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Discussions

Assessment of rockfall hazard on the steep-high slopes: Ermenek (Karaman, Turkey)

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Abstract

Ermenek is one of the curious settlement areas because of its topographical features in Karaman (Turkey). The city is located in northern side of the very steep cliffs formed by jointed limestone which are suddenly increased from 1250 m to 1850 m. Moreover, these cliffs having almost 90° slope dip are the main rockfall source areas due to their lithological characteristics, climatic effects and engineering properties of rock units. Up to now, depending on rockfall events, almost 500 residences were damaged severely, and losses of lives were also recorded in Ermenek. The rockfall phonemon are initiated by discontinuities, lithological changes, weathering and freeze-thaw process in the study area. In this study, extensive fieldwork including determination of location and dimension of hanging, detached and already fallen blocks, a detailed discontinuity survey, description of geological, morphological and topographical characteristics was performed. Besides, rockfall hazard is evaluated by two-dimensional rockfall analyses along 10 profiles. During the rockfall analyses; run out distance, bounce height, kinetic energy and velocity of various size of blocks for each profiles are determined by using RocFall v4.0 software. The results obtained from rockfall analyses were used to map the areas possible rockfall hazard zones and rockfall source areas were interpreted.

According to rockfall analysis, field study and laboratory testing, protective and preventive recommendations can be suggested for the areas under rockfall threat. But, the most widely-known remedial measures in literature such as trenches, retaining walls (barrier), wire meshes, cable/streching nets and rock bolting etc. are not sufficient in the study area, due to topographical, atmospheric and lithological features. For these reasons, firstly total evacuation of the danger zone should be applied and then hanging blocks in the reachable locations can be removed taking safety measures in this area to make it safer for the living people.

Keywords: Hazard, Rockfall, Limestone, Zonation map, Ermenek.

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Introduction

Rockfall is a fast movement of the blocks which are detached from the bedrock along discontinuities that slides, rolls or falls along vertically travels down slope by bouncing and flying along trajectories (Varnes, 1978; Whalley 1984; Dorren 2003). Due to their high speed and energy, rockfalls can be admissible as a substantially destructive mass movement resulting in significant damage and loss of live. This movement is mainly controlled by the geological conditions of the rock units, climatic influences and the weathering processes. Besides, discontinuity patterns and the related intersections are also played an important role of the size and shape of the detached blocks (Perret et al. 2004).

The slope characteristics are very significant factors for the rockfall events. The normal (r_n) and tangential (r_t) components of coefficient of restitution, are related to the slope characteristics that control behavior of the falling blocks and they are the most crucial input parameters for rockfall analyses (Chau et al. 1996). Both components of coefficient of restitution are related to material covering the surface, vegetation, surface roughness, and radius of the falling rocks (Dorren et al., 2004). The coefficient of restitution with normal and tangential components are best determined by the field tests and back analysis of the fallen blocks. Although many researchers are revealed several techniques to determine the coefficient of restitutions, these parameters should be identified individually for each side because of the different geometrical features and mechanical properties of the slopes (Agliardi and Crosta 2003; Dorren et. al, 2004; Evans and Hungr 1993; Robotham et al. 1995; Pfeiffer and Bowen 1989; Ulusay et al. 2006; Topal et al 2007; Topal et al., 2012, Buzzi et al 2012). On the other hand, slope inclination and slope properties are also affecting the runout distances of the falling blocks (Okura et al., 2000). The slope surface of a hard rock and free from vegetation cover is more dangerous then the surface covered by vegetation or talus material because of the fact that it does not retard the movement of falling blocks.

To simulate fall of a blocks down a slope and to compute rockfall trajectories, various two dimensional (2D) or tree dimensional (3D) and 2D-3D Discontinuous Deformation Analysis (DDA) programs have been developed and tested during the last few years and many of study considering with rockfall analyses and simulations are carried out. Additionally, the rockfall susceptibility and hazard maps are produced using both two and tree dimensional rockfall analysis technique considering with mostly traveling distance of falling blocks. (Bassato et al. 1985; Falcetta 1985; Bozzolo and Pamini 1986; Hoek 1987; Pfeiffer and Bowen 1989; Azzoni et al. 1995; Jones et al. 2000; Guzetti et al. 2002, Guzetti et al, 2003; Agliardi and Crosta 2003; Schweigl et al 2003; Perret et al 2004; Yilmaz et al. 2008,

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Tunusluoglu and Zorlu 2009, Binal and Ercanoglu 2010; Zorlu et. al 2011; Katz et al 2011; Topal et al 2012; Chen et al. 1994; Keskin 2013).

In this study, rockfall analyses are performed in Ermenek district located on very steep cliffs considering past recorded phenomenon and recently ongoing threats of event (Fig 1). The rockfalls occur very close to residential area and already damaged the houses and unfortunately have been losses of lives. To reveal the rockfall potential of the study area, an extensive field work including detailed discontinuity survey, determination of location and dimensions of hanging, detached and already falling blocks, and also back analyses was carried out. Two dimensional rockfall analyses are conducted along 10 selected profile to assess the block trajectories, runout distance, kinetic energy and bounce high of the blocks, based on field and laboratory test data. Then a rockfall danger zonation map was produced by means of the results obtained from rockfall analyses and areal extention of rockfall was delineated. When considering location, climatic adversities and geological factors of the study area, some remedial measures can be arguable. Despite the unfavourable conditions, possible remedial measures are suggested for the study area.

Geological Settings

The Ermenek basin is one of the Neogene intramontane molasse basin formed in Central Taurides, the orogenic belt's segment streching between the Isparta angle to west and the Ecemiş Fault to the east (Özgül, 1976; Ilgar and Nemec, 2005). The Ermenek basin and the adjacent Mut Basin lies between the Cukurova basin complex to the east and the Antalya basin complex to the west and is situated within the central part of the Taurides, an E-W trending orogenic belt that originated through compressive deformation during the initial stage of closure of the southern branch of the Neo-Tethyan ocean in the Early Cenozoic (Safak et al. 1997). The basins evolved as extensional grabens related to preexisting fractures. Depozition resumed in Early Miocene time, with Mut basin hosting alluvial sedimentation and the Ermenek basin becoming a large clastic lake. The two basins, formed as separate interamontane depressions, were then inundated by the sea near the end of the Early Miocene and jointly covered with an extensive, thick succession of late Burdigalian-Serravalian carbonates, including reefal and platform limestones (Ilgar and Nemec, 2005).

The tectonic history of Southern Turkey can be summarised into three major periods; (1) Late Palaeozoic to Middle Eocene: formation of the Tethiyan orogenic collage. (2) Middle Eocene to Middle Miocene: Tauride Orogeny during continued north-south convergence and collision; migration of deformation front south of Turkey. (3) Late Miocene to recent: collision of

Eurasia with the Arabic Plate and start of the Neotectonic Regime (Bassnt et al 2005). Due to this complex tectonic movement the Taurus Belt exhibits very complicate stratigraphic sequence and litological diversity (Fig 2).

The basement of the Ermenek basin consists of Paleozoic and Mesozoic units, which are generally exposed at the southern part of the basin. Palaeozoic units compise of shale, limestone, dolomitic limestone, and quartzite. While Lower-Middle Triassic units contains limestone, shale; Upper Triassic units consists of sandstone, conglomerate and limestone; Jura-Cretaceous time is represented by dolomitic limestone (Gul and Eren, 2003). Eocene and Palaeocene sedimentary units contain fossiliferous limestone (Tepebasi Formation) unconformably overlie the Cretaceous limestone and ophilotic melange. Oligocene lacustrine deposits represent by Pamuklu Formation including coal layer as Yenimalle Formation, overlies unconformably Eocene-Oligocene units in the area. The Yenimahalle Formation has a great lateral extentention in the Ermenek basin consists of six main facies association, which range from alluvial to offshore lacustrine deposits, up to 300 m in thickness. Middle and Upper Miocene units unconformably overlie the Lower Miocene unit in the basin are characterized by Mut, Köselerli and Tekecati Formations. Koselerli Formation comprises claystone, limestone, clayey limestone, gravelly sandstone and marl deposits representing centre of the reef (reef core facies). Mut formation also consist of reef limestones deposits in shallow marine environment including limestone with clayey or fossiliferous, and distinctive patch reefs are common in this formation (Gul and Eren, 2003). The last unit of the Miocene age sequence of the basin is Tekecati Formation consists of limestone, fossiliferous limestone, clayey limestone and mudstone as assessed typically shallow sea sediment belong to a reefal environment (Yurtsever et al. 2005). All these formations of Middle and Upper Miocene also interfinger and they have transitional contacts with each other (Fig 3).

