



Large-Scale Rockslide Inventories: From the Kokomeren River Basin to the Entire Central Asia Region (WCoE 2014–2017, IPL-106-2)

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Abstract

Large-scale bedrock landslides are among the most hazardous natural phenomena posing a threat to communities living in mountainous regions and in the river valleys therein. Their study requires regular mapping of past features and compilation of uniform and representative inventories. This paper presents the main activities of the World Center of Excellence on Landslide Disaster Reduction of the Geodynamics Research Center—branch of JSC “Hydroproject Institute” (Moscow, Russia) and of the Kyrgyz Institute of Seismology (Bishkek, Kyrgyzstan). Their activities include compilation of a landslide inventory for the Kokomeren River Basin in Central Tien Shan, where the annual Kokomeren Summer School on Rockslides has been carried out since 2006, and of the uniform inventory of large-scale bedrock landslides (rockslides) for the entire Central Asia region, including the Djungaria, Tien Shan and Pamir mountain systems. Basic principles of rockslides identification and the structure of the database are described in brief.

Keywords

Rockslide • Inventory • Kokomeren • Djungaria • Tien shan • Pamir • Central Asia

Introduction

Compilation of the landslide inventories is the first and critically important step in understanding the spatial and temporal distribution of these hazardous natural phenomena, in revealing factors governing their distributions and in correct assessing landslide susceptibility and, further, landslide hazard and risk.

The Central Asia region (Fig. 1), embracing the Djungaria, Tien Shan and Pamir mountain systems, is one of the global landslide hotspots (Nadim et al. 2006).

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Besides numerous landslides in soft sediments, widely developed in the foothills and often covered by loess, this region is extremely rich in large-scale bedrock landslides, most of which are prehistoric. The majority of the historical case studies, including the world’s largest non-volcanic slope failure—the 2.2 km³ Usoi rockslide, were triggered by large earthquakes, although several non-seismic slope failures have been reported from this region as well.

Despite an arid climate favorable for the long-term preservation of landslides and facilitating their identification on remote sensing data, no complete rockslide inventory has been compiled up to now for the entire Central Asia region that includes six states—Afghanistan, China, Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan. Detailed inventories of the landslides in soft sediments were compiled for large parts of the study region (Niyazov 2009; Havenith et al. 2015a, b) while rockslides were mapped and studied in detail more locally (see, e.g., Fedorenko 1988).

Although bedrock landslides are, luckily, rather rare phenomena compared to slope failures in soft sediments,

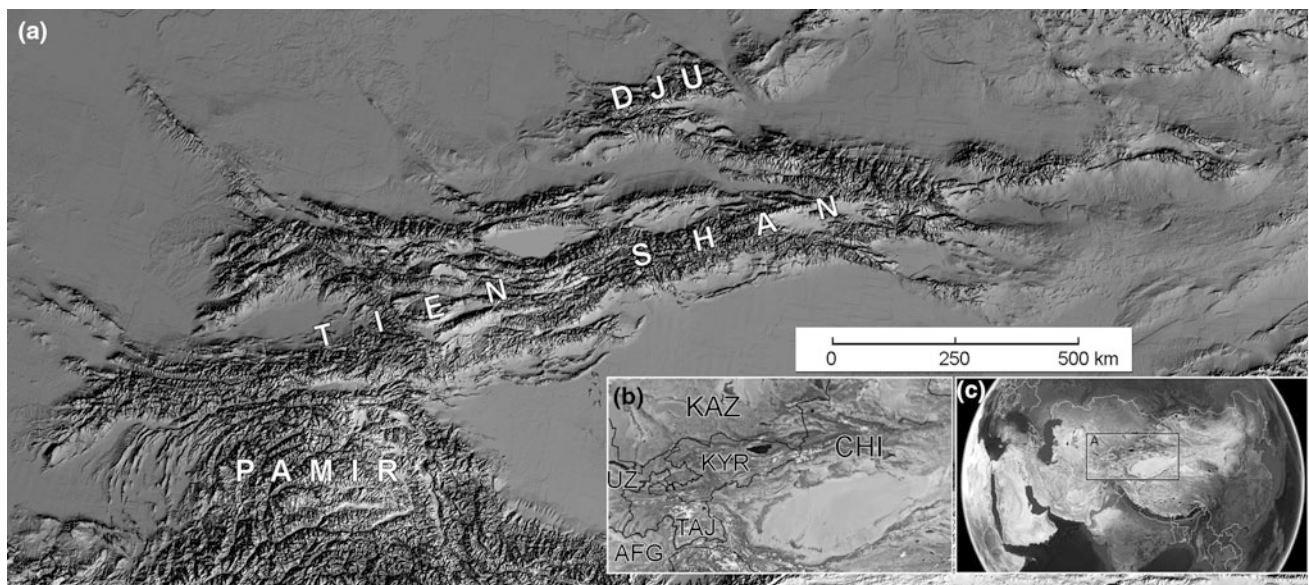


Fig. 1 a the 30" SRTM DEM of the study region; b political boundaries in the Central Asia region (from Google Earth); c location of the study region (*outlined*) in Asia. *DJU* Djungarian Range, *AFG*

