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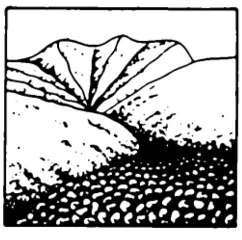

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Geological and geotechnical findings of the catastrophic debris flow near Tskneti, Georgia, June 2015

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In June 2015 a flash flood caused by a failure of a natural dam originated by a hazardous debris flow in the Vere valley hit Tbilisi. 23 persons lost their lives and property damages were huge. The catchment area is a region of high landslide susceptibility with a range of active and expectable processes with differing intensities/volumes. The event of 2015 must be seen as mega-event with recurrence periods of several 1000s of years or more. However, the landslide has created even more unstable conditions and weakened an already semi-stable system. As conclusion, the likelihood for medium to large subsequent events has risen significantly. Along with the planning of the reconstruction of the Tskneti-Samadlo-road and the Tskneti-Akhaldaba road some detailed geological investigations, e.g. large-scale engineering geological mapping, laser scanning, monitoring of groundwater level, movement measurements etc. were carried out or are still in progress. These first results brought some evidence of geological, hydrogeological and geotechnical setting in the Tskneti region and the types of processes (weathering, changes of water level) and landslides (rock slides, rockfalls, creeping etc.) that provided debris for the catastrophic event in 2015. This paper tries to give an idea of the general geomorphological and geological setting and the processes and shows which measures have been taken already and what is planned in the future to protect both roads and Tbilisi from further catastrophic hazards.

debris flow, flash flood, geological mapping, geomorphology

Геологические и геотехнические уроки катастрофического селя около Цхнети, Грузия, в июне 2015 года

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В июне 2015 года в Тбилиси произошло внезапное наводнение, вызванное прорывом естественной плотины, подпруженной оползнем в долине реки Вере. 23 человека погибли, а материальный ущерб был огромным. Водосборная зона является областью повышенной оползневой опасности с рядом активных и потенциальных процессов различной интенсивности и объема. Катастрофа 2015 года должна рассматриваться как выдающееся событие с повторяемостью в несколько тысяч лет или более. Однако оползень создал неустойчивые условия и ослабил уже недостаточно стабильную систему. В итоге, вероятность средних и значительных последующих событий значительно возросла. Наряду с планированием реконструкции дороги Цхнети-Самадло и дороги Цхнети-Ахалдаба были выполнены и продолжаются в настоящее время подробные геологические исследования – крупномасштабное инженерно-геологическое картирование, лазерное сканирование, мониторинг уровня грунтовых вод, измерения движения и т. д. Полученные предварительные результаты выявили в Цхнети следы геологических, гидрогеологических и геотехнических условий и типы процессов (выветривание, изменение уровня воды) и массовых смещений (обвалы, оползни, медленные смещения и т.д.), которые дали материал для катастрофического события 2015 года. В статье дается представление об общей геоморфологической и геологической обстановке, о процессах и показывается, какие меры уже приняты и что планируется в будущем для защиты дорог и города Тбилиси от дальнейших опасностей.

сель, селевой паводок, геологическое картирование, геоморфология

Introduction

On the night of 13-14 June 2015, a disastrous flash flood hit the Georgian capital Tbilisi directly affecting more than 700 people, causing 23 fatalities and over USD 24 million in physical damage [*UNDP, 2015*]. The flash flood originated in the Vere river west of Tbilisi [*UNDP, 2015; Gaprindashvili et al., 2016*]. It was caused by exceptionally long and heavy rainfalls in the previous ten days resulting in an already high discharge and a large landslide of approx. 1 million m3 temporarily blocking the river and ultimately causing the flash flood after failing of the dam [*UNDP, 2015; Gaprindashvili et al., 2016*]. Peak discharge during the event has been estimated to be 468 m^3/s almost doubling the discharge during the catastrophic flood in 1960 (259 m^3/s discharge) [*UNDP, 2015*]. Following a flood recorded on 4 June (155 m^3/s discharge) this were the highest consecutive floods ever recorded in the Vere river [*UNDP, 2015*]. Vere river flows into Mtkvari river in Tbilisi.