A Digital Elevation Model (DEM) of the study area was constructed by implementation of contour lines of 1:25,000 scale topographic maps with an equidistance of 10 m. When considering DEM, the altitude values of the northern and the south-eastern parts of the study area vary from 1,200 to 1,860 m (Fig 4a), slope gradients exceed 90º from 0º (Fig 4b) and the general physiographic trend of the study area is about S-SE (Fig 4c)

Field investigation and engineering properties of the rock

Rockfall events are observed in the very steep cliffs formed by jointed limestone which are suddenly increased from 1250 m to 1850 m. The limestone of Mut Formation is not form from a single lithological property it is also formed by succession of different lithologies which is one of the triggering factor of the rock fall events. Owing to its complex lithological structure, the field studies are also carried out more detailed considering with lithological differences. A systematic sampling was conducted to determine the lithological and geomechanical properties of Mut formation with different facieses. Petrographic investigations of the limestone specimens from the systematic sampling along X-X' line (Fig 5) of formation consists of routine observations under polarized microscope. According to the results of the petrographic analyses, the specimens are formed by four lithological units such as, fossiliferous limestone, claystone-marl, clayey limestone and limestone. The results of petrographic thin-section analyses are summarized in Table 1.

The X-ray diffraction analyses (XRD) are also applied to the specimens to assess the relative quantity of minerals (Table 1). The XRD diffractograms are obtained at General Directorate of Mineral Research and Exploration X-Ray Laboratory. The X-ray diffraction and the thin-section analyses results show it is obvious that Mut formation arise four different litological units.

During the field studies a series of systematic scan-line surveys were carried out to determine the orientation and spacing of discontinuities based on ISRM (1978) and ISRM (1981). According to scan-line survey, five main discontinuity sets were determined via contour diagrams using a computer program, name of DIPS 5.1 (RocScience Inc. 2006). The dip and dip direction of values of the major sets are 86/154, 85/210, 87/173, 84/077 and 55/155 (Fig 6). The discontinuities have high persistence (>20 m), very tight to very open aperture (from 0.1 mm to >10 cm) without infilling. The discontinuity surfaces are rough, undulating and groundwater seepage is not existed through discontinuities surface. The average spacing value of discontinuities is determined as 170 cm. and the discontinuity spacing histogram is given in Fig 7.

Kinematic analyses of the discontinuities are conducted for western, northern and eastern slopes of the study area. Kinematic analyses show that two different failure types observed on the slopes. Although sliding is encountered as a main failure type on the each slope, toppling type of failure is occurred only western and northern part (Fig 8).
During the field work, already fallen and hanging blocks in various dimensions were observed in the study area. For real approaches at rockfall modeling, size, location and runout distance of fallen blocks were determined (Fig 9). In addition to various sizes of hanging blocks, different rockfall source area was also observed during the field study (Fig 10). Besides, block samples were taken in the field for laboratory test. While taken block sample, systematic sampling was carried out from bottom to top of slopes due to its different

lithological and mineralogical features of Mut formation. The tests performed in the laboratory are unit weight, apparent porosity, void ratio, water absorption by weight, water absorption by volume and uniaxal compression strength for each sampling zone. When applying the tests, the procedures suggested by ISRM (1981) suggested methods are taken into consideration. The average unit weight of limestone samples (23.9 kN/m^3) were the highest than the fossiliferous limestone (22.2 kN/m^3), claystone-marl (20.4 kN/m^3), and clayey limestone (21.5 kN/m^3) sample. The uniaxial compressive stress values of samples were found vary in a large range. The average uniaxial compressive strength values of limestone, fossiliferous limestone and clayey limestone were 55 MPa, 48 MPa and 36 MPa respectively. The standard core sample can not be extracted from highly weathered zones of claystone-marl for uniaxial compression tests. To cope with this difficulty, the Schmidt hammer index test was performed in the field. The average Schmidt hammer rebound number of the claystone-marl was obtained as 33 and the uniaxial compression strength value was found as 22 MPa indirectly. The results obtained from the tests with statistical evaluations are given in Table 2.

Rockfall analyses

Various two or three-dimensional computer program are existed to simulate fall of boulder and compute rockfall trajectories, (Bassato et al. 1985; Falcetta 1985; Bozzolo and Pamini 1986; Hoek 1987; Pfeiffer and Bowen 1989; Azzoni and de Freitas 1995; Jones et al. 2000; Guzzetti et al. 2002). In this study, rockfall simulations of Ermenek steep cliffs carried out using Rockfall V.4 software (Rocscience Inc. 2002). Rockfall V.4 is a two-dimensional software program performing statistical analyses of rockfall and calculation engine behaves as if the mass of each rock is concentrated in an extremely small circle. While simulate rockfall trajectories, any size or shape effects must be accounted for by an approximation of, or adjustments to, other properties (Rockscience Inc. 2002). Some crucial parameters are required to design block trajectories and rockfall analysis, the coefficient of restitution (normal and tangential), slope geometry, roughness of slope and weight of hanging blocks. The slope geometry is revealed from 1/1.000 scale topographic map. When considering lithological features, distance from settlement district and location of rockfall source areas, ten slope profile selected for rockfall simulation analysis (Fig 11). In the field study, hanging blocks are determined and weight of reachable block is calculated by using unit weight and volume of the rock (Fig 12). The hanging or detached blocks had various dimensions due to the discontinuity orientation, spacing and their mineralogical composition affected by weathering processes. The calculated hanging blocks weights vary between 75 kg and 9.800 kg for different rockfall source areas (see Fig 10). For selected ten profiles, different rock masses (100 kg, 1.000 kg and 10.000 kg) were used in the rockfall analyses considering block sizes which are ideally represented field conditions. Initial velocity of blocks was preferred 0 m/s in the analyses considering the situation of the each block.

The slope characteristics are very important factors for the rockfall event because of the fact that the slope properties control the behavior of the falling blocks as runout distance of the blocks (Okura et al. 2000). The slope surfaces was played a considerable role in movement of falling or rolling blocks moving through the slopes. The slope faces are free from vegetation cover, they do not retard the movement of blocks. In this case, the blocks can be reached farther distance, on the contrary of the surface covered by vegetation or talus material. Because, the vegetation or talus material absorbs a high amount of the energy of the falling rock and will probably stop it (Hoek 2007). The retarding capacity of the slope surface material is expressed mathematically normal (R_n) and tangential (R_t) coefficient of restitution are affected by the composition of the material covering the surface and slope roughness. The coefficient of restitutions can be obtained from back analyses in the field or theoretical estimations (Agliardi and Crosta 2003; Dorren et. al, 2004; Evans and Hungr 1993; Robotham et al. 1995; Pfeiffer and Bowen 1989; Ulusay et al. 2006; Topal et al. 2007). Back analyses were performed to determine the coefficient of restitution with ten blocks in the field considering the size and the shape of the blocks and the slope characteristics (Fig 13). The results of the analyses, normal and tangential coefficients of restitution values belong the fallen rocks are determined as (0.33±0.04) and 0.63±0.19) respectively. In addition to coefficients of restitution, friction angle was determined by field back analyses as 32.5˚. During the rockfall analyses 1.000 rock blocks were thrown. The slope roughness which is another input parameter of rockfall simulation analyses was taken as 2˚ in based on the angle between rough surfaces. The input parameters used for rockfall analyses are given in Table 3.