Afghanistan, *CHI* China, *KAZ* Kazakhstan, *KYR* Kyrgyzstan, *TAJ* Tajikistan, *UZ* Uzbekistan

their effects could be extremely disastrous, due to their abnormal mobility and ability to form large natural dams.

Study of such features in the Kokomeran River basin in Central Tien Shan (Kyrgyzstan) has been supported by several IPL Projects since 2005 (the last one is IPL106-2). The main goal of these projects was the organization of the annual International Summer School on Rockslides and Related Phenomena (the Kokomeran Summer School) that has been carried out since 2006, supported by the International Consortium on Landslides (ICL) and International Program on Landslides (IPL). Acknowledging the success of these activities, the Geodynamics Research Center—branch of the JSC “Hydroproject Institute” (ICL Member since 2003) and Kyrgyz Institute of Seismology were awarded status as a World Center of Excellence on Landslide Disaster Reduction (WCoE) for the periods of 2008–2011, 2011–2014 and 2014–2017.

Based on the experience gained in this region, we started compilation of a rockslide inventory of the entire Central Asia region.

Rockslides in the Kokomeran River Basin

The Kokomeran River basin (41.6°–42.4°N, 73.9°–74.6°E) (Fig. 2) is extremely rich in impressive bedrock landslides and rock avalanches of different types (see Fig. 2) ranging in

volume from a few million up to ca. 1.5 billion cubic meters. They originated on slopes composed of different types of bedrock—Paleozoic granites, gneiss, sedimentary terrigenous rocks metamorphosed to a varying extent and Neogene conglomerates, sandstones and siltstones. About 25 rockslides were identified within a limited area of about 80 × 50 km, some of which formed natural dams while other transformed into highly mobile rock avalanches up to ~6 km long.

Since most of these features are located close to roads and are attainable during one-day trips from the base camp, this region was chosen for the two-week long annual field training course—the Kokomeran Summer School, which started in 2006 (Strom and Abdrakhmatov 2009). This area can be considered as a field museum of large-scale rockslides, not masked by thick vegetation and not disturbed by excessive human activities. It provides an excellent opportunity for students, young researchers and engineers to learn more about such phenomena, their distribution, origin, emplacement mechanisms and geological and geomorphic conditions favorable for their formation. Besides young professionals and students several experienced researchers participated in the Kokomeran Summer School too (Fig. 3).

The full-color Guidebook was printed and provided to Kokomeran Summer School participants and also has been uploaded on the IPL website for general use <http://iplhq.org> Download GUIDEBOOK.

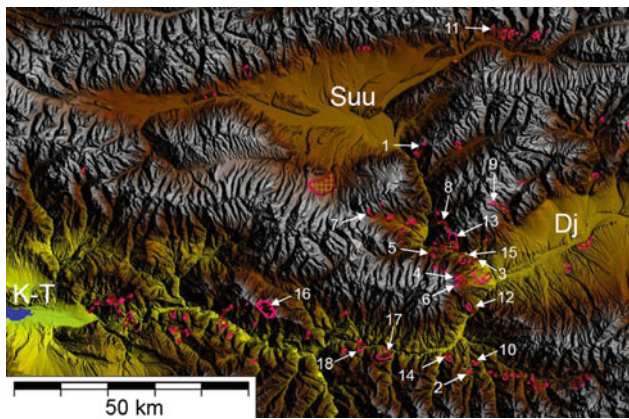


Fig. 2 Large landslides, rock avalanches, and caldera-like collapses in the Kokomeren River basin and adjacent part of the Naryn River basin. Suu, Dj, and K-T—the Suusamy, the Djungal, and the Ketmen-Tiube intermountain depressions. Selected features, most of which are studied during the training course: 1 Seit, 2 Ak-Kiol, 3 Mini-Köfels, 4 Kashkasu, 5 Northern Karakungey, 6 Southern Karakungey, 7 Chongsu, 8 Sarysu, 9 Ming-Teke, 10 Lower Ak-Kiol, 11 Snake-Head, 12 Lower-Aral, 13 Kokomeren, 14 Ornok, 15 Displaced Peneplain, 16 Kyzylkiol, 17 Karachauli, and 18 Lower Kokomeren