The landslide leading to the blockage of the Vere river occurred between Tskneti and Akhaldaba south of the Vere river and was a highly complex process of different types of landslides, such as rock slides, debris slides, earth slides and debris flows [*UNDP, 2015; Gaprindashvili et al., 2016*]. In the landslide area two important roads were completely destroyed by rock slide (upper Samadlo road) and debris flow (lower Akhaldaba road), isolating Akhaldaba from Tskneti, which is the villages main source for supplies and food [*UNDP, 2015; Gaprindashvili et al., 2016*].

Caucasus Road Projects, Ltd. (CRP) is currently reconstructing the roads, while a group of international experts including Trumer Schutzbauten from Austria and Baugeologisches Buero Bauer (BBB) from Germany is consulting CRP in topics about landslide hazard assessment, mitigation and development of an early warning system (EWS). This paper will give an overview about the first geological and geotechnical findings regarding the landslide.

Study site

The landslide area is located about 10 km west of Tbilisi between the villages of Tskneti and Akhaldaba (Fig. 1). The upper scarp of the landslide is located at 1410 m amsl, almost at the ridge of the mountain range west of Tskneti. From the scarp to Akhaldaba road (910 m amsl) the average slope angle is very steep at about 29°. From Akhaldaba road to Vere river (620 m amsl) the average slope angle is much lower at about 6.5°.

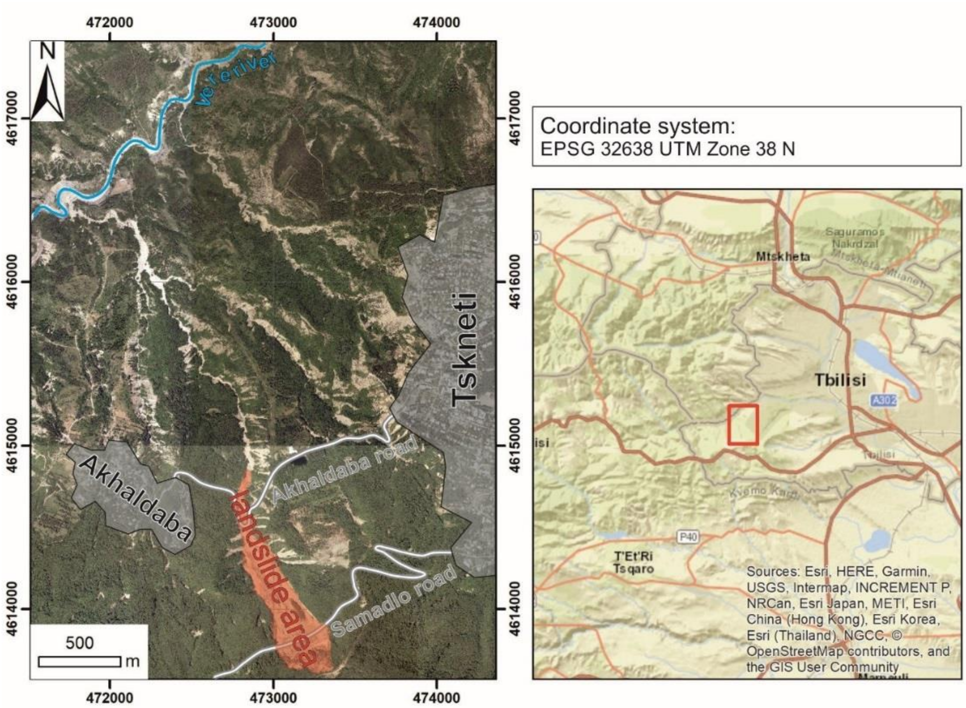

Fig. 1. Location of the Landslide area between Tskneti and Akhaldaba. Orthophoto provided by Municipial Development Fund

Rock basement consists of two sedimentary formations of Tertiary age [*Gudjabidze, 2003*]. One formation is of Oligocene age and consists of clay- and thin layers of sandstone [*Gaprindashvili et al., 2016*]. In the lower horizon of this formation claystones are more dominant, while in the upper horizon sandstones are predominant [*Gaprindashvili et al., 2016*]. Thickness of this formation can reach 2.000 m [*Gaprindashvili et al., 2016*]. The second formation is of Upper Eocene age and is formed by thick-bedded sandstones with alternating layers of claystone as result of flysch deposits [*Gaprindashvili et al., 2016*]. The rock formations are strongly faulted and fractured [*Gaprindashvili et al., 2016*].