Rockfall simulation analyses were performed ten profiles as mentioned above. The limestone and fossiliferous limestone units resisting against weathering, upper zones of weaker lithological unit claystone-marl accepted as rockfall source areas, based on field conditions (Fig 14). During the rockfall analyses, different rock masses (100 kg, 1.000 kg, 10.000 kg) were used for each profiles considering the real masses of hanging blocks in the study area. One of the typical examples of a rockfall trajectory is given in Fig. 15 .The runout distance, bounce height, kinetic energy and velocity of the blocks were predicted by rockfall analyses. According to the results of the analyses, maximum runout distance reaches 660 m, kinetic energy 1.750.000 kJ and velocity is 46.3 m/s for the free falling of the 1000 kg blocks. The results of analyses are summarized in Table 4. A rockfall danger zone map was produced by using the results obtained from rockfall analyses considering maximum runout distance of

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falling blocks Fig 16. According to map, areal extention of all blocks for each profile would be able to reach to the roads or settlement area. It is apparent that the settlement area was located in the danger zone. Although some preventative measures can be applied to reduce rockfall hazard, it was directly depend on topographical and lithological factors of the potential rockfall source area. Also the aesthetic and socio-economic conditions were limited to the existing preventative measurements. Construction of trenches, retaining walls (barrier), wire meshes, cable/streching nets, rock bolting and evacuation of the danger zone can be used as preventive measures in the rockfall areas. But, the most widely-known remedial measures in literature are not proper in the study area, due to topographical and lithological features. Thus, to apply trenching and fencing is not possible due to the big size of hanging blocks have relatively high kinetic energy and bounce height. Rock bolting can not be applied higher elevations because the slopes have considerably steep cliffs and large block sizes. Therefore, it is recommended that the hanging blocks in the reachable locations should removed taking safety measures. Although total evacuation of the danger zone is not preferred by the residents, in opinion of the authors of this study, it is indispensible in the study area.

Results and conclusions

Ermenek is a spectacular settlement area located in very steep cliffs with a height of 1850 m. The settlement was subjected to rockfall event several times and resulted in loss of life and property. During the fieldwork and depending on laboratory test results, the rockfalls were initiated by discontinuities, weathering process and characteristics of limestone having different lithological facieses. Considering the scan-line survey, five main discontinuity sets were determined. To understand of rockfall mechanism, relevant with lithological features, X-ray diffraction and thin-section analyses were taken into consideration and revealed that the limestone formation are formed by four lithological units such as, fossiliferous limestone, claystone-marl, clayey limestone and limestone. Thus rockfall occurs uppermost level of limestone and fossiliferous limestone due to existence of weaker claystone-marl at the lower level of the facies.

Two dimensional rockfall analyses were performed using the data collected from field study and laboratory test results along 10 profiles. Rockfall analyses were indicated that the roads and the settlement area were remaining in the rockfall danger zone. Considering topographical and lithological limitations, commonly used remedial measures are not

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preferred in present study. Total evacuation and cleaning the loose blocks in accessible locations are recommended.

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Table 1 Results of the thin-section petrographic and X-ray analyses

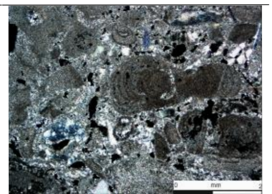
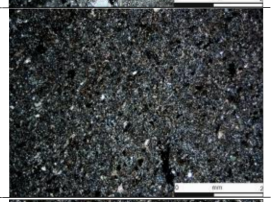
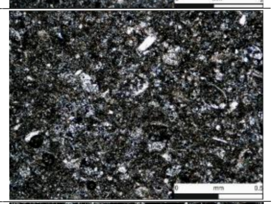
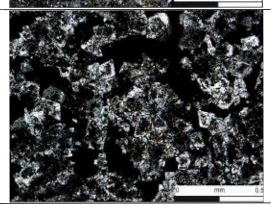
Specimen No	Petrographic description	X-ray analsis result	Microscopic photograph
HK05-1	Limestone	Calcite, Quartz	
HK05-2	Clayey Limestone	Calcite, Qartz Chlorite, Dolomite	
HK05-3	Claystone-Marl	Calcite, Dolomite, Simectite	
HK05-5	Fossiliferous Limestone	Calcite, Dolomite	

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Table 2 Laboratory and field test results

	Limestone				Clayey limestone				Claystone-Marl				Fossilliferous Limestone			
	Max.	Min.	Average	Standart Deviation	Max.	Min.	Average	Standart Deviation	Max.	Min.	Average	Standart Deviation	Max.	Min.	Average	Standart Deviation
Unit weight (kN/m^3)	24,3	23,2	23,9	0,31	22,0	21,2	21,5	0,22	20,7	20,2	20,4	0,19	23,6	20,5	22,2	0,99
Void ratio (%)	7,26	3,70	5,33	1,16	19,05	16,62	17,67	0,77	24,37	20,02	21,47	1,28	21,99	7,36	11,88	3,40
Porosity (%)	6,77	3,57	5,05	0,96	16,00	14,25	14,98	0,55	19,59	16,68	17,67	0,86	18,02	6,85	10,47	3,77
Water absorption by weight (%)	2,86	1,45	2,07	0,42	7,39	6,48	6,81	0,29	9,44	7,89	8,48	0,44	8,63	2,86	4,70	1,97
Water absorption by volume (%)	6,77	3,57	5,05	0,96	16,00	14,25	14,98	0,55	19,59	16,68	17,67	0,86	18,02	2,86	10,47	3,77
Uniaxial compressive strength (MPa)	73,4	46,2	55,3	10,58	39,8	32,4	36,1	2,57	27,4	18,1	22,2	3,90	59,6	29,4	48,1	12,08
Schmidt hammer rebound number	55				39				25				48			
Number of Samples	13				11				11				10			

Table 3 Input parameters used in the rockfall analyses

Parameter	Value
Number of rockfall	1000
Minumun velocity cut off (m/s)	0.1
Coefficient of normal restitution	0.33±0.04
Coefficient of tangential restitution	0.63±0.19
Friction angle(Φ)	32.5˚
Slope roughness	2
Initial velocity (m/s)	0 ± 0.5

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Table 4 Results of the rockfall analyses

Profile Number	MaximumSlope Height (m)	Weight of block (kg)	Runout distance (m)		Bounce height (m)		Kinetic energy(kJ)		Velocity (m/s)	
			Max	Min	Max	Min	Max	Min	Max	Min
		100	683	170	7	0,5	14000	1000	16	1
1	88	1000	585	195	3	0,5	120000	5000	14	2
		10000	480	160	7,25	0,5	1400000	10000	16	2
		100	535	233	2,8	0,5	2200	1025	6,3	2
2	33	1000	280	233	3	0,5	18200	1247	7,21	1,02
		10000	277	222	3,2	0,45	62033	6300	3,27	1,03
		100	272	115	13,25	1,23	14027	60150	16,29	8,23
3	334	1000	275	48	19	2	1750000	7350	46,3	8,23
		10000	263	72	108,5	13,5	11200000	860000	63,5	9.87
		100	323	75	68,3	4,3	34500	6350	28,43	3,45
4	145	1000	312	80	11,8	3,05	583400	54000	34,42	3,02
		10000	325	82	13,8	6,32	6973000	425000	33,25	2,1
		100	273	32	57,32	11,3	64300	8920	36,32	12,32
5	123	1000	281	40	68,32	4.06	670000	33000	33,24	4,2
		10000	283	45	68,3	4,23	6270000	4350000	33,5	6,7
		100	235	12	8	2	102500	5000	46	3,8
6	103	1000	232	11	6,4	1,8	958000	5800	45	4,2
		10000	88	43	18	3,2	10500000	560000	43,5	3,8
		100	7,8	2,8	1,2	0,2	8320	1823	12	5
7	336	1000	7,5	1	1,1	0,18	83000	31000	11,5	7
		10000	7,6	1,2	0,8	0,2	7000000	480000	11,5	3
		100	77	23	15	3,8	14300	3200	16,7	2,9
8	104	1000	76	24	55	12	870000	38000	45	5
		10000	34	27	57	8	8650000	43000	42	7
		100	249	215	18	3	72000	11000	38	11,5
9	95	1000	248	235	21	3,2	630000	42000	36	8
		10000	248	234	24,5	0,5	7120000	1050000	37	12
		100	670	480	1,9	0,5	24500	1800		
10	68	1000	660	510	2,4	0,5	653000	43500	34,5	5,2
		10000	660	512	3	0,25	6250000	254000	34	4,3

