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S.S. Chernomorets, G.V. Gavardashvili

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Geomorphological and geological analysis of Akchour landslide in Rif Mountain, Morocco

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Natural hazards in prone areas become increasingly intense as a result of climate change and human impacts. In northern Morocco, Rif Mountains are characterized by the presence of high altitudes reaching 2456 m and steep slopes. The geological terrains are mainly represented by marls under humid climate. These conditions make this region vulnerable to landslides which constitute a real threat to local population and socio-economic activity. The present work deals with the case of an important landslide in Taourart-Akchour, located 9 km far from Chefchaouen town (North of Morocco). This landslide occurred after the heavy winter rainfall of 2010. The resulted damage was considerable without loss of human life fortunately. The superposition of Triassic limestone on Neogene marls, combined with a slope of 19%, favored the sliding. Indeed, the morphological structure established from remote sensing analysis and field survey, shows that this landslide is a complex rotational one in a geological thrust sheet context.

landslide, thrust sheet, Rif, Morocco

Геолого-геоморфологический анализ оползня Акчор в горах Эр-Рифа, Марокко

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Опасные природные процессы становятся все более интенсивными в результате изменения климата и воздействия человека. В северном Марокко горы Эр-Риф характеризуются большими высотами, достигающими 2456 м и наличием крутых склонов. Горные породы представлены преимущественно мергелями. Эти особенности территории в условиях влажного климата обусловливают высокую уязвимость региона для оползней, которые представляют реальную угрозу местному населению и социально-экономическим объектам. Данная работа посвящена исследованию случая схода оползня в Тауар-Акчуре, расположенном в 9 км от города Шефшауэн (север Марокко). Этот оползень сошел после интенсивных зимних осадков в 2010 году. Жертв среди населения не было, однако причиненный ущерб был значительным. Залегание триасового известняка на неогеновых мергелях в сочетании с 19%-ным наклоном склонов способствовало оползанию. Действительно, морфологическая структура, выявленная на основе анализа данных дистанционного зондирования и полевых исследований, показывает, что этот оползень относится к типу сложных оползней с вращением, возникающих вследствие осевой нагрузки.

оползень, осевая нагрузка, горы Эр-Риф, Марокко

Introduction

The Rif Mountain is known as prone area for landslides which damage the infrastructures and impact the sustainable development of the region. The studied Akchour landslide is located near Chefchaouen Natural Park and due to its size, has caused significant damages: destruction of houses, roads and agricultural land crops.

In the Rif mountains many studies dealt with mass movements inventories, and mapping [*Avenard, 1965; Millies-lacroix, 1968; Margaa, 1994; Fares, 1994 and Fonseca, 2014*] with geological study of particular cases [*El Fellah et al., 1996; Faleh & Sadiki, 2002; Azzouz et al., 2002; Mansour, 1998*]. The first mapping and inventory study of mass movements had focused on the Sebou basin [*Avenard, 1965*]. In the central part of the Rif, Maurer (1968) focused mainly on mapping, particularly superficial ones. El Khattabi and Carlier (2004) discussed the relationship between rainfall and the mechanical parameters of materials and their influence on the safety factor (F), in the northern limit of the central Rif. The multi-fractal analysis performed on landslides in the central Rif [*Rouai & Jaaidi, 2003*] demonstrates that the spatial distribution of landslides is not a homogeneous fractal structure and showed self-organized behavior. Landslides were also studied and analyzed using the photogrammetry technique [*Mastere, 2011*].