Methods

Geological-geomorphological mapping

In order to develop an early warning system for the reconstructed roads BBB was assigned by CRP to carry out detailed geological mapping with focus on spatial distribution and properties of rock formations, geomorphological landslide features and possible landslide processes. The first stages of mapping were performed in November 2017 and March 2018. About 80 ha were mapped on a scale of 1 : 1.000. Mapping is fundamental and builds the essential basis for all further steps, like safety of construction works or development of EWS.

UAV mapping

Additionally, UAV mapping and photogrammetric reconstruction was carried out in March 2018 to create an up to date digital elevation model (DEM) of the landslide area (Fig. 2 A). This can provide a DEM at very high resolution and give us valuable information about the geomorphology of the landslide area. Future surveys are planned to quantify geomorphologic changes following the approach of multi-temporal DEMs of *Wheaton et al.* [2010]. About 27 ha were mapped with the UAV from the scarp of the landslide until 600 m below Akhaldaba road.

Terrestrial laser scanning

Terrestrial laser scanning (TLS) was performed on two locations inside the landslide area in March 2018 (Fig. 2 B). Above Samadlo road we scanned a suspected hazardous rock slide in order to accurately determine the volume of the rock slide. With consecutive TLS surveys in the future possible movement can be quantified, e.g. with the M3C2 algorithm developed by Lague et al. [2014]. Furthermore, we surveyed the area above and below the Akhaldaba road to quantify mobilizable volumes for debris flows and evaluate slope stability. Here we plan to carry out additional surveys in the future as well to quantify geomorphic changes.

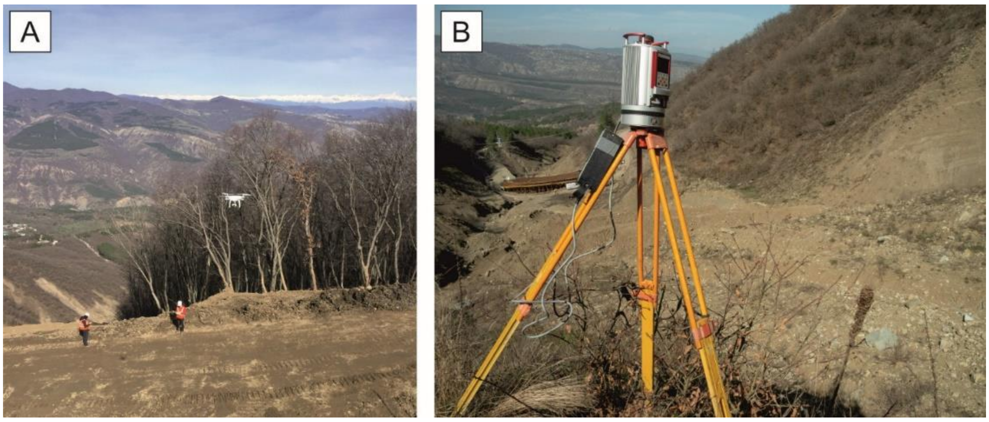

Fig. 2. UAV (A) and TLS (B) surveys were carried out in the landslide area in March 2018

Results

While data of the UAV and TLS surveys is still in extensive post processing, first results of geological and geomorphological mapping can already be presented (Fig. 4). The Oligocence formation (Fig. 3 A & B) is very thinly bedded and is predominantly composed of clay- and siltstones. Bedding is spaced between 0.5 cm and 15 cm (average ~0.02 m). Interlayers of sandstones are common. The formation crops out mostly below Samadlo road and dips north with and average angle of 30-35°, it is folded and faulted.