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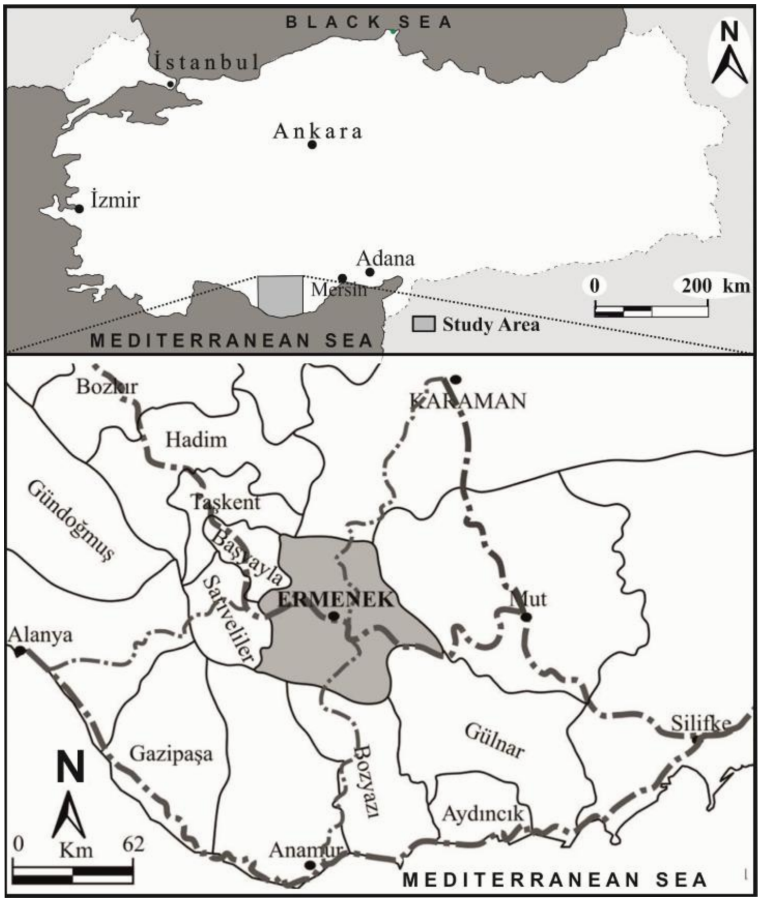

Fig.1 Location map of the study area

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Fig.2 General view of the study area

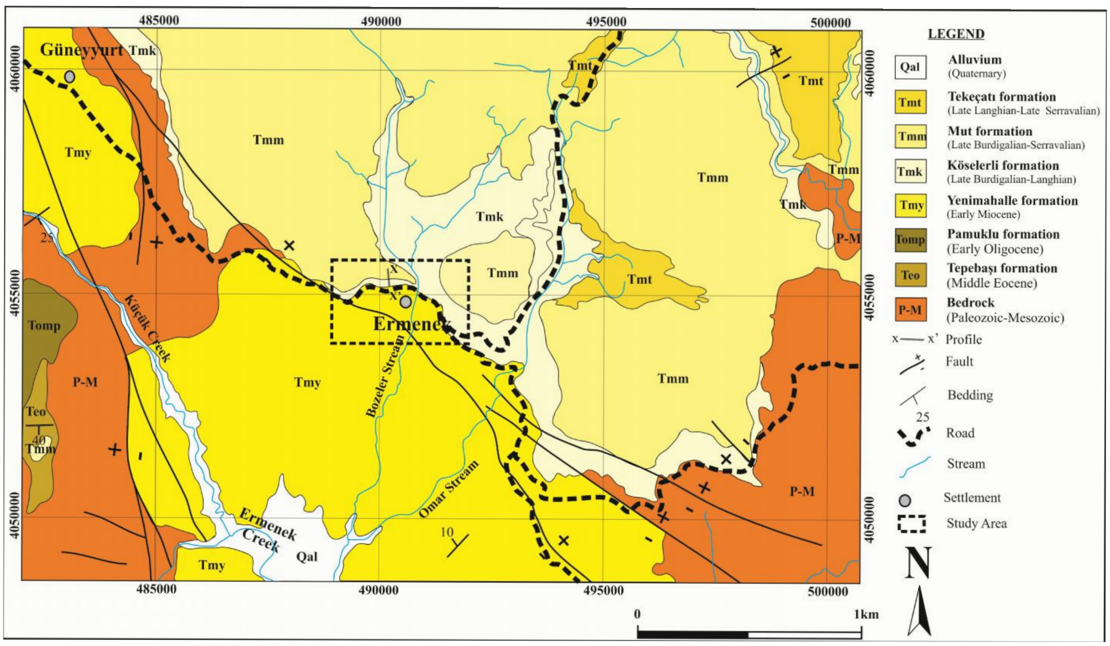

Fig.3 Geological map of the Ermenek region

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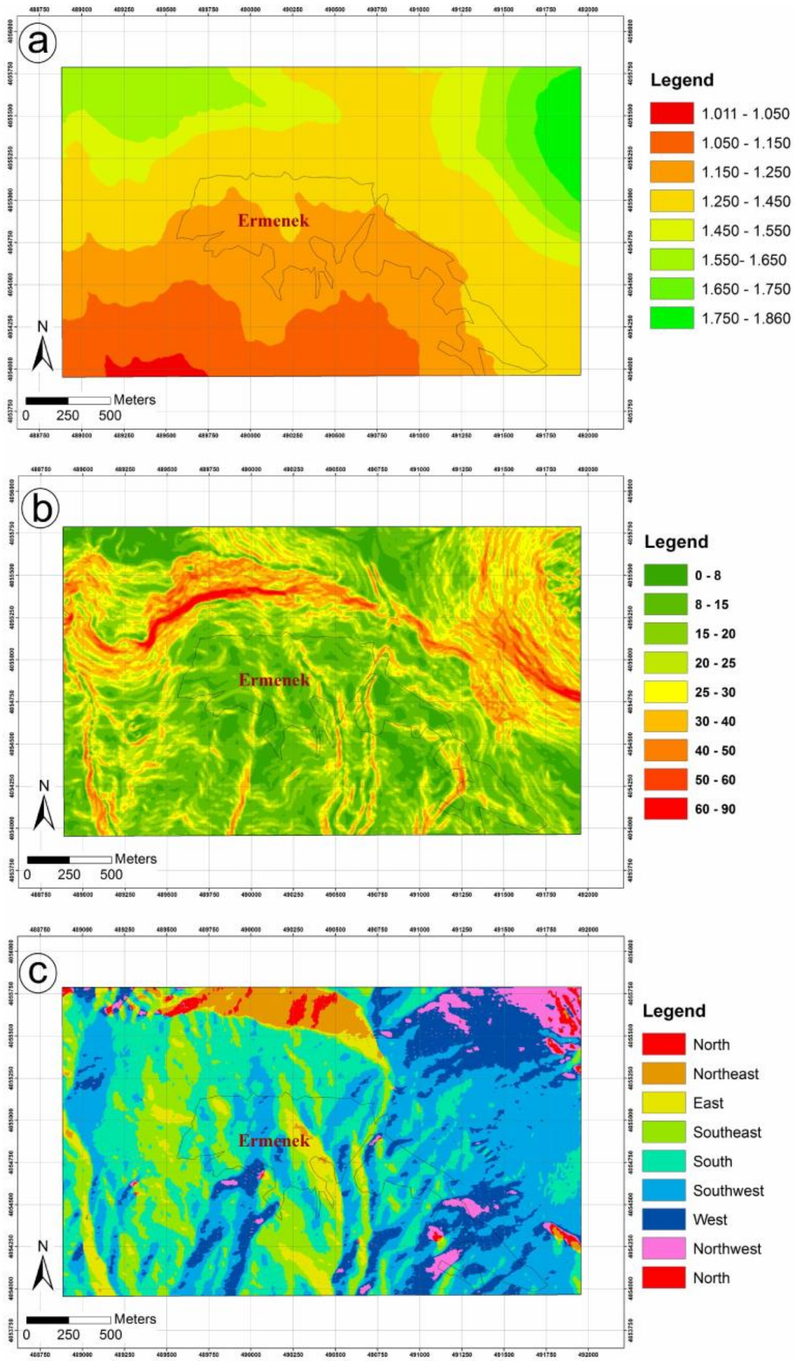