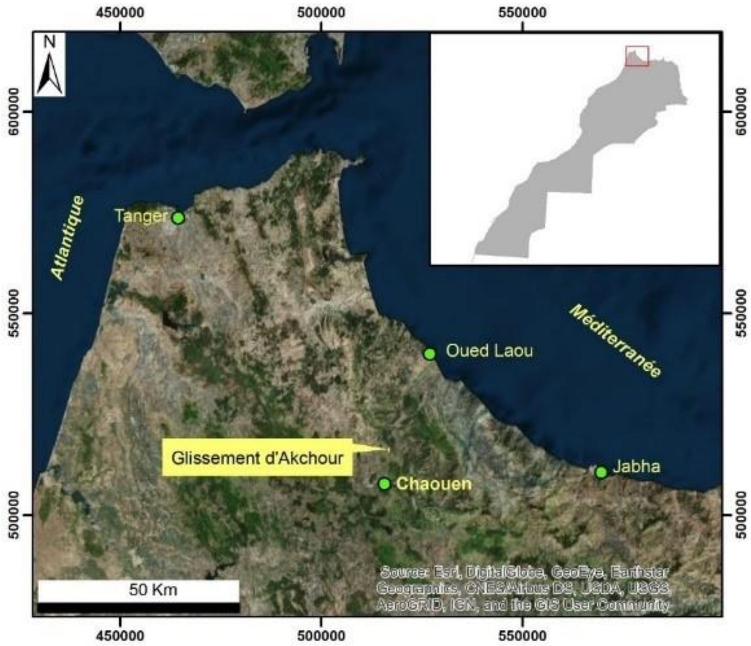
This work is interested to the Akchour landslide, in thrust sheet context (Michard et al., 2002). It consists of a geological characterization in order to understand the predisposition and triggering parameters of the mass movement (lithology, faults, slope gradient, stream network, rainfall and land use). These parameters have been mapped and classified in order to understand their interactions and their respective effects in the instability of this landslide.

Environmental context

Description the landslide

The studied area is located about 9 km north of the Chefchaouen city (Fig. 1) between the longitudes W 5.223983-W 5.205460 and the latitudes N 35.258807-N 35.240284 (WGS 1984). The landslide was occurred in 2010, causing significant material damages without deaths fortunately. According to a field survey carried out with the local population, the mass movement began in a progressive way ten (10) days before the rupture, which warned the people who took the precaution to escape. With an area of approximately 36 ha (Fig. 1-1), this slide has completely changed the local landscape. The agricultural lands were destroyed and become unusable. The Taourart village consisting of about 75 houses was almost buried under the landslide body, which pushed 500 people of this village to move out (Fig. 1- 2, 3 and 4).

The Akchour landslide is located in an important touristic area, which contain two routes that connect several villages to the main road network. Apart from the material damage caused by the landslide event (loss of houses and farmland), the destruction of these two routes handicap the socio-economic activity of this area. However, the reactivation risk of this mass movement is still persistent, especially since no security or stabilization measures have been undertaken.



a)

b)

Fig. 1. Akchour landslide: a – location on Google satellite image (from ESRI)); b – 1) general view of the landslide, 2) blocks of stones, 3) partially destroyed mosque by the sliding surface, 4) totally destroyed irrigation pipes

Climate

In the landslide area, the climate is Mediterranean, with high rainfall values are between November and February. The driest months are July and August [*Agence du Bassin Hydraulique de Loukkos*, *2012*]. Between December 2009 and March 2010, the Chefchaouen area received about 1100 mm (80% of annual rainfall) which give the highest cumulative values recorded over the last decade. Thus, these high rainfall values seem to allow the trigging of Akchour landslide during March 2010.

The local stream network consists of two small tributaries of the Talembote river. The beds of these two tributaries are completely modified. Indeed, before the sliding, these two tributaries intersect at a confluence point before joining the Talembote river. After the sliding, they become separated and revealed a small spring that could be the continuity of the subsurface flow of the western tributary.

Topography

The study area is characterized by a rugged and varied topography. The maximum altitude is about 2147 m at Jbel Tissouka. A slope analysis performed using the Jenks [Jenks, 1967] method show that the slopes below 15 ° cover 76% of the study area. The Akchour landslide is located in the slope class ranging from 16 to 25°(Fig. 2).

