# EMPLACEMENT KINEMATICS OF THE SEYMAREH ROCK-AVALANCHE DEBRIS (IRAN) INFERRED BY FIELD AND REMOTE SURVEYING

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## EXTENDED ABSTRACT

Comprendere la cinematica delle frane ed i loro meccanismi di rottura è essenziale per la definizione della pericolosità e per la ricostruzione di scenari di rischio funzionali a strategie di mitigazione. Le frane nel sud-ovest dell'Iran sono particolarmente numerose, specialmente nei bacini sedimentari degli Zagros. Secondo alcune stime basate su studi e ricerche fino ad oggi condotte,tra 10000 e 11000 anni fa, una grande frana (volume massimo stimato di 44 Gm$^3$) è avvenuta nella città di Pol-e-Dokhtar, nella regione del Lorestan (settore ovest dell'Iran). Poiché questa frana ha sbarrato il corso del fiume Seymareh, è nota come la frana di Seymareh. Questa giga-frana è ritenuta la più grande sulla superficie terrestre. Nel presente studio, per la comprensione della cinematica di messa in posto della frana Seymareh, sono stati rilevati con elevato dettaglio elementi morfologici visibili sull'enorme accumulo di frana che si estende per circa 24.5 km in larghezza e per circa 19 km in lunghezza. Tra gli elementi morfologici rilevati vi sono dorsali di compressione e cumuli di blocchi, che sono stati identificati e cartografati integrando un rilevamento da remoto con un rilevamento di terreno. A seguire, sono state misurate la curvatura e la direzione delle dorsali e le dimensioni principali dei blocchi avvalendosi anche del GIS. Le direzioni delle dorsali su un detrito di frana possono rappresentare indizi morfologici della cinematica relativa alla sua messa in posto; nel caso della Seymareh le direzioni prevalenti sono risultate essere NW-SE e NE-SW. Nel corso di una specifica campagna, sono stati, inoltre, prelevati campioni di terreno, rappresentativi della matrice del detrito di frana, in punti diversi dell'accumulo, per poterli caratterizzare in laboratorio e classificare secondo lo standard USCS. I risultati della classificazione di laboratorio effettuata sulla matrice campionata nell'accumulo della frana Seymareh, mostrano che, per - la maggior parte, essa è rappresentata da terreni limosi a bassa compressibilità (di tipo ML secondo la classificazione USCS) mentre una parte più ridotta è rappresentata da terreni ghiaioso-argillosi e ghiaioso-limosi (di tipo GC e GM secondo la classificazione USCS) . Per ciò che attiene la distribuzione di queste matrici nel detrito, i terreni GC e GM sono stati campionati per lo più in prossimità della zona di distacco della frana mentre i terreni ML sono stati prevalentemente campionati nelle posizioni intermedia e distale. La distribuzione di termini siltosi ed a grana grossa sono ascrivibili dalla Formazione di Asmari e la loro presenza nelle porzioni media e distale dell'accumulo di frana suggerisce che, già nelle fasi iniziali della messa in posto dell'accumulo di frana, il calcare della -Formazione di Asmari, che costituiva un'unica placca rigida originariamente a franapoggio sul versante dal quale si è distaccata la frana Seymareh, avrebbe raggiunto una minore distanza rispetto ai detriti generatisi dalle sottostanti formazioni a componente prevalentemente marnoso-argillosa (tra cui le Formazioni di Pabdeh-Gurpi). Ciò può essere giustificato anche alla luce della trappola sedimentaria rappresentata dalla paleo valle del Seymareh che avrebbe favorito l'accumulo dei primi detriti giunti, ascrivibili alla Formazione di Asmari. I detriti più fini si sarebbero, invece, accumulati in zona più distale rispetto all'area di distacco della frana muovendosi al di sopra della prima parte di deposito che aveva già colmato la paleo valle. La distribuzione e l'orientazione degli indicatori cinematici rilevati sul detrito di frana come anche la distribuzione dei terreni di cui esso è costituito portano, dunque, a confermare quanto già evidenziato da precedenti studi (HARRISON & FALCON, 1938; ROBERTS & EVANS, 2013), ossia che la frana di Seymareh può essere considerata una rock avalanche verificatasi in un singolo evento. Inoltre, i risultati preliminari della distribuzione dei blocchi ed alcuni affioramenti della Formazione di Gachsaran osservati durante i rilevamenti sul campo hanno portato al riconoscimento della superficie basale dei detriti di frana rendendo possibile avanzare alcune ipotesi sulla morfologia sepolta della paleo valle del fiume Seymareh.