The bedding of the Eocene formation (Fig. 3 C & D) is spaced closely to widely. Sandstones are predominant in the formation with interlayers of clay- and siltstones. Furthermore, conglomerates (Fig. 3 D), partly very coarsely grained, were found in this formation. Conglomerates exist both as concordant interlayers and unconformable fillings of erosive channels. Bedding is spaced between 1 cm and 2.5 m (average ~0.8 m). The formation crops out mostly above Samadlo road and dips north with and average angle of 30-35°, it is folded and faulted. Up to now it is not completely clear if the contact of the two rock formations is concordant or unconformable or even faulted.

As mentioned above, the rock formations dip north with an average angle of 30-35° and therefore bedding is more or less parallel to the slope itself. This geological setting makes the whole mountain range west of Tskneti highly susceptible to landslides. During mapping landslides were detected, that have not been active during the 2015 event, but have a much older movement history of a suspected 60 to 150 years (grey detachments in Fig. 4). Although there has been no full reactivation of theses landslides there are indicators for recent movements, that could lead to a reactivation in the future.

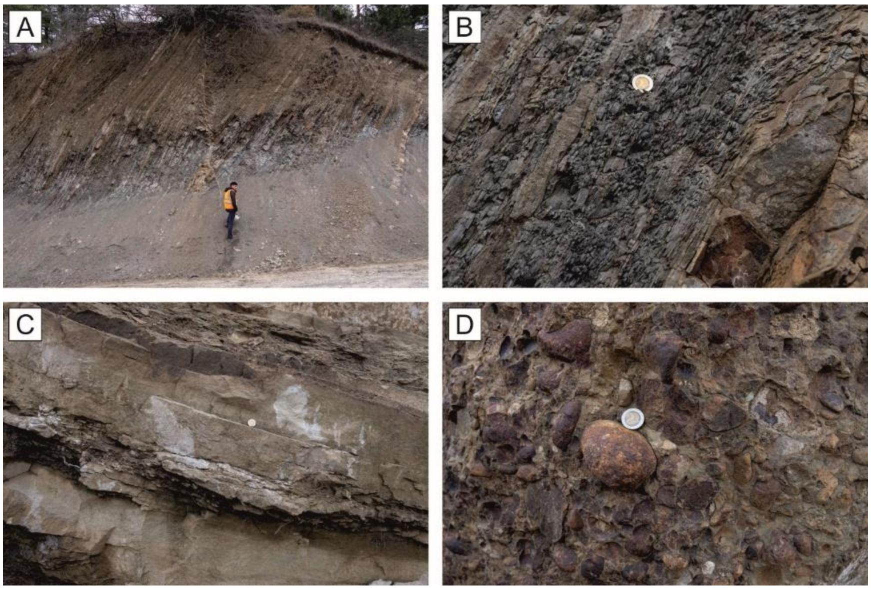

Fig. 3. Rock formations of the study site. A: Outcrop of thin-bedded rock formation at Samadlo road. B: Close up of thin-bedded rock formation with predominant claystone. C: Sandstone of the thick-bedded formation. D: Conglomerate of the thick-bedded formation. Photos: K. Keilig