Fig.4 Maps of the study area, and their distributions of (a) altitude, (b) slope gradient, (c) slope aspect

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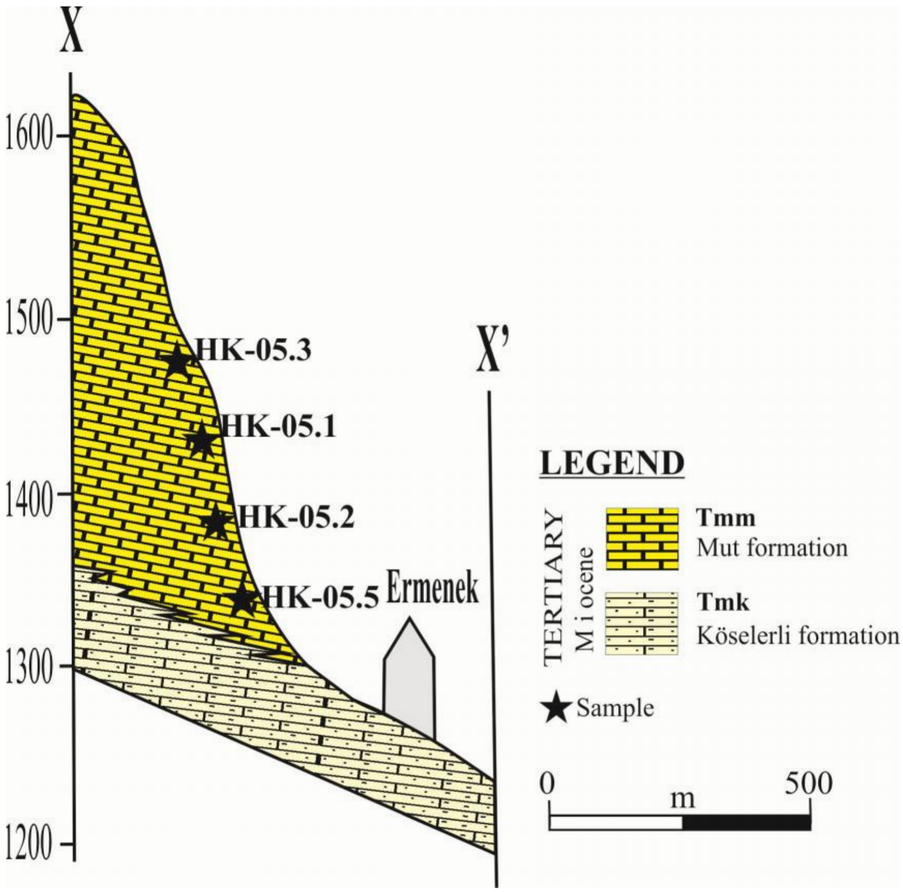

Fig.5 Systematic sampling locations along X-X' line

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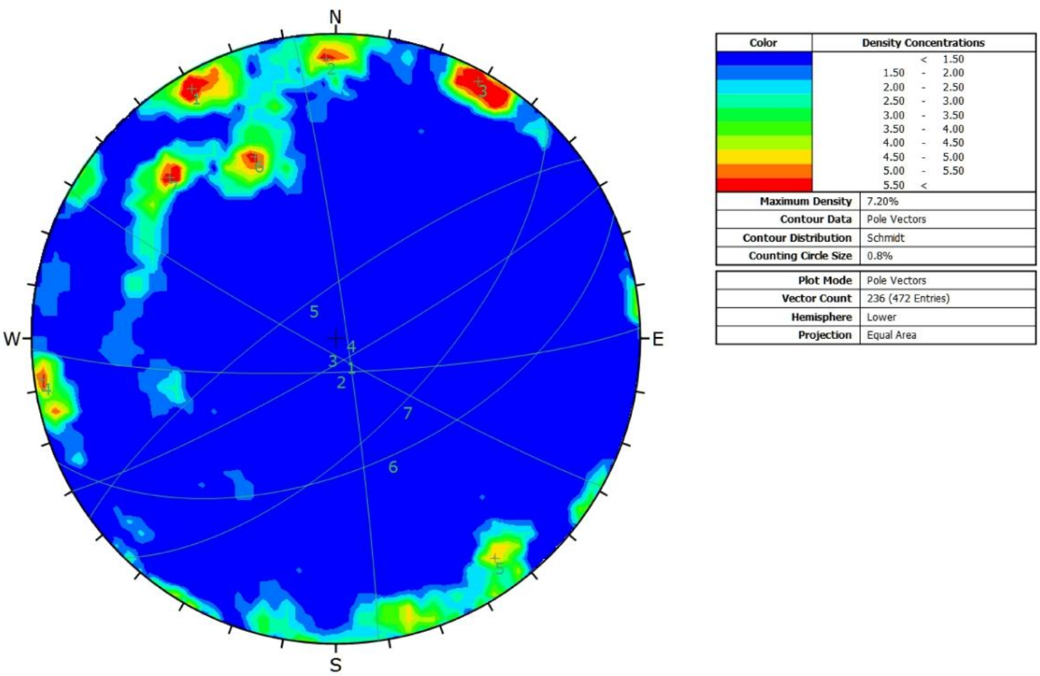

Fig.6 Contour diagram of major discontinuity sets

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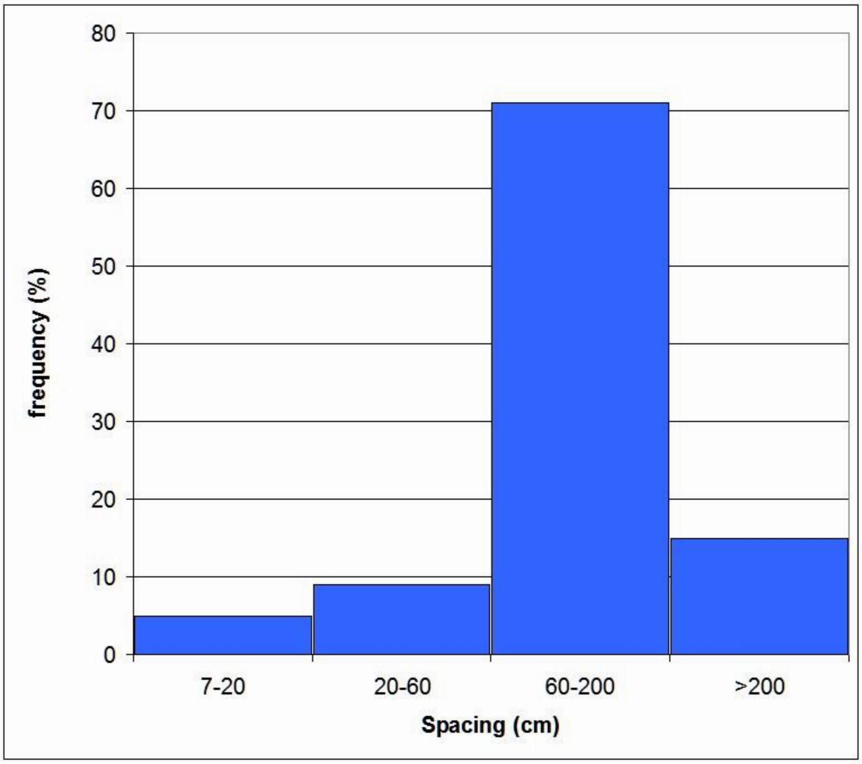

