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A Preliminary investigation of reactivated mass movement near the epicenter of 2005 Kashmir earthquake, NW Himalayas, Pakistan

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Abstract

Kashmir earthquake 2005 induced thousands of mass movements in the affected region of Pakistan. The Panjgran mass movement in the Neelum Valley area, close to the epicenter is one that obstructed the Neelum Valley communication system for many days even after the earthquake. SPOT-5 images and ground investigation were used to analyze the reactivated Panjgran mass movement characteristics. Mass movement travelled 650 m in the direction of north towards the Neelum river and caused severe damage to the Neelum road. Preliminary failure was initiated by the slumping in fractured sandstone of Miocene Murree Formation. While on the detachment zone, the rock fall mass separated from the bed rock, moved down hill and gathered at the bottom of the ridge. The total volume of Panjgran mass movement was estimated approximately 6.75 x106 m^3.The study shows that mass movement is the caused by the pre-existing slump on over steepened slope weakened and undercut by the river and ground shaking due to2005 earthquake of Kashmir.

Keywords: Mass movement;2005 Kashmir earthquake; Himalayas; Murree Formation; Neelum Valley.

1. Introduction

The 2005 Kashmir earthquake of the magnitude Mw. 7.6 occurred on October 8, 2005 at 18 km in the northeast of Muzaffarabad with its epicenter (34.493, 73.629) and a focal depth of 26km (USGS 2006; Fig. 1). The catastrophic earthquake was the destructive mountain disaster in the 100 year history of Kashmir (Bendicket al., 2007). According to the official sources, 73,000 people were killed, injured 69,000 people andleft homeless 2.8 million people by the earthquake. Furthermore, Several mass movements were triggered throughout the area which was affected by 2005 Kashmir earthquake. These are primarily rock falls, rock sides, debris falls and rock avalanches (Classification after Varnes 1978). The size of landslides varies from a few cubic meters to 98.0 million m^3 as reported for the Hattian Bala rock avalanche (Basharatet al., 2012)

The 2,930 mass movements were interpreted by satellite imageries within the area of approximately 3250 km^2 (Basharat, 2012; Basharat et al. 2016). Total 1293 mass movements were identified within an area of 750 km^2 at 174 locations near Muzaffarabad city and Balakot town (Owen et al., 2008). The spatial distribution of mass movement for the 2005 Kashmir earthquake shows that the distribution is primarily controlled by the Muzaffarabad Fault and the epicenter (Basharat et al., 2014).

The seismically reactivated Panjgran mass movement near the 2005 earthquake epicenter in the Neelum Valley area is an example (Basharat and Rohn, 2015; Fig. 1). This mass movement is the largest one having volume of 6.75 million m^3 around the epicenter which caused severe damage to landscape and buried 300-400 m Neelum road. Consequently, the Neelum road remained blocked for many days after the 2005 Kashmir earthquake. In this paper, we investigated the characteristics of Panjgran mass movement, such as volume, travel distance, and initiation mechanism as a case study.

2. Geological setting

The sedimentary to low grade metamorphic rocks units is twisted and folded to form Hazara Kashmir Syntaxis (HKS) (Calkins et al., 1975; Baig and Lawerance, 1987; Bassort et al., 1988). The Main Boundary

Thrust (MBT), the Panjal Thrust (PT) and the Himalayan Frontal Thrust (HFT) are folded in the study area, and to form antiformal structure (Wadia, 1931; Greco, 1991). This structure is known as HKS (Baig and Lawrence, 1987). The western limb of HKS is truncated by the Jhelum Fault (JF) and the Muzaffarabad Fault (MF). The MBT, PT, JF, and MF are the key tectonically active features in the HKS (Fig. 2; Armubruster et al., 1978; Le Fort, 1975; Yeats et al., 2006). These features are the major source of seismicity in the HKS.