Since 2006 about 100 students and landslide researchers from Argentina, Austria, Belgium, China (including Hong Kong), Czech Republic, France, Germany, Great Britain, Italy, Japan, Kyrgyzstan, New Zealand, Russia, Switzerland, Spain, Taiwan, Tajikistan and USA have attended it (Figs. 3, 4 and 5). Such joint work, apart from everything else, facilitates future cooperation of young landslide researchers.

Most of the case studies identified in this area were described in Abdrakhmatov and Strom (2006), Hartvich et al. (2008), Strom (1994, 1996, 2006, 2010, 2013a, b, c, d, 2015), Strom and Groshev (2009), Strom and Korup (2006), Strom and Stepanchikova (2008), and Strom and Zhirkevich (2013).

However, comparison of some suspicious sites in this relatively well-studied river basin with some didactic case

Fig. 3 Participants of the 2012 Kokomeren summer school at the outcrop of an active fault north of Chaek town. *First* from the left is Dr. Roman Lahodinsky (BUKU University), *second* from the left is Dr. James McCalpin—author of the famous “Paleoseismology”



Fig. 4 Participants of the 2009 Kokomeren Summer School on top of the Seit rock avalanche; its headscarp can be seen in the background

studies from other parts of the Central Asia region, allowed the identification of a new, previously unknown ~6 km long rock avalanche in the upper reaches of the Kashkasu river valley (compare Figs. 6 and 7). It highlights the importance of considering case studies from a much broader region even if the study area is limited to a particular river basin.

Compilation Methods for the Central Asia Rockslides Database

The arid climate typical of the Central Asian region facilitates long-term preservation of landforms created by bedrock slope failures and their expression on remote sensing data available at resources such as Google Earth, SAS Planet and Arc GIS Earth.



Fig. 5 Participants of the 2016 Kokomeran Summer School at the headscarp crown of the Ak-Kiol rockslide, which had dammed the lake visible in the background



Fig. 6 The 5.5 km long Urmochdara rock avalanche in the Gunt River basin (South-western Pamir) with the striated microrelief of the deposits indicating flow-like debris motion. RG—rock glacier with a totally different morphology

These resources were used for the regular surveying of the study area, with the aim of identifying landforms typical of both the source zones and the rockslide deposits. More than 800 features exceeding ca. 1 million cubic meters in volume have been identified up to now.

Their boundaries, digitized on the above mentioned resources, were imported in the Global Mapper GIS and overlaid on the 3" SRTM DEM that allowed measurement of their basic parameters, such as headscarp height and width,