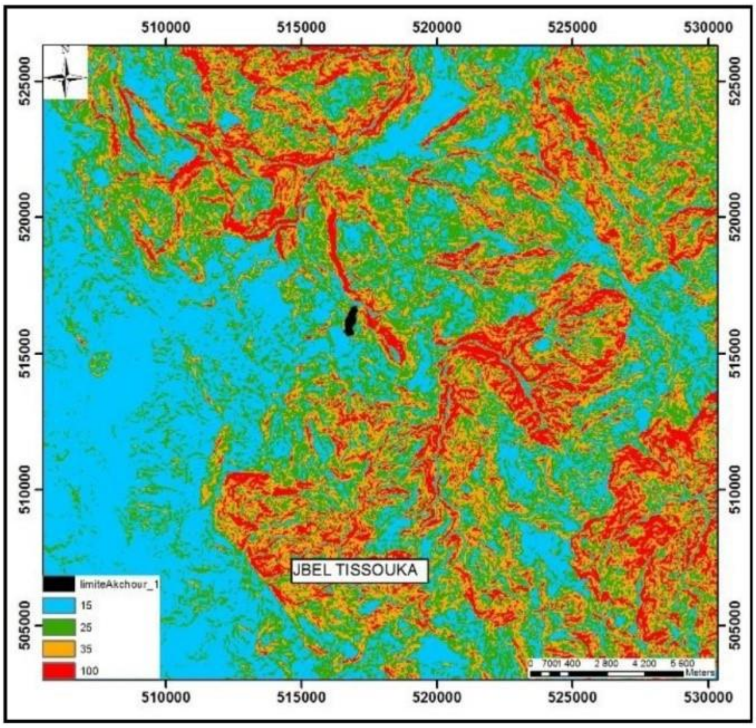


Fig. 2. Location of Akchour landslide on digital elevation model and slope maps

Geological setting

The geology of Akchour is composed of the Beni Hozmar unit which is part of the Gomarids, the predorsal unit (flysch) and the Tarhzoute unit (Fig. 3) [*Kornprobst et Wildi., 1975*]. The Beni Hozmar unit consists of mainly of paleozoic formations consisting of siluro-devonian schists, conglomerates, carboniferous flyschs, and permian marls. This sheet rests in reverse fault on the the predorsal layer of sandstone, oligocene brown clay in the upper part and marl at the base. The predorsalian unit is overlapped by the Tarhzoute unit (white massive limestone of the upper triassic and conglomerate of unknown age) [*Chalouan et al., 2008*].

The Akchour landslide is located in a moderate seismical activity area [*Cherkaoui and El Hassani, 2012*]. In 2005 the occurred earthquake close to Akchour landslide is about 2.7 km to the north having a magnitude of 3.1 on the Richter scale [ISC, “International Seismological Center”].

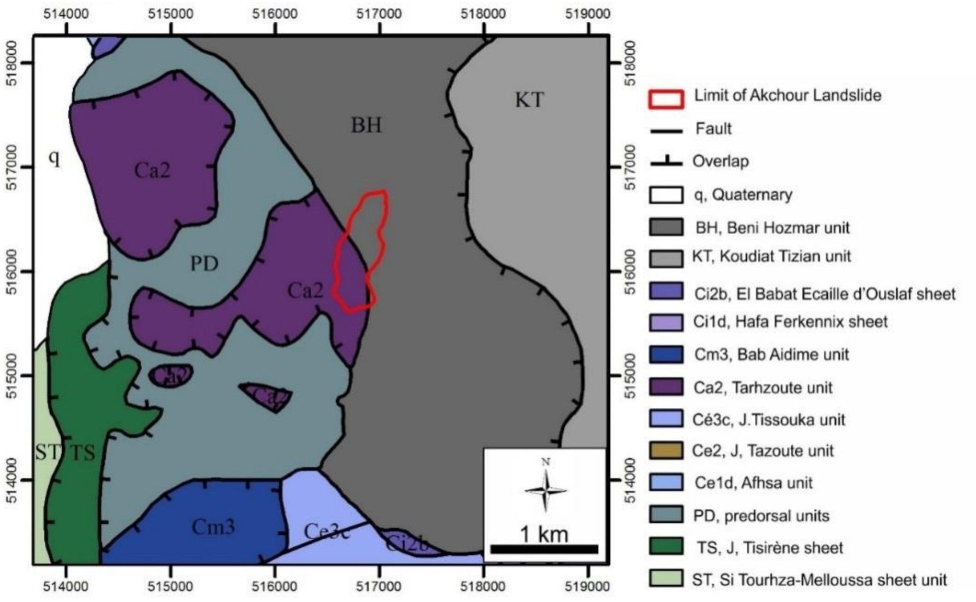


Fig. 3: Structural map of the study area showing the thrust sheets unit [*Kornprobst et Wildi., 1975*].