Fig.7 Discontinuity spacing histogram

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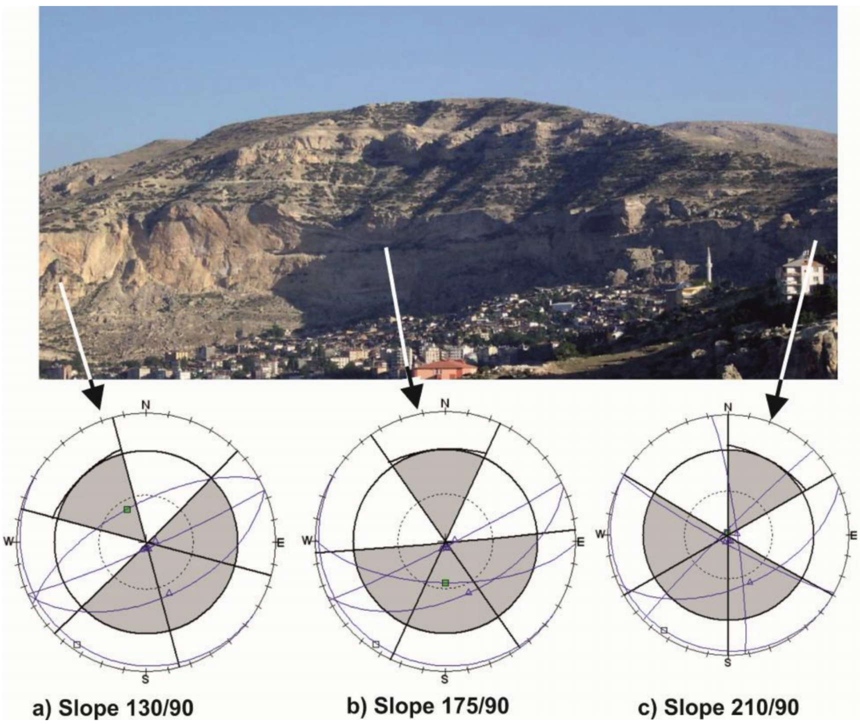

Fig.8 Kinematic analysis results of the slopes

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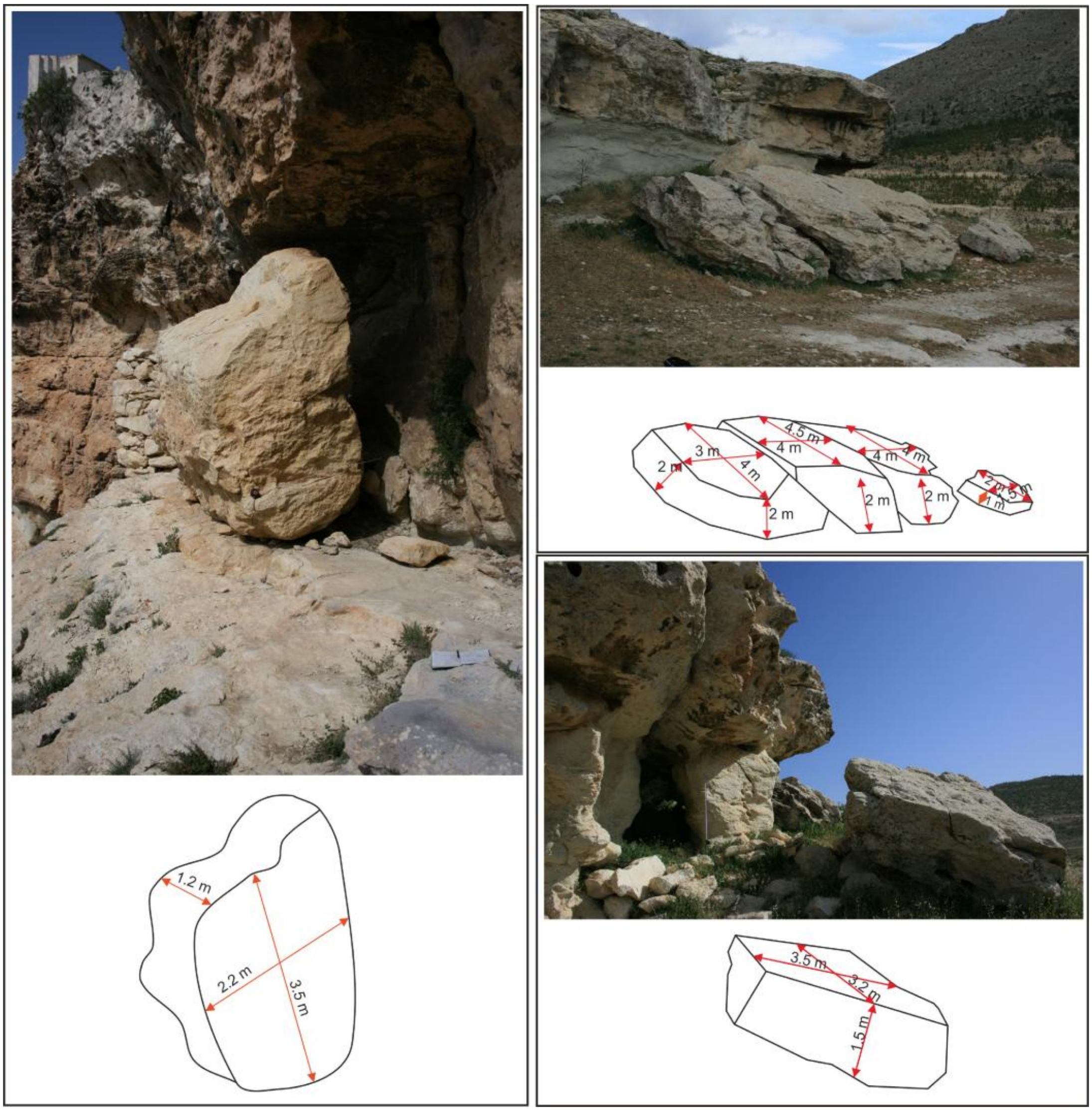