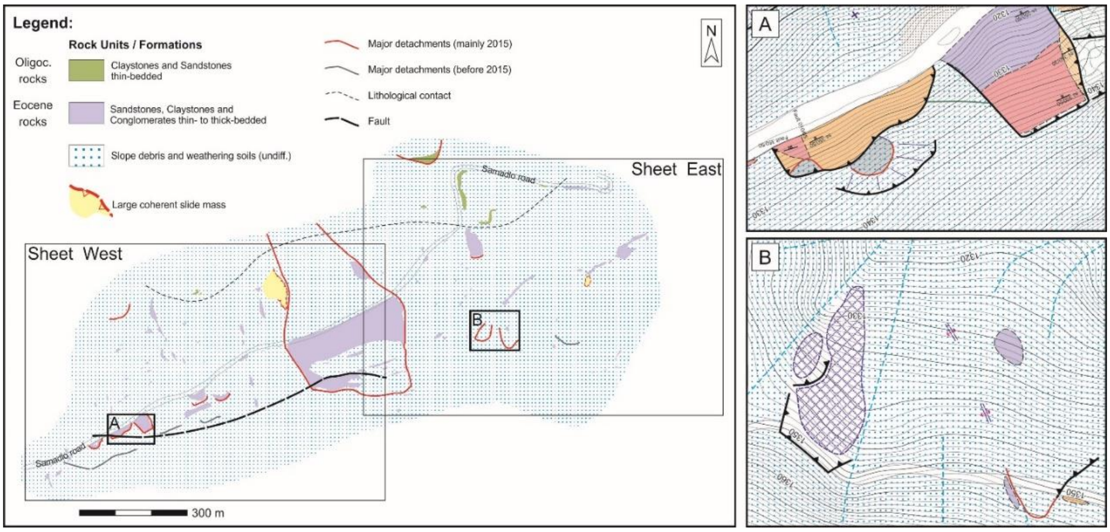

Fig. 4. Simplified geological-geomorphological sketch map of the landslide area (left), based on the high-resolution mapping (A and B)

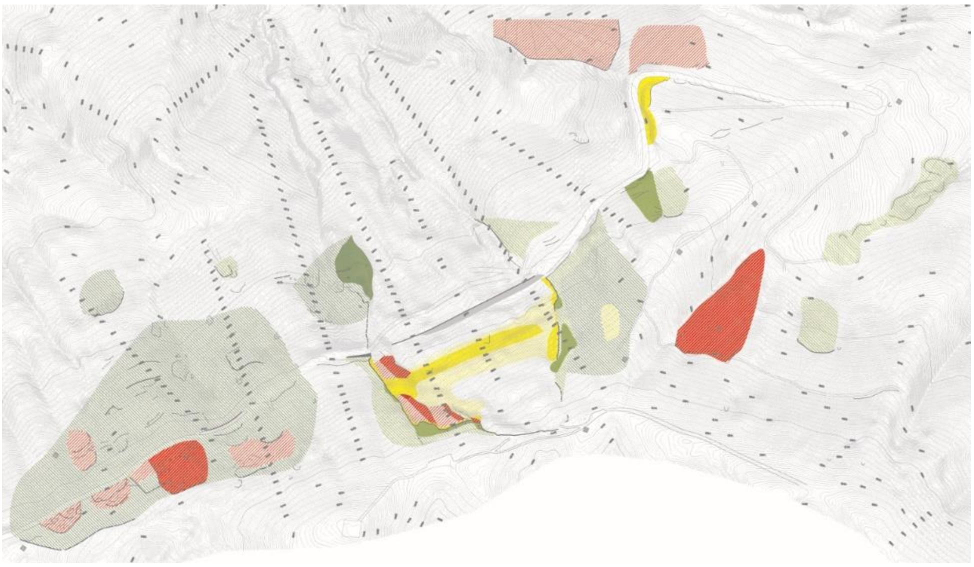

Fig. 5. Map showing different types of movement types (colours) and probabilities (symbols)

Based on the geological-geomorphological findings we generated a map that distinguishes the different types of occurring landslides as well as their activity or the probability of failure (Fig. 5). This can help deciding which types of retaining structure, monitoring system or immediate measure should be installed in the future.

As a result of mapping we developed a preliminary concept for the triggering mechanism of the landslide (Fig. 6). We suspect groundwater and pore pressure to be the main trigger during the 2015 event. The groundwater level must have risen significantly during the ten days of heavy rain prior to the event. The stratification and jointing of the rock formations lead to groundwater flow parallel to the slope and possible clay layers could prevent groundwater from leaking on the surface. Therefore, in the lower parts of the slope pore pressures must have risen immensely leading to explosion-like escapes of water and destabilising slopes until failure in the area around Akhaldaba road (“groundwater explosions”). The landslide then prograded to the upper parts of the slope.