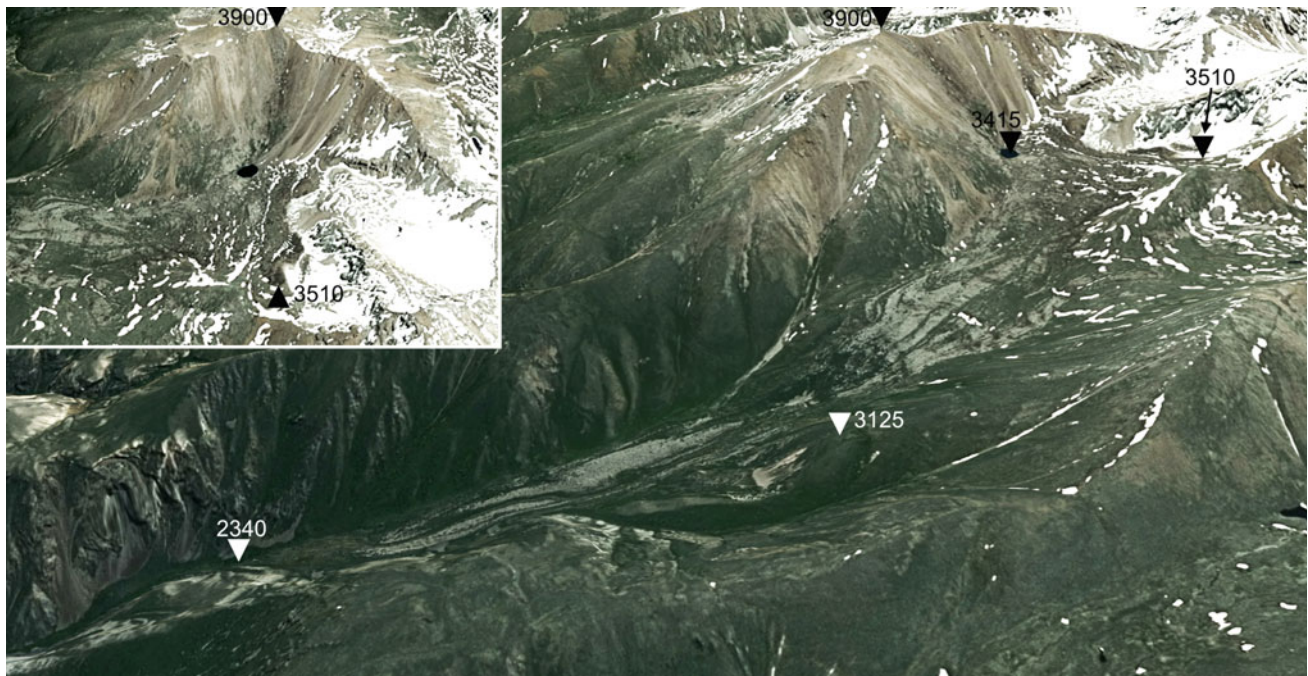


Fig. 7 A rock avalanche about 6-km long, with evidence of flow-like motion of debris, in the upper reaches of the Kashkasu River, Central Tien Shan. It was identified based on its similarity to the Urmochdara rock avalanche. The ~500 m high headscarp is shown in the *inset*

deposit area, width, and runout, vertical distance between headscarp crown and the tip of the deposits, etc.

Besides the well-developed bedrock landslides that had already failed, evidence of deep-seated gravitational slope deformations (DSGSD) that can, under certain conditions, convert into catastrophic rock slope failure (Fig. 8) are identified, digitized and included in the database.

The volume of the deposits was calculated for each case individually. Considering the unknown morphology of both the source zone and depositional area prior to slope failure, the accuracy of the volume assessment is estimated as $\pm 30 - 50\%$. However, such accuracy seems to be sufficient for the statistical analysis of basic relationships between the magnitude of the phenomena (characterized by its volume) and its main geometrical parameters (runout, area, H/L ratio) and such parameter as the DBI—the Dimensionless Blockage Index (Ermini and Casagli 2003). It is higher than the scatter of the landslide volume versus area relationships, which usually are about 1 order larger (Honious et al. 1997; Guzetti et al. 2008).

Considering the significant scatter of volume estimates, some smaller features were included in the database even though, after being identified and outlined on space images, they were found to be smaller. In addition, small rockslides that form clusters accompanying larger slope failures were

included in the database and described, considering their importance for revealing possible triggering factors of large-scale rockslides formation (Strom 2013b, c).

Besides rockslides and the DSGSDs, landslide-dammed lakes, both existing, filled, and breached, were mapped, along with evidence of outburst floods that were identifiable at several sites.

Structure of the Database

The rockslide database is compiled as an Excel spreadsheet. Parameters characterizing each landslide are grouped in several blocks: General information, Headscarp geology and parameters, Overall parameters of the rockslide deposits, Rock avalanche parameters, Landslide dams and dammed lake parameters. They are listed in the following tables.

Each landslide has its ID, which includes the Country name (Afghanistan, China, Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan), its coordinates (for reference and easy search), individual feature name and date of the event, if available. Some comments describing the most peculiar characteristics of the features in question are added (Table 1).

The geology and morphology of the source zone is described in Table 2. Quantitative parameters presented here

