

# Lithological properties and environmental importance of the Quaternary colluviums (Muğla, SW Turkey)

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**Abstract** The colluviums are one of the common Quaternary deposits of the SW Turkey grabens. The protection of the colluviums is important for agriculture, ecology and safety of constructions. This study concentrates on the sedimentary properties of colluviums and environmental issues relating to them. The colluviums of the Muğla crop out in the northern-normal faulted margin of the Muğla Polje. These colluviums form wedge-shaped and narrow small strips (total 6 km in length, 250–300 m in width and 20 m thick), and contain four main facies delineated with respect to the field observations. These facies are A-Boulder facies, B-Cobble facies (gravel  $\geq 94$  % including cobble 10–46 %; mud + sand  $< 6$  %), C-Granule–pebble facies (gravel 83–94 %; mud + sand 6–17 %), and D-Fine-grained facies (matrix dominated; gravel  $< 83$  %; mud + sand  $> 17$  %). Three representative sections were measured and 14 sieve analyses were made during this study. These colluviums include poorly to very poorly sorted angular limestone fragments bearing breccia. The colluviums are underlain by crystallized Liassic limestone and laterally passing into the alluvial sediments in a downdip direction. Tectonic activity, climate, gravitational forces and host rock characteristics are the primary controlling factors in the development of colluviums in Muğla. Agriculturally fertile soil derived from colluviums has decreased due to new residential areas and road construction. Moreover, excavations due to urbanization are causing many stability problems (landslides,

debris flows, and rock fall–slides). The heavy rainfall and seismicity of the area increase the effects of these stability problems.

**Keywords** Colluvium · Polje · Normal fault · Quaternary · Muğla, SW Turkey

## Introduction

Colluvial and alluvial sediments have formed preferred settlement areas since ancient times (Mackel et al. 2003). The colluvium includes a non-homogeneous mixture of soil, loess, cobbles and boulders and may form in front of the slopes of moderate to steep grades (Blair and McPherson 1994; Clemmensen et al. 2001; Löwner et al. 2005; Nichols 2005; Pope and Wilkinson 2005). Soil derived from the colluvial sediments has been agriculturally productive for settlers and can easily be excavated for buildings (Bauziene 2002). The colluvial sediments also bear the records of the environment, climate, human activities (deforestation, land use) and geomorphological processes (Nemec and Kazancı 1999; Clemmensen et al. 2001; Leopold and Völkel 2007; Emadodin et al. 2011; Gradziński et al. 2014). The slope-waste sediments on and in front of a hill including colluviums are classified depending on their geometry, sediment type and transporting agency (Lapidus and Winstanley 1990; Nemec and Kazancı 1999; Çiftçi 2003). These sediments can occur worldwide, from the cold climatic polar region to the hot or wet equatorial region (Gradziński et al. 2014). However, their preservation potential is low due to their lithification process (Gradziński et al. 2014).

The mass wasting processes in the colluvial sediments (landslides, slope failures including debris flow, soil and