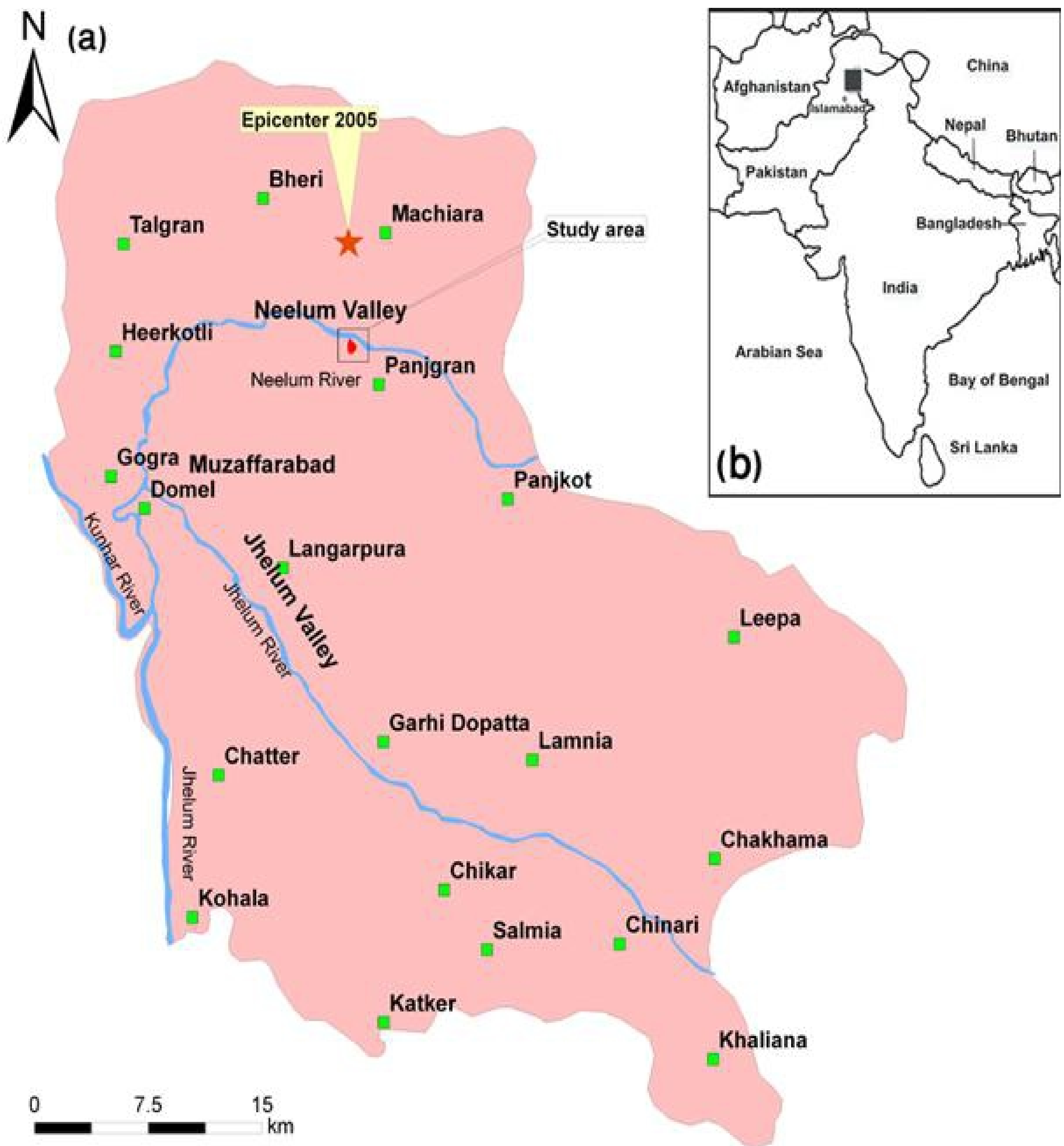

Fig. 1. (a) Map shows the geographical location of the study area (map of Muzaffarabad district digitized and modified after the map from Planning and Development department AJK, 2010).
(b) The geographical location map of Pakistan. Approximately 26,000 fatalities can be directly or indirectly linked to the landslides induced during earthquake (Petley, 2006). The economic loss was assessed to be 5.2 billion US $ (ADB and WB, 2005).

The rocks from Precambrian to Tertiary are exposed in HKS. The rock units comprises the Hazara Formation, Tanol Formation of Precambrian age, the Muzaffarabad Formation of Cambrian, the Panjal Formation of Triassic-Carboniferous, the limestone shale sequences of Paleocene-Eocene, the Murree Formation, the Kamlial Formation of Miocene, and Quaternary sediments (Fig. 2).The active MF thrusted the Cambrian Muzaffarabad Formation, while Jhelum Fault emplaced the Hazara Formation ofPrecambrian over the Murree Formation of Miocene (Baig and Lawrence, 1987). The core HKS has sandstone, mudstone, shale, and claystone of Murree Formation. These sediments lie in the footwall of the MBT. The Hazara Formation and Panjal Formation lie in the hanging wall block of the MBT. The Hangu Formation, Lockhart Limestone, Patala Formation, Margalla Hill Limestone, Chorgali Formation and Kuldana Formation were mapped collectively as Paleocene-Eocene sequence.