Findings about the degree of jointing and block sizes during mapping were used to quantify rock fall energies and dimension a rock fall barriers for Samadlo road (Fig. 7). Construction of the rock fall barrier started in April 2018 and it will be installed along the whole width of the landslide area of 2015 above the Samadlo road.

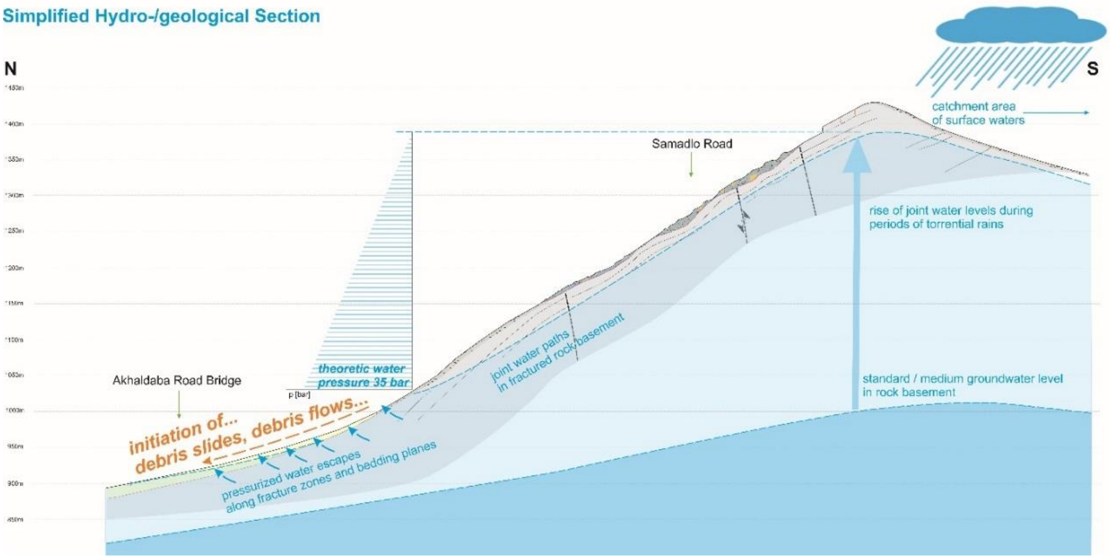

Fig. 6. Preliminary model of triggering mechanism for the large landslide near Tskneti

Fig. 7. Ongoing construction in April 2018 of posts for rock fall barrier by Trumer protecting the Samadlo road. Photo: D. Dumbadze

Conclusions

Climatic conditions before the disastrous flash flood in 2015 were exceptional and were caused by the unfavourable combination of very high water discharge in the Vere river and a landslide that temporarily blocked the river and eventually failed. The mountain range on which the landslide occurred is very susceptible due to the unfavourable dipping of the bedding and the alternating sequence of ductile claystones and brittle sandstones.

Mapping is essential for creating a geotechnical model of the slope, determining the factors for slope failure, guaranteeing safety of construction works and developing an EWS. Since there are indicators for further movements, mapping should be continued on the remaining parts of the slope in our opinion.

Outlook

Mapping of the uppermost part of the landslide scarp and its surroundings have proven essential, but extension of the mapping area will be needed to qualify the danger for Akhaldaba village or get more information about other potentially unstable parts of the mountain range. Further surveys with UAV and TLS are already planned for this fall and are going to be continued in the next years. Installation of several crackmeters is currently in process in order to measure deformations in suspected rock slide locations. Deformation of shallow and deeper landslides will be obtained with wire extensometers to find out if movements still continue in new slides or old slides are being reactivated. Boreholes for both deformation and groundwater measurements are already planned and drilling and installation works commence. Additionally, it is planned to carry out geophysical measurements in 2018. This will be fundamental for verifying the currently preliminary model of the triggering mechanisms for the landslide as well as determining deformations, depth of sliding plains and other important aspects of the slope.

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