## ABSTRACT

Understanding the kinematics of landslides helps us to better constrain failure mechanisms and it is useful to define hazard and consequent risk scenarios for mitigation strategies. According to the literature, between 10 and 11 ka, a huge landslide (up to 44 Gm$^3$) occurred close to the Pol-e-Dokhtar city in the Lorestan region (west of Iran). As this landslide blocked the Seymareh River, it is known as Seymareh landslide. Seymareh giant landslide is the largest landslide documented on the Earth surface and is of great interest for earth scientists. We deepened the analysis of the emplacement kinematics of this enormous landslide, using remote and field surveying. The boundary of landslide debris, the ridges, gullies and clusters of blocks inside the debris area were recognized and then ridges curvature and direction and major block dimensions were measured also using GIS tools. Ridges directions inside the landslide debris preliminarily suggest the kinematics of the mass mobility. Furtheremore, soil samples were took from matrix of landslide debris at different places inside the rock avalanche debris area for their classification according to the USCS standard. The results of grain size analysis on the matrix of the soil samples in combination with Atterberg limits in different regions of the debris show that the most of the matrix is represented by ML while a more reduced part is represented by GC and GM soils. GC and GM soils were mainly distributed closer to the detachment zone of the Seymareh landslide, while ML soils are mainly distributed in middle and distal positions.

The preliminary results of block distribution and some outcrops of Gachsaran Formation observed during field surveys led to recognition of the landslide debris basal contact that helped us to speculate on the paleo-valley hidden morphology.

**KEYWORDS:** *landslide dam, kinematics, rock avalanche, debris, remote surveying*

## INTRODUCTION

Landslides in the South-West of Iran are relatively abundant specially in Zagros sedimentary basins. One of the oldest and most important of these landslides is Seymareh landslide in the foreland margin of the Zagros Mountains (Iran) which is one of the largest known landslides on the Earth's continental surface with a volume of 44Gm$^3$ (ROBERTS AND EVANS, 2013). The landslide occurred along the provincial border between Ilam and Lorestan, 60 km west of the Iraq border. A huge avalanche crossed two valleys and travelled about 19 km far, damming up the two major rivers of Seymareh and Kashkan. Two large lakes and a small lake formed and remained filled for a long period of time until they eventually breached the natural dam and eroded a channel through it. Many researchers have examined different aspects of Seymareh landslide. HARRISON & FALCON (1937, 1938) were the first researcher who studied the Seymareh

landslide and provided the information on geology and structure of the source area, the geomorphological setting and the main geometry of the landslide. WATSON & WRIGHT (1969) characterized the geomorphology and stratigraphy of the debris and discussed the origin of the initial rockslide. They also express that evidence of large blocks on the surface probably reflects that Asmari limestone was above other rocks when the slide began. ROBERTS & EVANS (2013), based on the distribution of Asmari limestone in the distal debris, suggested that during initial failure the upper plate overrode the lower plates to travel the farthest. SHOAEI & GHAYOMIAN (2000) estimated the volume of rockslide as 24-32 Gm$^3$ that is in contrast with 38 Gm$^3$ of initial volume estimated by ROBERTS & EVANS (2013). SHAYAN (2006) based on geomorphologic field and documentary surveys and historical details concluded that the age of event was about 1100 years ago. He also expressed that the Asmari limestone departed from Kabir –Kuh anticline crest and moved along a NW direction towards the Seymareh River valley which is not in agreement with NE direction that has been reported by ROBERTS & EVANS (2013) based on field measurements of bedding surface orientations. HARRISON & FALCON (1938) were the first researchers that interpreted the Seymareh landslide as a single event and recently ROBERTS & EVANS (2013) by studying the failure mode and debris morphology strongly suggest that the Seymareh rock avalanche was an instantaneous single event. This is in contrast with the interpretation of KENT (1966, p. 80), who, suggested that the pile of Eocene marls and shales at the foot of the central part of the scar was emplaced after the main movement in a relatively minor secondary slip. Also, YAMANI *et alii* (2012) due to the thickness and extent of the lacustrine, sediments, morphometry and especially altitudes of lacustrine argue that Seymareh landslide occurred in three or four stages. The aim of current research is to understand the kinematics of landslide debris emplacement by analyzing ridge direction, block cluster location and grain size distribution of some samples of matrix took from the landslide debris.