Methodology

To study the Akchour landslide, a multidisciplinary methodological approach was adopted:

• The landslide morphology was approached through the study of 1/20 000 aerial images taken after the sliding. Pair of stereographic images was transformed into composite images (Fig. 5) with red and cyan colors. Using the Arcgis software, this operation allows mapping and highlighting the elements of the slide, through these available mapping tools.

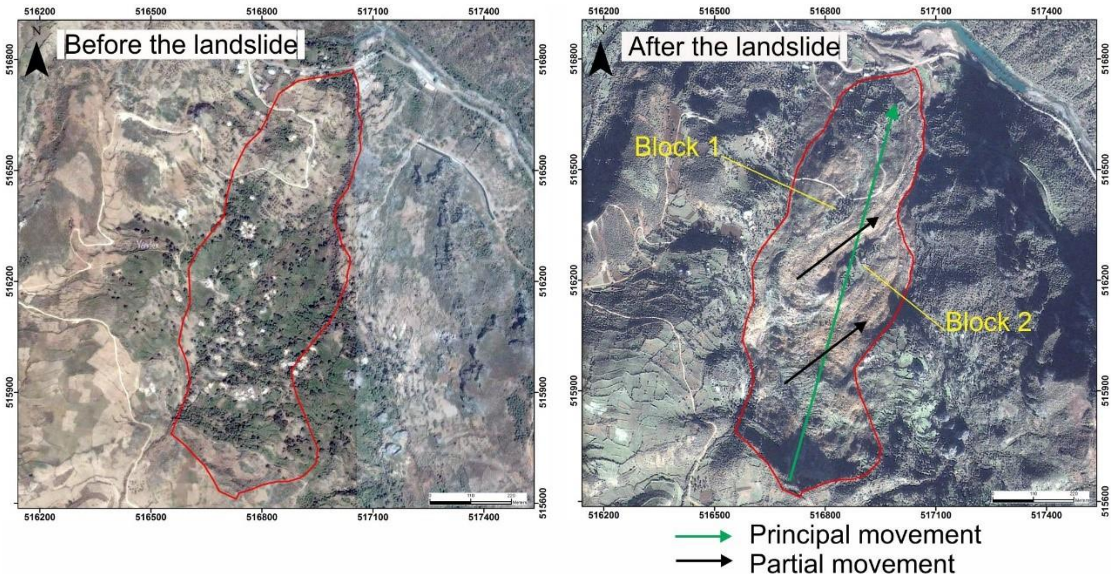
• A comparative geological and hydrological studies were done using two Google Earth images taken before and after landslide in order to understand how the movement occurs and to evaluate damages of agricultural terrains and infrastructures.

Analysis and results

Morphology

The visual interpretation of the satellite images (Fig. 4) shows that the gravitational movement of the sliding mass has two directions: a main SSW-NNE one (green arrow) and a secondary (black arrow) SW-NE direction. The comparison between the two satellite images shows that the ground motion is not homogeneous, a land block inside the landslide, has not undergone a notable displacement, but it is quite visible that is tilted.

The figure 6 shows the structure of the slide extracted from the composite image of aerial photos (Fig. 5). This structure shows, at first sight, that the slide is composed of several units, with differential movements. Apart from the sliding surface to the south and west, the slipped body contains several secondary sliding surfaces that relax the movement stress. These surfaces are located in the middle part of the slide; this is due to the combined movement towards the northeast that was guided by the orientation of the local slope (towards the NE). The movement features recorded by stereoscopic analysis are: escarpments, crown and slump blocks.



a) b)

Fig. 4. Initial view (2005) (a) and post landslide view (2014) (b) of the landslide (source: Yandex and Google).