Fig.9 Fallen blocks and their sizes

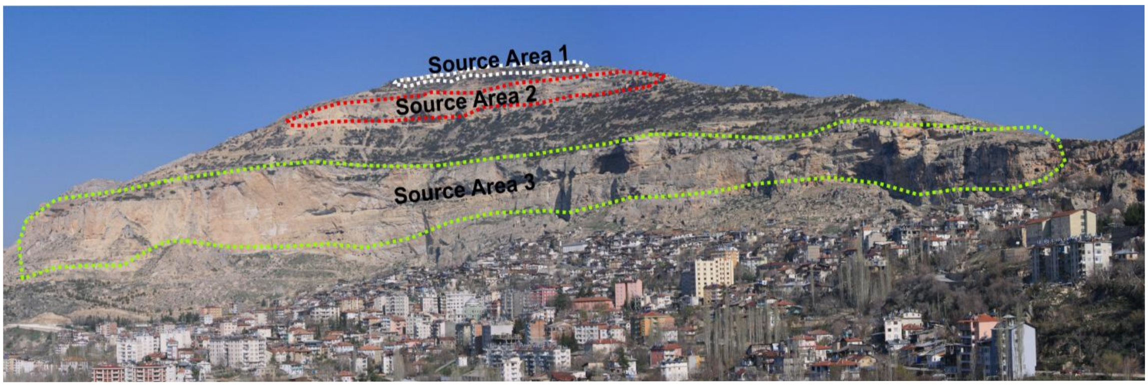

Fig.10 Rockfall source areas of the Ermenek region

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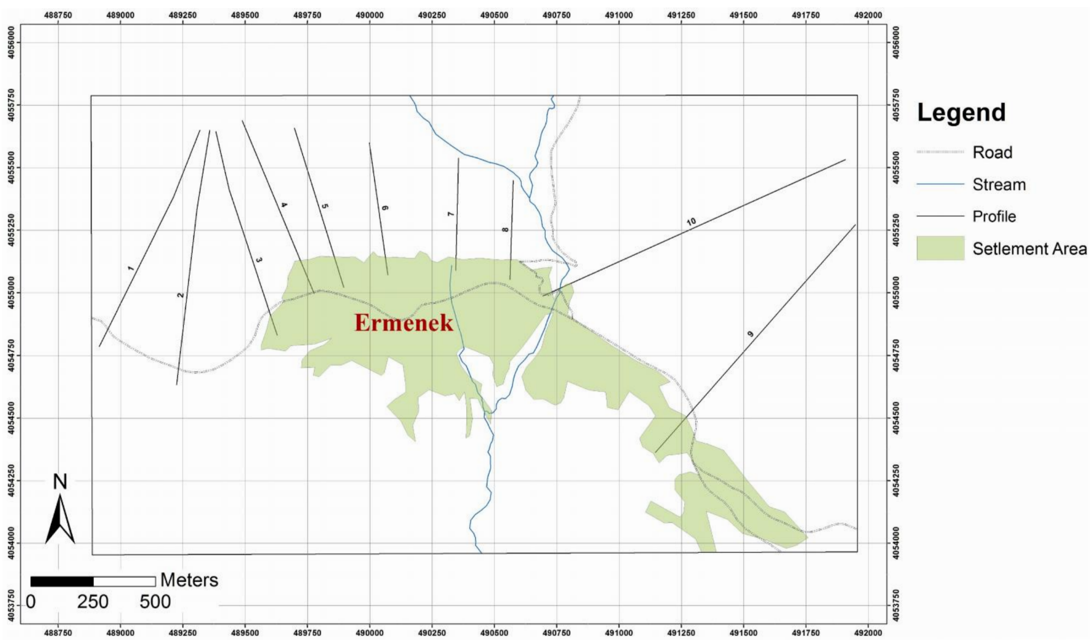
533 

534 **Fig.11** Rockfall profiles analyzed in the study area

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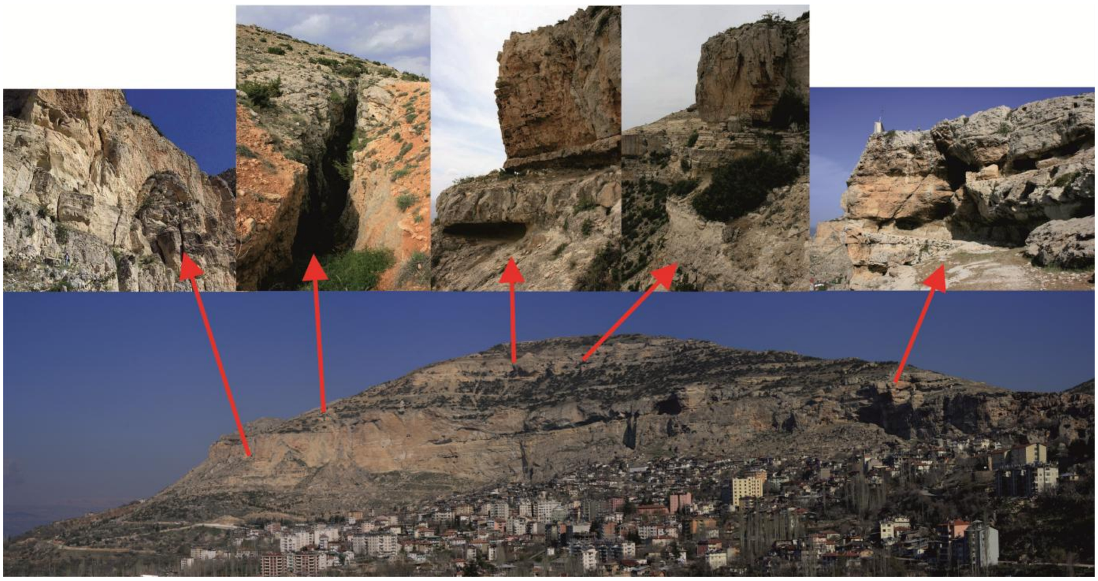

536
537
538 **Fig.12** Photograph showing hanging blocks and their location in the study area

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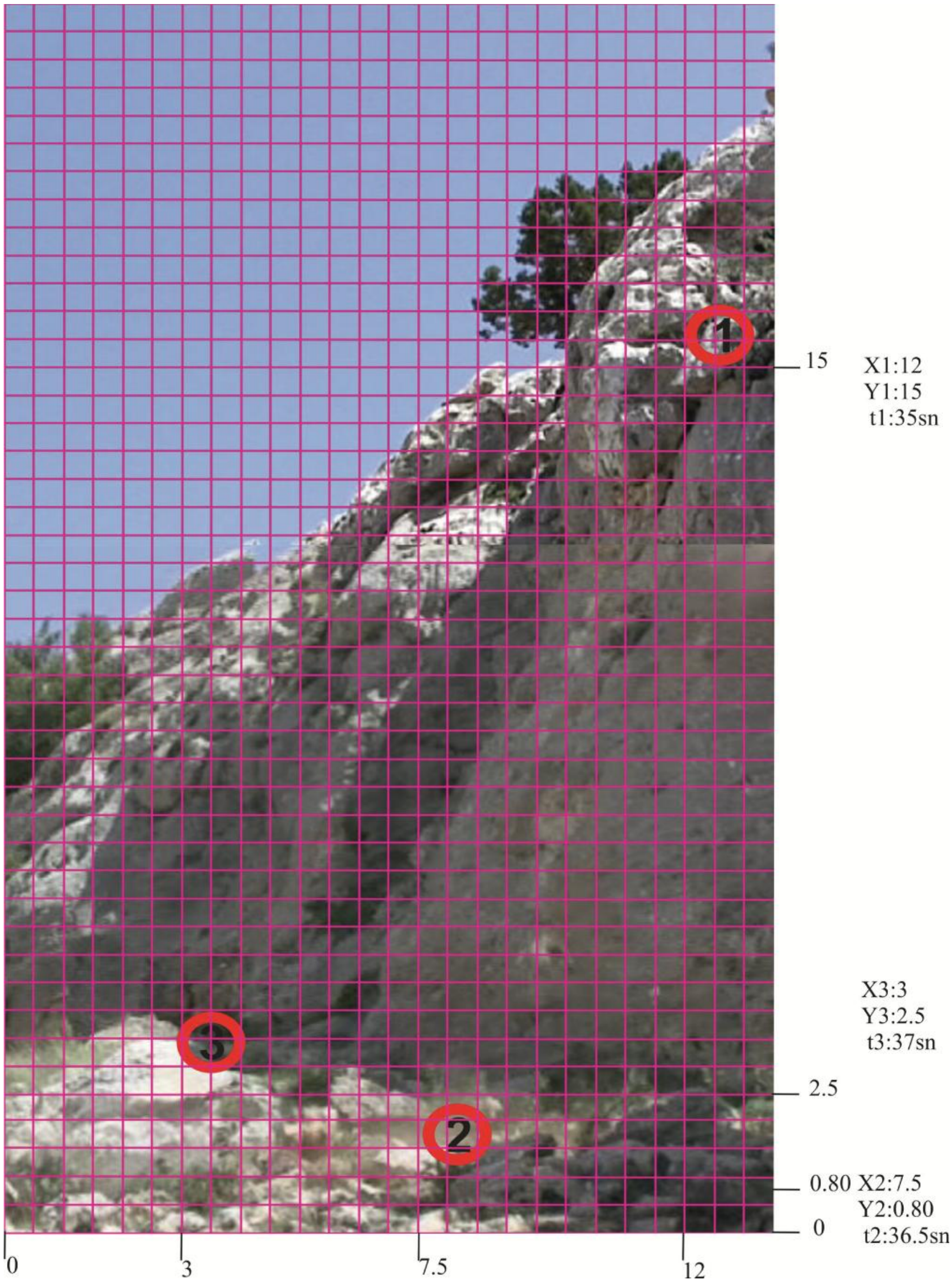