## STUDY AREA

The study area is located in the Zagros Simply Folded Belt more precisely along the North-East slope of the Kabir-Kuh fold where the outcropping stratigraphy is that typical of a passive margin that evolves in a foreland basin. In other terms, it is characterized just by the apposition of contrasting lithologies such as: limestone, marls, anhydrates, sandstones. In Figure 1, it is possible to observe that the stratigraphic column is composed by the cristalline limestone of Ilam-Surgah and Sarvak Formations (Late Cretaceous), hemipelagic-pelagic calcareus shales of Pabdeh-Gurpi Formations (late Paleocene-early Oligocene), massive stratified limestones of Asmari Formation
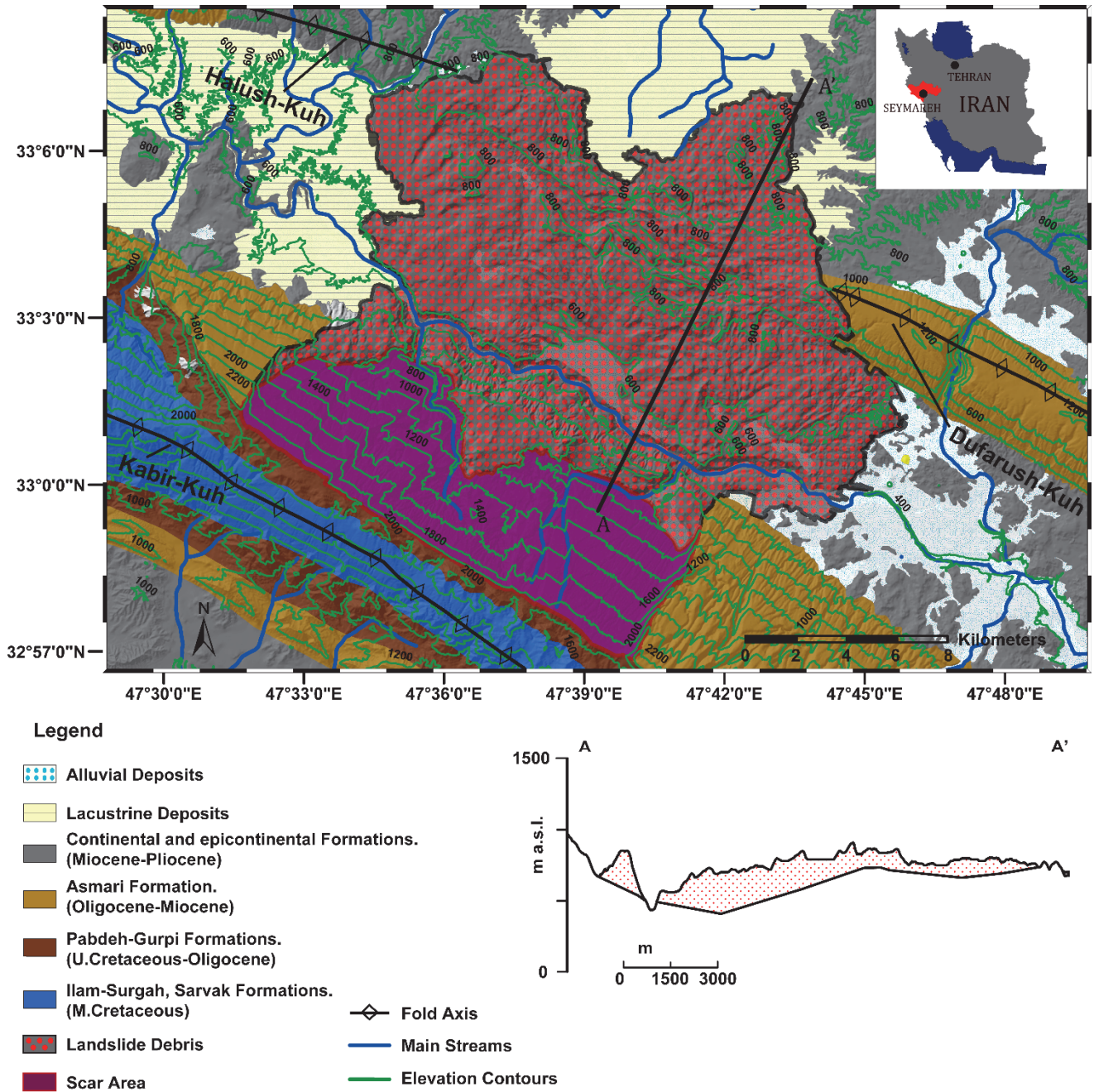
*Fig. 1 - Geological map of the Seymareh landslide area and Cross section of the Seymareh Landslide deposits*

(Oligocene- Miocene), continental and epicontinental formations of Gachsaran, Agha Jari and Bakhtiari, consisting on anhydrates, sandstones and conglomerates (early Miocene-early Pleistocene). The most recent deposits outcropping in the Seymareh landslide area are ascribable to conglomerates pertaining to inactive fans, lacustrine deposits linked to the landslide damming and alluvial terraces.