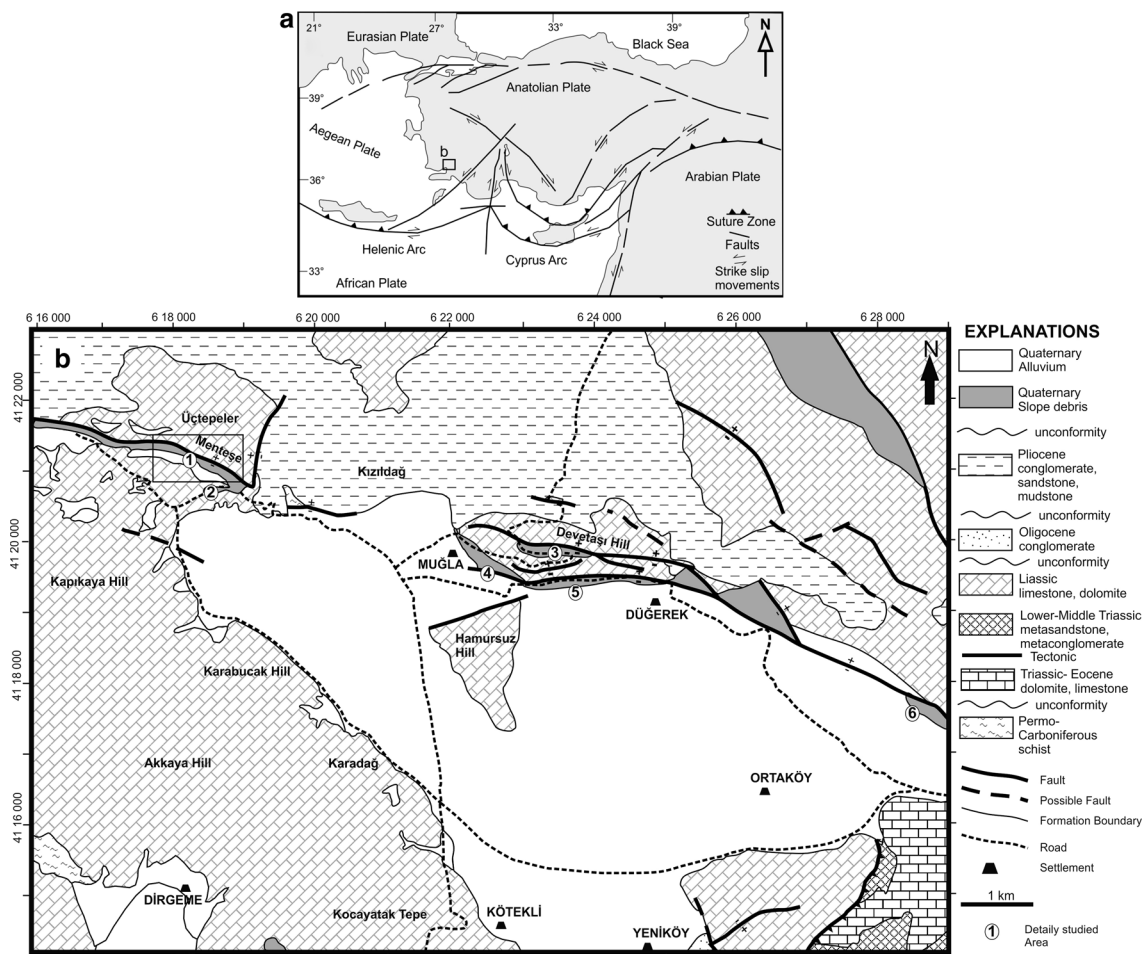
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rock slides) have threatened public life in different parts of the world (Nemec and Kazancı 1999; Karikari-Yeboah and Gyasi-Agyei 2000; Schulz et al. 2008; Baeza et al. 2010; Lara and Sepulveda 2010; Du et al. 2013; Sun et al. 2013). The landslides and destabilization of colluvium sediments are caused by heavy rainfall or climatic conditions (China, Keqiang et al. 2008; Germany, Mitusov et al. 2014), human activities (Germany, Zolitschka et al. 2003), layering structure and morphology of the colluvium (Virginia, USA, Gray and Gardner 1977; Hawaii, USA, Kaya and Kwong 2007; Turkey, Topsakal and Topal 2014) and earthquakes (China, Xu et al. 2014). The nature, sedimentary facies, engineering geological properties, and controlling factors of the colluviums must be adequately studied to prevent mass wasting. Moreover, Gradziński et al. (2014) have emphasized that geographers and geomorphologists have studied surficial processes of colluviums, while their

sedimentary facies and their ancient equivalents have not been studied in detail.

SW Turkey (Fig. 1a) contains several active elongated grabens that are filled with Neogene to Recent, shallow marine, continental deposits including colluvial and alluvial deposits (Nemec and Kazancı 1999; Bozkurt and Mittwede 2005; Sözbilir 2005; Alçiçek 2007; Taymaz et al. 2007). The fault orientation, host rock type, fluvial pattern, and several other factors control the sedimentation in these grabens. The Muğla and its surroundings is one example of these grabens (Bozkurt and Mittwede 2005; Sözbilir 2005). The older rock distributions and stress distributions may prevent longer faults and the development of elongated grabens in this region. The NE–SW-directed ellipsoidal, wide, plain polje restricted by normal faults has developed on the karstified Mesozoic carbonates (Fig. 1b).



**Fig. 1 a** Location map of the study area, including main tectonic features of Turkey and surrounding region (modified from Savasçin and Oyman 1998). **b** General geologic map of the city centre and surrounding regions (modified from Aktimur et al. 1996; Gül et al.