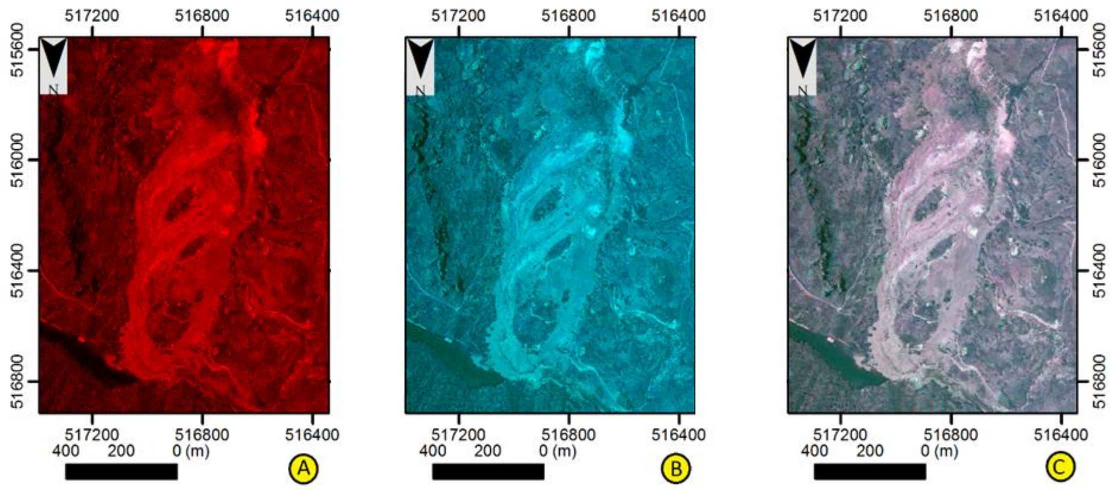


Fig. 5. A – red band of left aerial photo. B – cyan component (Blue and green bands) of the right aerial photo. C – composite Image (Red and Cyan)

Geology of the Akchour site

The geometry of the geological layers in the vicinity of the landslide was approached through a geological cross-section (Fig.7 C, D). This SSW-NNE cross-section shows the limit between the predorsal and beni hozmar units. This limit is represented by a subvertical NW-SE fault (geological map of Talembote cross-section KK ') located probably in the middle of the landslide. In fact, the massive triassic dolomite and limestone formations (TlCB formation in Fig. 7A) overlap the micaceous sandstone and brown clay formations and the eocene marls (egPD).

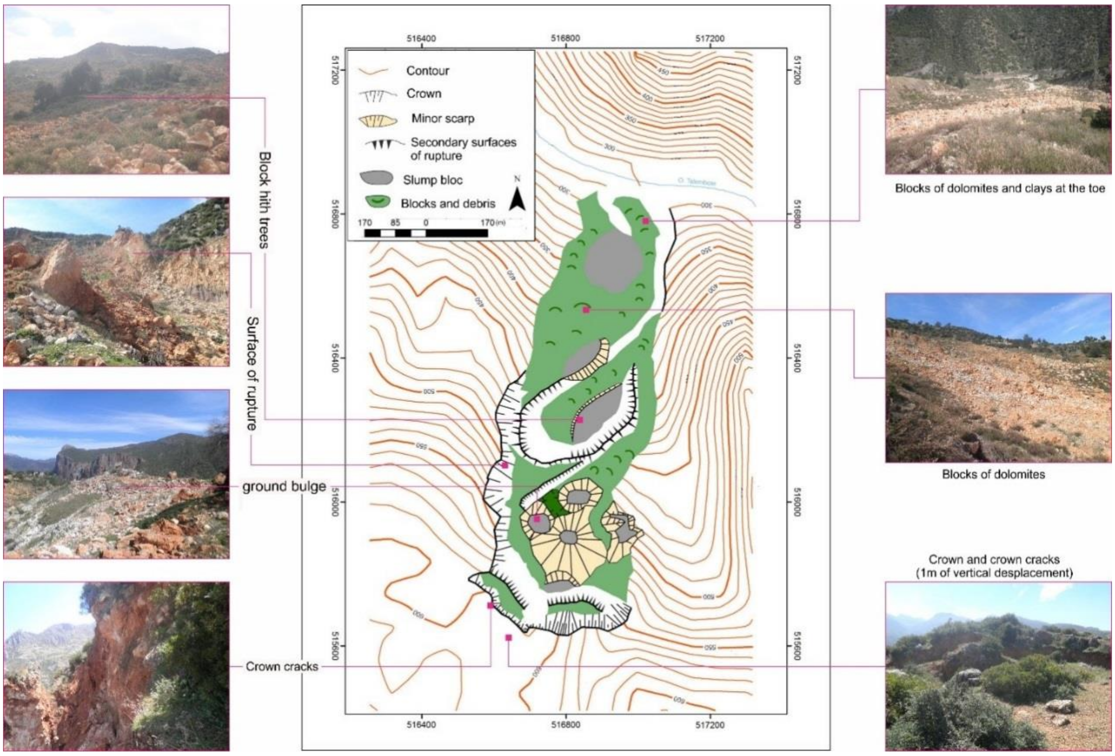


Fig. 6. Morphology of the Akchour landslide extracted from the composite image data