The geological setting of the study area is such that it is situated nearby MBT and PT. The Panjal Formation is present in-between the MBT and PT (Fig. 2). And it is thrusted over the Murree Formation (Khan, 1994). Highly fractured, jointed, and sheared sequence of rocks along the MBT is present. The Panjal Formation has faulted contact at its base and MBT with the Murree Formation is at upper contact (Khan, 1994). Murree Formation is widespread in Neelum Valley. Murree Formation is mostly exposed along the river cuts and banks of the River Neelum. Brittleness of these rocks and steep weakened undercut slope controlled the initiating of the mass movement near MBT.

The study area is located in the Neelum Valley and is categorized as rugged topographic characteristics and steep slopes. Topographically, the study area is mainly hilly and mountainous with valleys and stretches of plains and is very prone to mass movement because of the unstable conditions of its rock masses. This instability is the main cause of failure to many mass movements in this region. The elevation ranges between 780-2860 meters, high angle slopes and steep escarpments are prominent features of the area. The entire valley is drained by the Neelum river and its tributaries. Due to extremely difficult terrain, the valley is divided by its forested, north facing left bank. The right bank is south-facing and to a large extent deforested. The climate varies considerably in the northern and southern parts of the Neelum Valley area. Moreover, it varies greatly with altitude. The northern and north eastern parts of Neelum Valley are very cold in winter, while the southern parts remain cold in winter and moderate to hot in summer. The climate of the area is sub-tropical highland type with an average rainfall of 1200-1300 mm per year (Planning and Development Department, 2010).

The Panjgran village is situated in the Neelum Valley which lies to the north-east of Muzaffarabad city, from where the passage of Neelum riveris from northeast to north-west (Figs. 1 and 3).The epicenter of the earthquake was located about 7 km north-west of this village. The elevation of the study area varies from 850 m to 1450 m, whereas the Panjgran mass movement was reactivated at 1450 m elevation and blocked the main Neelum Valley road for many days (Fig.3). Almost 300-400 m roads were collapsed due to the reactivation and movement of the slump material at the base. However, no causality occurred during this mass movement

3. Material and method

In this study, SPOT-5 image, DEM and ArcGIS 9.3, along with ground based field investigation were employed to map and characterize the reactivated Panjgran mass movement. The field was conducted in November 2009-10 and mass movement was mapped on a scale of 1:10,000. A Map with detailed geotechnical information and a longitudinal profile with geological features were prepared to recognize the characteristics and mechanism of the mass movement (Figs.4 and 7). Global Positioning System (GPS) was utilized for location and elevation measurements. Distance was measured by Laser distance meter (RIEGL FG21-HA) for the absolute horizontal measurement with an accuracy of ± 1 m. The geological map of the study area compiled after Calkins et al. (1975), Hussain et al. (2004), Kaneda at al. (2008) and Basharat et al. (2014) to understand the tectonic features and geological units of the area.

4. Description of Panjgran mass movement

The Panjgran mass movement in the Neelum Valley area is located 35 km away from the Muzaffarabad city (Figs.1, 3 and 4). It is anold mass movement of the area which was reactivated in the 2005 Kashmir earthquake. Panjkot ridge (34° 25′ 47″ N; 73° 37′ 12″ E, altitude 1,450 m asl) was the initiated point of this mass movement.The mass movement moved towards northeast of the Neelum river (Figs.4 and 5). The Neelum river had frequent undercut and oversteepened the slope in the area. This was one of the reasons to reduce the overall stability of the slope (Fig.6a).