## MATERIALS AND METHODS

So far, no attention has been given to Seymareh landslide debris as a possible indicator of its emplacement kinematic after the slope collapse.

In this study, a detailed analysis of Seymareh landslide debris mobility was carried out based on field and remote surveying. In a first step, the landslide debris boundary, as well

as the ridges and blocks on the landslide debris have been mapped in GIS through the interpretation of satellite optical images (Google Earth, Images © 2019 CNES/Airbus) as presented in Figure 2.

Successively, a field survey has been carried out to confirm the presence of all recognized ridges and blocks and to collect some samples from the landslide debris matrix.
Bedrock outcrops along the river gorge and below the debris allowed to identify the basal surface of the landslide debris.

Then, the ridges curvature and direction respect to the north were measured with the aim of understanding the emplacement kinematics of the rock avalanche debris.
Furthermore, following the USCS standard (ASTM, 2000) we classified the matrix samples related to the landslide debris which have been analyzed in terms of spatial distribution.

## RESULTS
### Kinematic analysis of debris emplacement

The emplacement kinematics of the Seymareh rock avalanche debris can be inferred from the collected geomorphological evidences within the accumulation area, i.e. kinematic indicators as ridges and blocks (Fig. 3).

As shown in Figure 3, kinematic arrows deduced from the ridge orientation analysis show two main orientation, NE-SW and NW-SE. The block distribution also revealed that a back and forward motion involved the landslide debris during its emplacement as the huge blocks are distributed not only along the front of the landslide mass but also in its middle zone where the Dufarush-Kuh ridge is expected to be buried.

These evidence led us to confirm what was already been stated in the previous studies (HARRISON & FALCON, 1937;
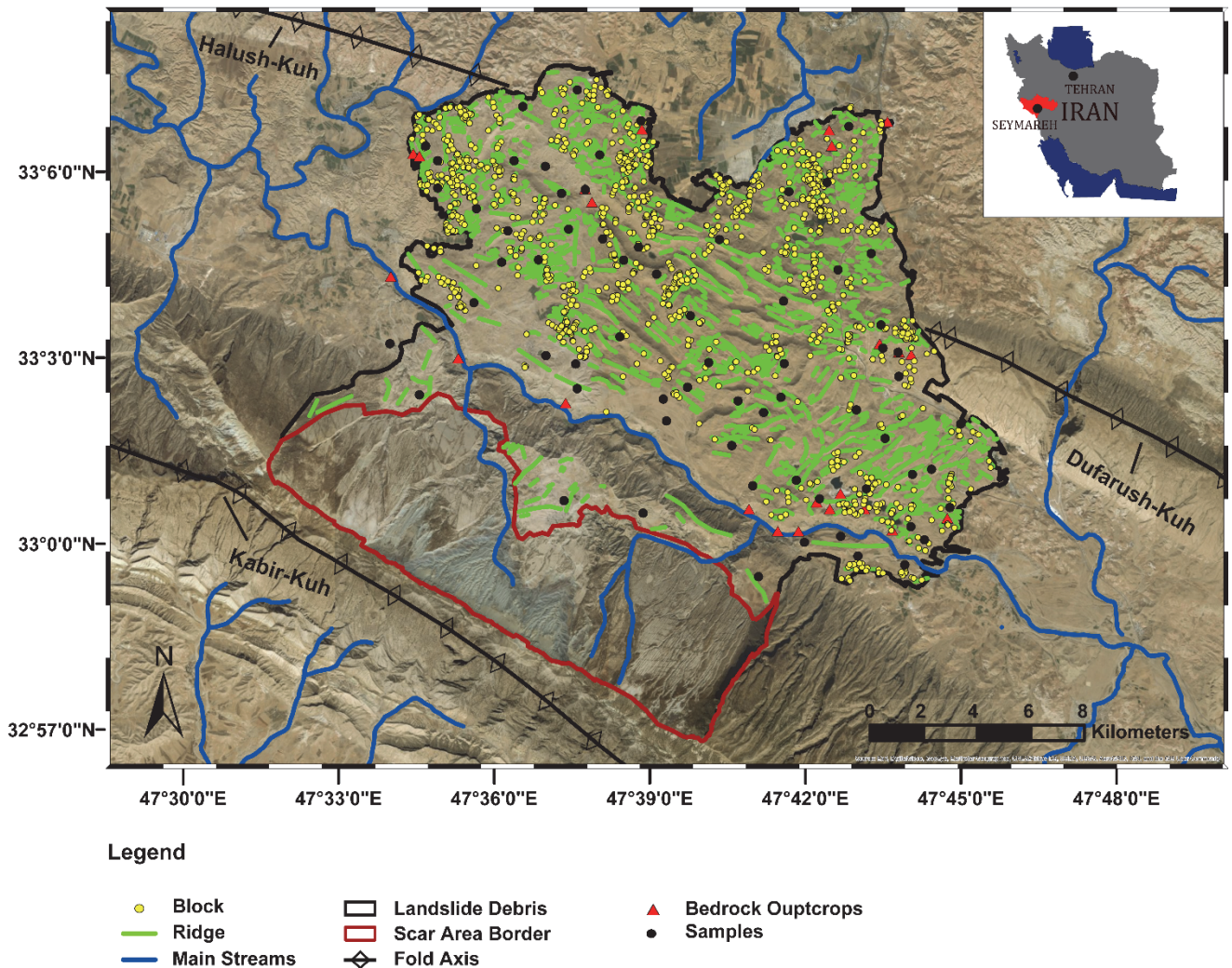