Fig.13 Back analyses in the field to determine the coefficient of restitutions

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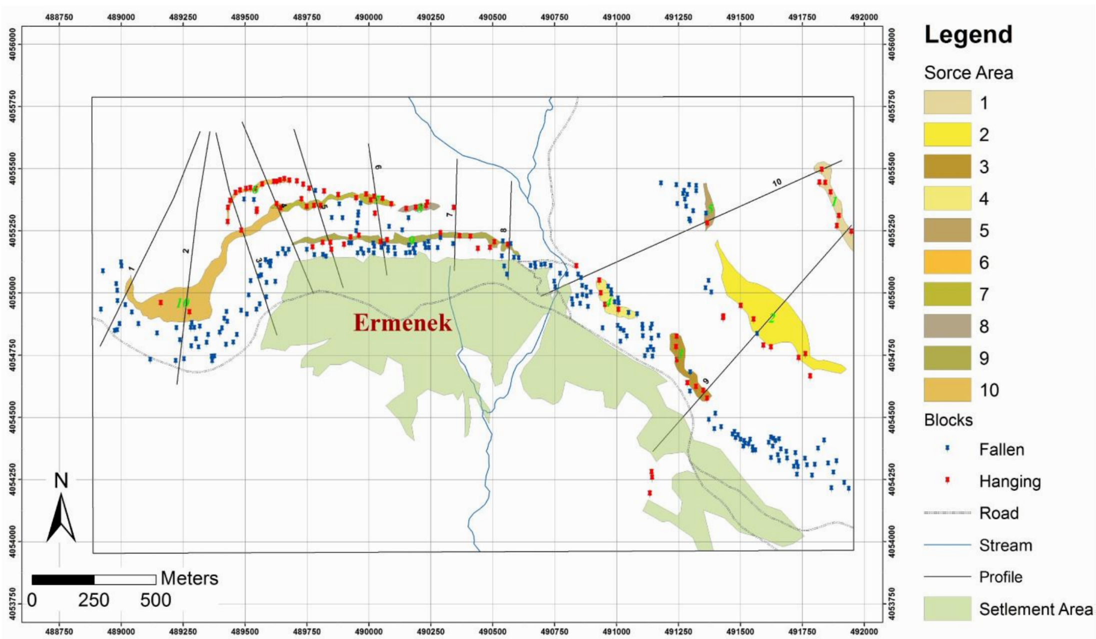

Fig.14 Distribution of fallen and hanging blocks of the rockfall source areas

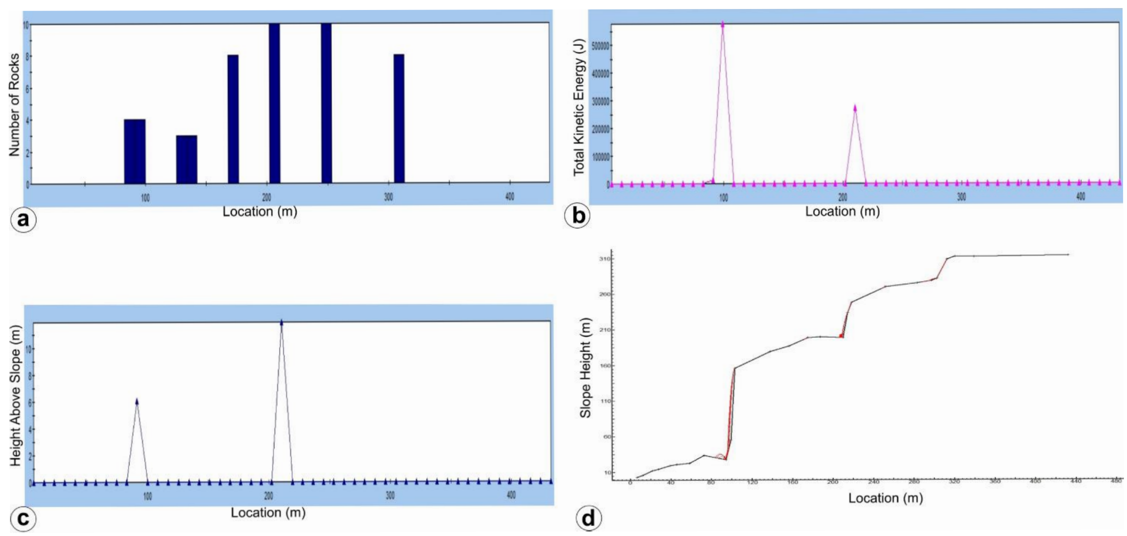

Fig Fig.15 An example for the rockfall analyses results (a) runout distance (b) total kinetic energy (c) bounce height (d) the typical rockfall trajectory

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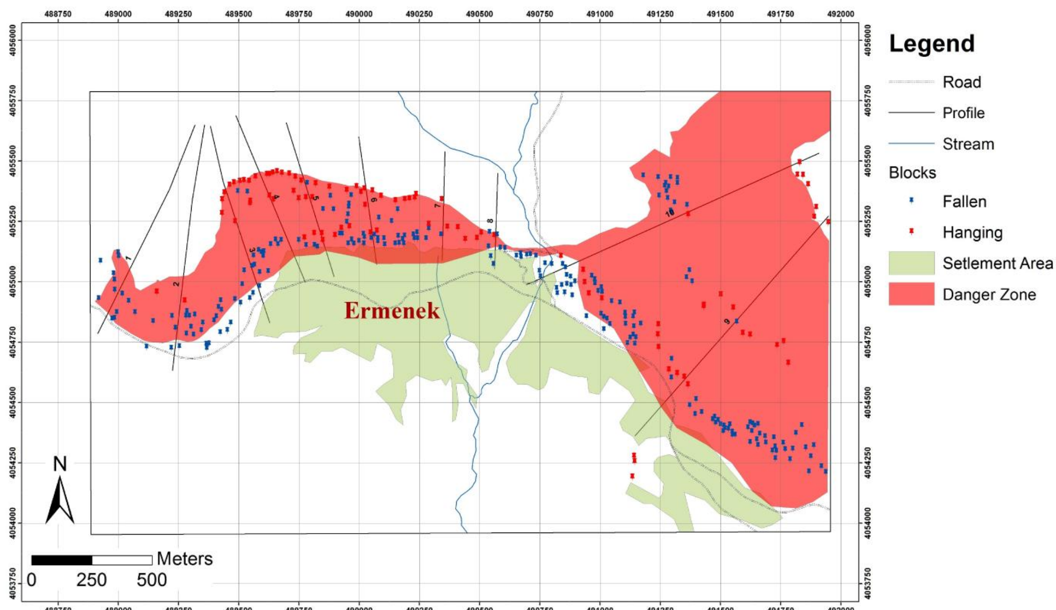

Fig.16 The map showing the rockfall danger zone of study area