The landslide occurs within the Murree Formation of Miocene age. Lithology of Murree Formation at landslide locality may be described as a series of alternate beds of sandstone, mudstone, clay stone and shale (cyclic deposition). The main lithology exposed is shale/clay with thin beds of sandstone and siltstone. The shale/clay and mudstone is exposed at scarp, along the right flank and within the displaced material along the road which has swelling potential. In rainy season, the argillaceous material, absorbs water and accelerate the mass movement. On the left flank of landslide thin beds of sandstone and siltstone are exposed which form series of deformed isoclinals folds. In the middle portion of the slide, above the road cut, the thin beds of sandstone and siltstone were also observed.

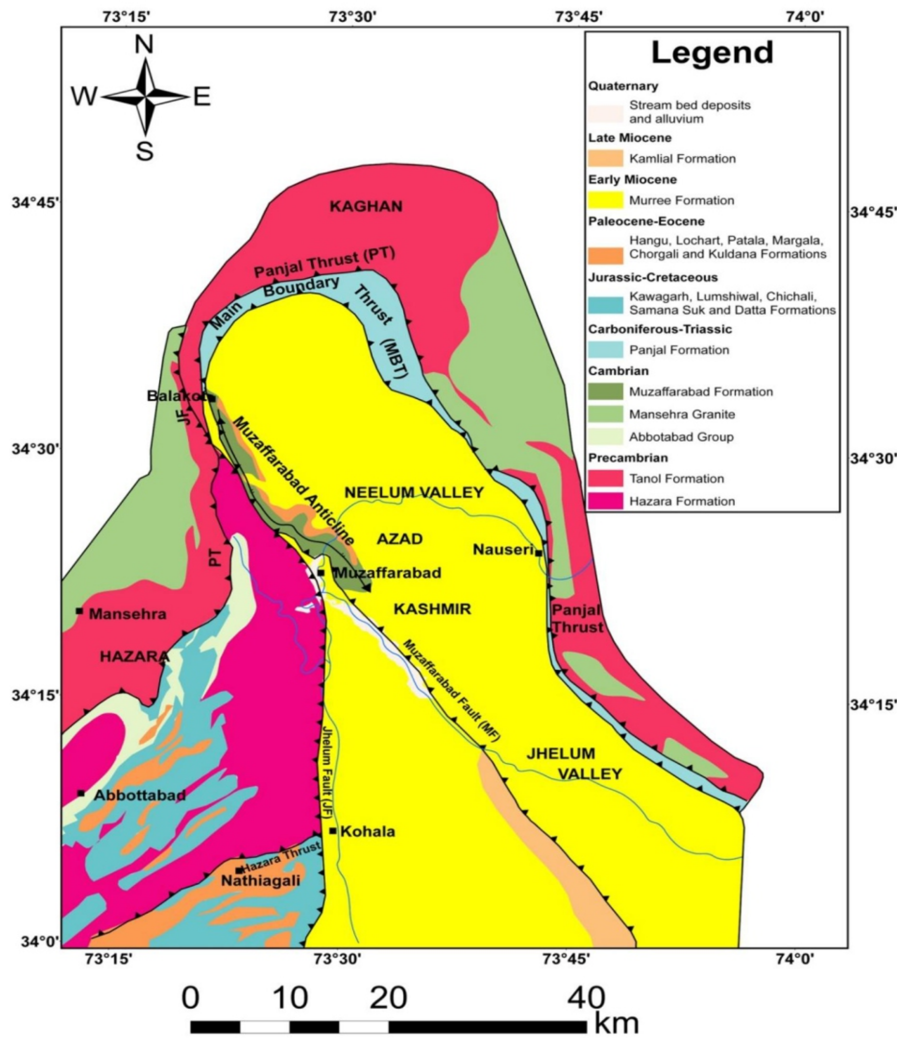

Fig. 2. Geological map of Hazara Kashmir Syntaxis (compiled after Wadia, 1931; Calkins et al., 1975; Baig and Lawrence, 1987; Greco, 1991; Hussain et al., 2004; Kaneda et al., 2008; Basharat et al., 2014).

The main scarp of the landslide is developed by the failure of the clays and soil along the slope. The length of the main scarp varies along the circumference of the scarp. However, the maximum distance of the displaced material from the top of main scarp is 150m. The scarp of the landslide is composed of fractured sandstones, siltstones, shale and claystone of Miocene Murree Formation.There are evidences of rock fall with boulders of sandstone accumulated at the base of the scarp. The main body of the slide shows evidence of slump failure with curved surface of rupture. The slumped material makes a flat with scarce vegetation and below it the displaced material makes a secondary scarp just above the road section.