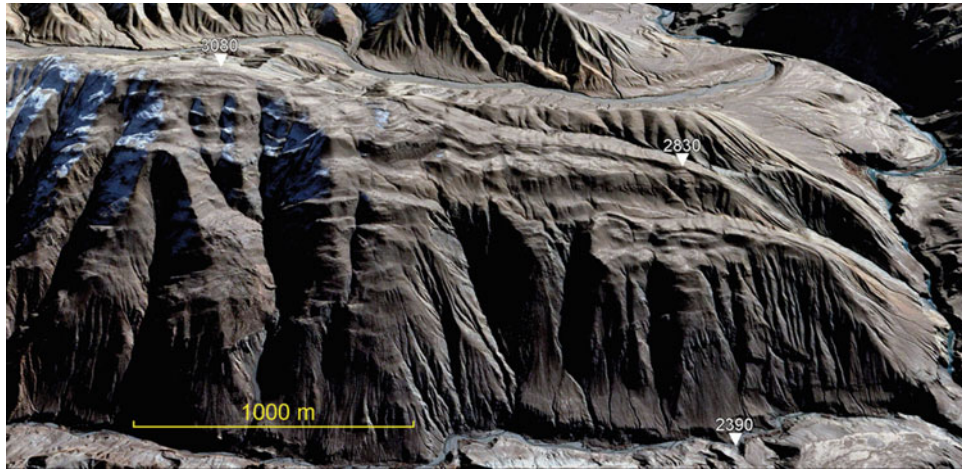


Fig. 8 Deep-seated gravitational slope deformation in the Betdjin Creek valley (Chinese Tien Shan) at 41.146°N, 78.354°E 3D Google Earth view

Table 1 General information

Rockslide ID	Date (if known) and name (if given)	Comments	Latitude	Longitude
1	2	3	4	5

Table 2 Headscarp geology and parameters

Rock age	Rock type:	Rock sequence from top to bottom	Headscarp height (km)	Mean slope angle (°)	Headscarp width at its base (km)
6	7	8	9	10	11

Table 3 Overall parameters of the rockslide deposits

Area of the deposits (km ²)	Total area affected (km ²)	Volume (10 ⁶ m ³)	Total length (km)	Maximal deposits' width (km)	Maximal height drop (km)	Height drop to the tip (km)	Confinement	Runup (km)
12	13	14	15	16	17	18	19	20

Table 4 Rock avalanche parameters

Rock avalanche type	Volume		Rock avalanche Length (km)	Rock avalanche height drop (km)	Secondary scar/jump height (km)
	(10 ⁶ m ³)	% of total rockslide volume			
21	22	23	24	25	26

Table 5 Dammed lakes parameters

Dam parameters			Lake parameters				
Effective height (m)	Dams' width (km)	The lowermost part of the dams' crest position	Type (existing, breached, filled)	Maximal depth (m)	Length (m)	Mean width (m)	Volume (10 ⁶ m ³)
27	28	29	30	31	32	33	34

and hereafter were measured based on the Google Earth data and 3" SRTM DEM.

The third block (Table 3) includes parameters characterizing each rockslide as a whole. As mentioned above, rockslide volume—one of the most critical parameters—was estimated on an individual basis for each feature, approximated by a combination of simple 3D geometrical figures—prisms, pyramids, cones.

Next block (Table 4) includes parameters of the mobile avalanche-like parts of rockslides classified as Jumping and Secondary rock avalanches (Strom 1996, 2006).

Considering the significant hazard presented by rockslides damming rivers and by their outburst floods, quantitative and qualitative data characterizing rockslide-dammed lakes are presented in the special block of the database (Table 5).

Conclusions

Compilation of the more or less uniform database of the Central Asian large-scale bedrock landslides and of associated features such as landslide-dammed lakes and DSGSDs will form grounds for a more rigorous regional rockslide susceptibility analysis and hazard assessment. Such analysis should be performed with due regard to the variability of the geological and geomorphic conditions of these mountain systems that predetermine formation of large-scale bedrock landslides, as well as to the variability of the tectonic (earthquakes) and climate-related (rainstorms, snow melt) triggering factors.

Compilation of the rockslide database will provide a valuable set of data for better understanding regularities in the occurrence and evolution of such phenomena, their spatial and temporal distribution over the entire region and of mechanism of rockslide and rock avalanche motion.

Such a database could be used by landslide researchers interested in new impressive examples of large-scale catastrophic bedrock landslides and in new data supplementing those derived from case studies from other regions. It can be used by emergency experts working on landslide and outburst flood hazard assessment and by researchers and practitioners in the fields of paleoseismology and seismic hazard assessment, since large-scale bedrock landslides are often considered as being triggered by large past earthquakes. The database will aid hydraulic engineers working on dam projects in the Tien Shan and Pamir mountainous rivers, considering the high potential of the Central Asian rivers for hydraulic energy

production and the significant threat posed by large landslides to the safety of hydraulic schemes.

The results of this research project that, in addition to the Kokomeran Summer School, became the second main goal of our WCoE, will be presented in a book entitled: "Large landslides in Central Asia: distribution, impacts, and hazard assessment" that is planned to be published by Elsevier Publishers in 2017.

Acknowledgements Authors want to express sincere gratitude to ICL, IPL and to the Executive Director of ICL Prof. Kyoji Sassa for permanent support provided to organize the Kokomeran Summer School.

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