*Fig. 2 - Map of the kinematic indicators on the Seymareh landslide debris*

WATSON & WRIGHT, 1969; ROBERTS, 2008; ROBERTS & EVANS, 2013; SHOAEI, 2014) that a part of the Dufarush and Halush anticlines in front of Kabir-Kuh are buried under the landslide debris. It means that during landslide debris emplacement the part of debris with higher energy overpassed these two anticlines and the rest of debris swept back in the valley. As shown in Figure 1, the paleo valley morphology has been reconstructed based on field observations which allowed to recognize undisturbed outcrops of the Gachsaran Formation and their location at the original elevation; moreover, the distribution of the kinematic indicators extracted from ridges direction as well as the block clusters location within the landslide mass suggest the position of the depocenter of the the Seymareh valley before the landslide emplacement. The so derived reconstruction of the paleo valley morphology indicates that paleo Seymareh river was flowing to the NE of the present river gorge.

*Matrix classification*

USCS classification system was used to classify the landslide debris matrix and to point out possible relations between soil group distribution and emplacement kinematics of the landslide debris. The results of USCS classification are shown in Figure 3. Based on the obtained results, 3 groups of matrixe can be distinguished: clayey gravel (GC), silty gravel (GM) and low compressibility silt (ML). The first and second groups are mainly located in the proximity of the detachment area while the third group is located in the middle and distal area. Such an evidence coupled with the kinematic indicators and the Asmari Formation blocks distribution confirms what stated by ROBERTS & EVANS (2013), i.e. that during initial failure the Asmari Formation limestone (upper plate) overrode the lower plates to travel the farthest. Lower weaker plates were involved in the slope collapse immediately after the stiffer plate of the