This slope failure was linked with the failure of escarpment in the study area. Besides the steep slope of the material, the construction of Neelum road at the foot of the mass movement was the principal driving force for the slump. The top of this mass movement overhead the main escarpment is very steep, with agricultural land. The residential houses and agriculture terraces were present around the escarpment. Also there exists a thick forest in the north-east side of the escarpment. The fissures are present and are parallel to the escarpment in the western boundary of the landslide (Fig.6b). The length of fissures are about 1 to 5 m, with width of 8 to12 cm. The depth is measured about less than 1 m. The scarp of the landslide is mainly consists of weathered sandstone, siltstone, shale, and claystone of Murree Formation of Miocene age (Fig.6c). The scarp in the western side is about 30 m. The height of the scarp is measured about 200 m from the top of the Panjkot ridge. The scarp is circular in shape. The scarp of the mass movement dips towards the Neelum river. Figs.4and 7 shows the geometry and initiation of the Panjgran mass movement.

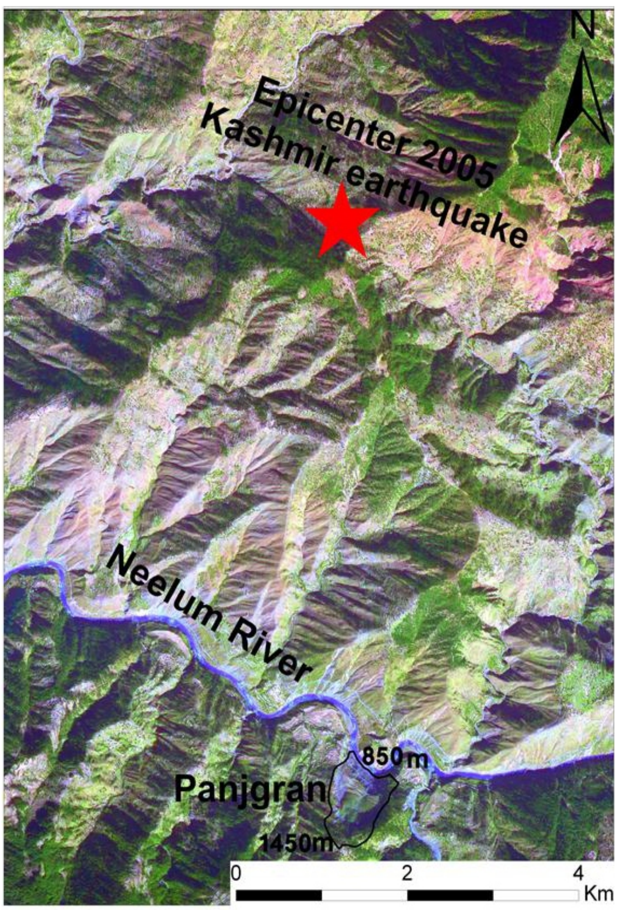

Fig. 3. SPOT image of the epicentral area, the most affected by the mass movements. Outline shows the boundary of the Panjgran mass movement.

