Berlin Heidelberg, 17-53.

Strom A., Abdrakhmatov K. (in press). Rockslides and rock avalanches of Central Asia: distribution, morphology, and internal structure. Elsevier.

Strom A., Zhirkevich A. (2013). "Remote" landslide-related hazards and their consideration for the hydraulic schemes design. In: Genevois R., Prestinnizi A. (eds). Proc. Int. conference on Vajont – 1963-2013. Italian Journal of Engineering Geology and Environment, Book series No 6., 295-303.

Vilímek V., Emmer A., Huggel C., Schaub Y., Würmli S. (2013). Database of glacial lake outburst floods (GLOFs) – IPL Project No. 179. Landslides. doi: 10.1007/s10346-013-0448-7