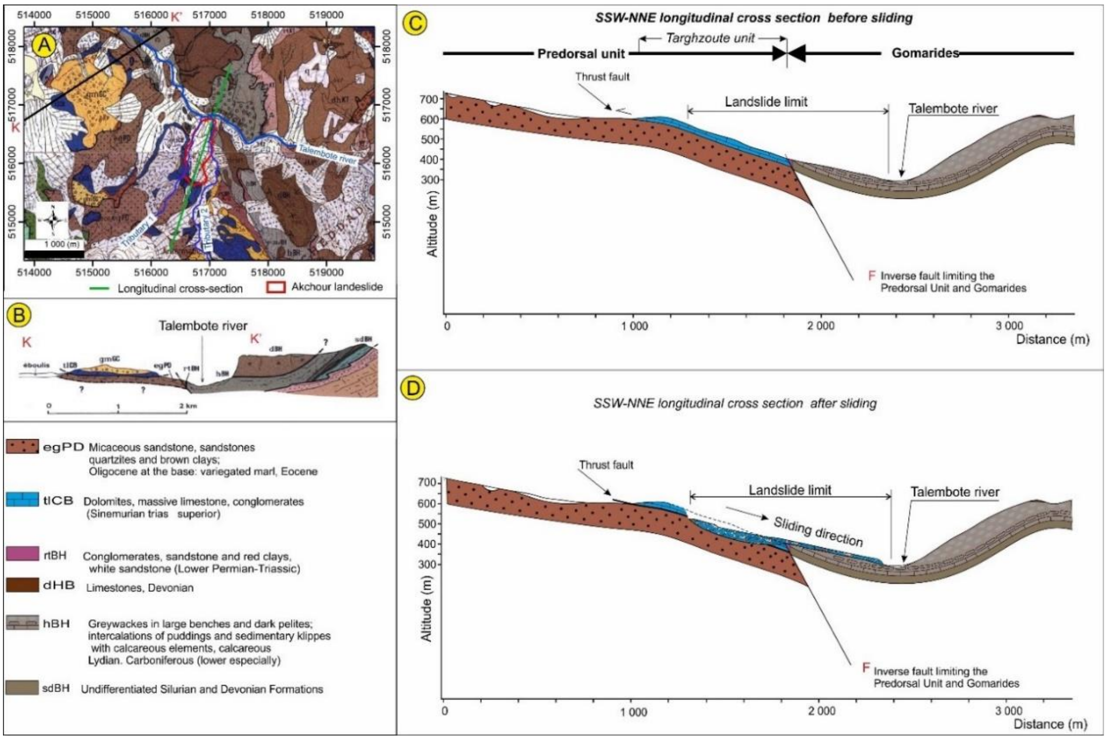


Fig. 7. A – location of the geological cross-sections on the topographic map 1 / 50,000. B – geological cross-section at the NW of the slide (KK’). C – Longitudinal cross-section before sliding. D – Longitudinal cross-section after sliding

Conclusion

In this case study, using anaglyph method, it was possible to map the landslide structure and to understand the geometry and dynamics of its components, especially in the no access zones. The mapped components have been geologically identified in the field; they consist of triassic limestones overlapping eocene clays in the main direction of the mass movement. Landslide dimensions' features identify the movement as a rotational deep-seated mass movement. The slope, geological characteristics and the location of the studied landslide in a high rainfall area are considered as the main predisposition and triggering factors.

The irrigation by simple gravity system of affected lands must be considered. Indeed, the continuous water infiltration during the dry period (irrigation period) would be probably one of the causes of the triggering.

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