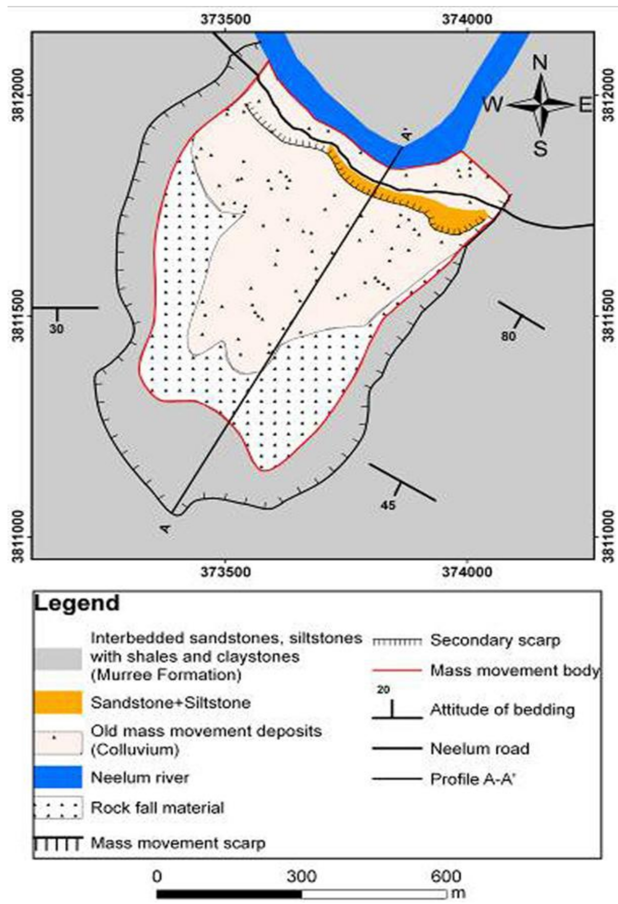

Fig. 4. Geotechnical map of the Panjgran mass movement and the location of the geological longitudinal profile shown in Figure 7.

Surface area is calculated 0.39 km^2 (Table 1). The landslide started at an elevation of 1450 m asl from the Panjkot ridge. The length of landslide is about 950 m. The maximum width of landslide is about 650 m. The rough estimated average depth of mass movement is about 25 m (Table 1). The volume of the landslide is calculated approximately 6.75 x106 m^3. The Fahrböschung angle is measured to be about 35º (Fig.7).

The mass movement is classified as rotational slide. The strata of the slope dip in opposite direction of the hill side. The preliminary slope movement involved the slumping at the base of mass movement, composing weathered jointed sandstone and shale. On the upper part of the mass movement, rock fall material is exposed at the scarp face and is detached from the bed rock where it moves in the direction of down slope (Fig.6c). At the base of the escarpment, the previously slumped mass is present which is outspread to the full width of the mass movement. The slump is covered by the rock debris at most of the parts. However, the rock fall also occurred by the earthquake at the top of the ridge. The lower part of the slumped mass, below the main road is categorized the steep slope with slope angle of more than 50º (Figs. 5 and 6a).

The main body of the landslide contains mainly shale fragments with abundant gravel, pebble and coble fractions of sandstone. The thick deposit of unconsolidated material along the traveling path increased the volume of landslide. The debris material travel towards the valley floor. However, a large amount of debris material was deposited at the middle and lower part of the main slide. In the middle portion of the slide above the road, the thin sandstone and silt stone exposures are present within the debris material which is highly jointed and cracked with 4-6 meters thick accumulated debris above it

The mass movement deposit has an area of 0.278 km^2 (Table 1). The deposit material is mainly composed of shale, clay, sandstone, silt stone and mud stone of Miocene Murree Formation. The size of the material varies from boulder to sand. The boulder size is greater than1 m^3 in diameter. The deposited material at the toe was transported by the Neelum river during seasonal water level rises.

Fig. 5. Overview of the Panjgran mass movement which occurred close to the epicentral region of the 2005 Kashmir earthquake. Note, the position on an undercut slope of Neelum river.

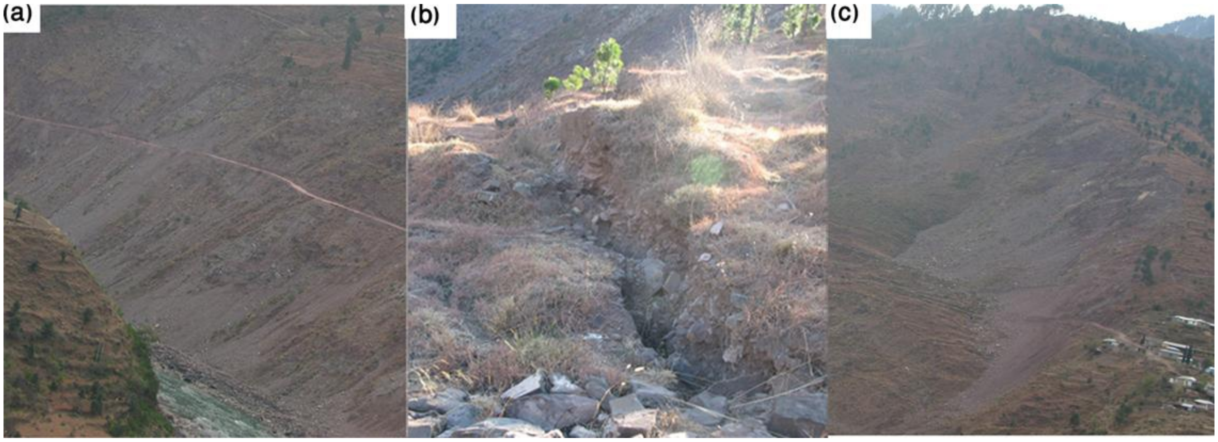

Fig. 6. (a) Nearly 300-400 m road were totally destroyed due to the reactivation of the slump material during the 2005 Kashmir earthquake, (b) Grounding cracking on the western flank of the Panjgran mass movement, and (c) The source area of Panjgran mass movement.