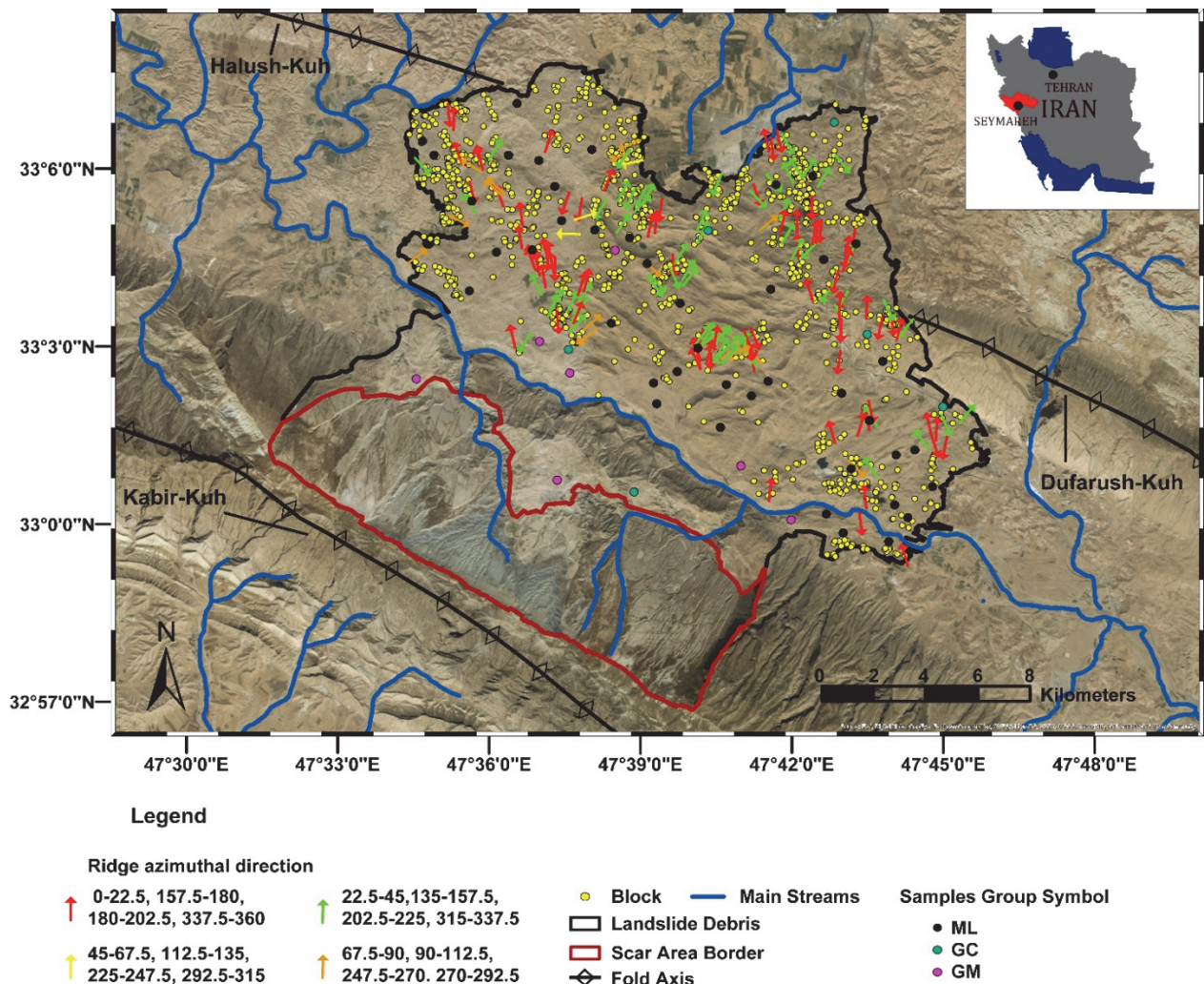


*Fig. 3 - Kinematic indicators and landslide debris matrix classification based on USCS (ASTM, 2000): ML – low compressibility silt; GC – Clayey gravels; GM – silty gravel*

Asmari Formation. The lack of preservation of intact portions of the collapsed stratified rocks, the intense fragmentation of the involved rocks in the landslide debris, the huge block cluster distribution which reveals a coarsening forward sizing and the main concentration of the huge blocks all along the perimetral zone of the landslide debris justify that the Seymareh landslide resulted in a rock avalanche; moreover, the kinematic indicators coupled with the huge blocks distribution also outline that such a rock avalanche consisted in an instantaneous and single event of generalized slope failure.

## CONCLUSIONS

This study provides new evidences on the emplacement kinematics of the Seymareh rock avalanche debris, based on mobility indicators by both remote sensing analysis and geomorphological field surveys. The distribution of huge blocks is in agreement with the orientation of the kinematic indicators. Based on these results it can be deduced that the Seymareh landslide was a single-event rock avalanche filling a paleo valley enclosed between two anticline ridges. The USCS classification of the matrix sampled within the landslide debris allowed to recognize GC, GM and ML soils. Fine-grained soils (ML) mainly compose the debris matrix in the middle to distal portions, while the coarse-grained (GC and GM) soils are mainly distributed within the debris in the proximity of the detachment area of the Seymareh landslide. This could be explained by a two-time emplacement kinematic, including a first step in which the fragmented stiff plate of the Asmari Formation filled the paleo valley of the Seymareh River so favoring, in a following step, the run out of the finer debris originated from marls and clayey of the Pabdeh-Gurpi Formation.

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