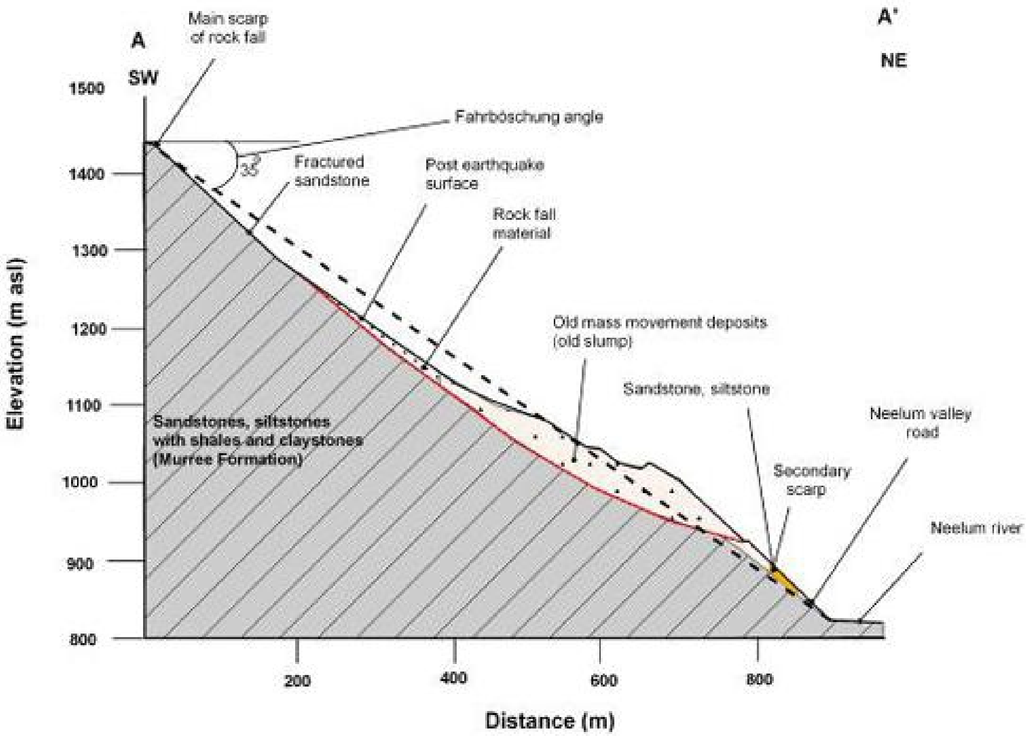

Fig. 7. Geological longitudinal profile of Panjgran mass movement. Location of the profile is shown in figure 4.

Table 1. Geometric characteristics of the Panjgran mass movement triggered by the 2005 Kashmir earthquake.

Location Name	*Crown elevation (m)*	*Length (m)*	*Maximum Width (m)*	*Estimated depth (m)*	*Height (m)*	*Fahrböschung angle*	*Total surface area (m^2)*	*Deposit area (m^2)*	*Estimated volume (10^6 m^3)*
Panjgran	1,450	950	650	25	600	35º	390,000	278,000	6.75

5. Conclusions

The Panjgran mass movement was reactivated during the earthquake of 2005 in northern Pakistan. The factors controlling the landside activity includes steep slope, presence of clayey material and river under cutting. In the slump zone, the slope failure was classified as rotational slide. Destabilization of the slump zone was because of the undercut erosion due to Neelum river and due to the construction of the Neelum road. In addition, the mass movement is the result of preexisting slump on over steepened slope undercut by the Neelum river.

Author's contribution

Muhammad Basharat is the main author of the manuscript. Yasir Sarfraz prepared the maps and figures. Khawaja Shoaib Ahmed carried out the Field investigation along with Muhammad Basharat. Muhammad Zeeshan Ali reviewed and proof read the manuscript.

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