2013; geologic maps obtained from <https://www.mta.gov.tr>). 1 Menteşe Cooperative Region, 2 Boulder facies observed in the southeast of the Menteşe Cooperative Region, 3 Devetaşı Hill, 4 Düğerek Road Quarry, 5 Düğerek Road Cut Slope, 6 Quarry

The centre of the Muğla Polje is filled by well-rounded alluvial sediments, while the basin margin (especially the northern margin) is filled with NW–SE-oriented narrow strips or step-type, angular colluvial wedge sediments (Fig. 1b; Aktimur et al. 1996; Gül et al. 2013). Most of the old Muğla houses and new Menteşe Cooperative houses are situated on the colluviums. Thus, determination of the local lithological properties of the colluvium is very important for the safety of these structures. A similar situation is observed in other parts of western Anatolia. The purposes of this study are to explain variations in the sedimentary facies of the recent colluviums, and discuss control factors on the sedimentation and their environmental importance.

## Materials and methods

### General properties of the study area

The population of the central Muğla Province is approximately 99,900 (TURKSTAT 2013). This number is expected to increase in coming years. Throughout the province of Muğla, a Mediterranean climate prevails, with hot and dry summers, and rainy winters. The average temperature range is  $-10.0$  to  $41.2$  °C (56 years average; MGM 2013a); the annual average rainfall is 1130.5 mm (40 years average; MGM 2013b). Three main regions, namely the Menteşe Cooperative Region (NW), Düğerek District (central), and Quarry (SE) have been selected for detailed studies of colluvium (Fig. 1b).

### Research methods

The lateral and vertical continuity of the colluviums has been revealed by the field studies. Fourteen loose colluvial sediment samples were collected for sieve analysis in different parts of the study area (Table 1; Figs. 1b, 2). The sieve analysis was performed in the General Geology Laboratory of the Department of Geological Engineering of the Muğla Sıtkı Koçman University. A frequency (%) versus grain size ( $\emptyset$ ) graph, cumulative retaining percentage (%) versus grain size ( $\emptyset$ ) graph, cumulative passing percentage (%) versus grain size (mm) graph, and the classification of the colluviums based on Folk (1974) are presented in Fig. 2. Sieve analysis results and statistical evaluations of them are given in Table 1. Raw data from sieve analysis are presented in the appendices; weight of retained material (g)—Appendix Table 3; frequency percentage (%)—Appendix Table 4; cumulative retained weight percentage (%)—Appendix Table 5; cumulative weight passing percentage (%)—Appendix Table 6; and statistical values obtained from Fig. 2—

Appendix Table 7. Four sedimentary facies were separated according to grain size (Tables 1, 2) in the colluvium examined. The colluvial sediments were photographed in detail for the facies description (Figs. 3, 4); three sedimentary sections were measured in the central part colluviums (Fig. 5).

## General geology

The Kavaklıdere Group (Permo-Carboniferous) is the oldest unit of the study area, containing graphite schist (Fig. 1b; Aktimur et al. 1996). The Marçal Group (Triassic–Eocene) includes limestone, dolomite, dolomitic limestone and clastics (Aktimur et al. 1996; Şenel and Bilgin 1997). The Ören Group is made up of the Lower–Middle Triassic metasandstone–metaconglomerate of the Karaova Formation; and the Liassic Gereme Formation containing calcite-filled fractured, gray, rudist, extraclast (quartz) and stylolite-bearing, cleaved, fine-to-medium-crystalline or micritic, crystallized limestone–dolomitic limestone (Aktimur et al. 1996; Gül et al. 2013). The Gereme Formation is a main source of the colluviums (Figs. 1b, 3, 4). All old units are a part of the Lycian Nappes transported from the northern region (Şenel and Bilgin 1997).

The Mortuma Formation (Oligocene) consists of an alternation of sandstone and conglomerate (Aktimur et al. 1996). The Milet Formation (Pliocene) comprises mainly conglomerate, sandstone and claystone, marl and limestone (Aktimur et al. 1996). The Quaternary deposits include colluviums, alluvial fan deposits and alluviums unconformably covering older units (Fig. 1b; Aktimur et al. 1996; Gül et al. 2013). The colluviums have accumulated at the front of the faulted basin margin in a wedge shape and contain angular/sub-angular, poorly sorted gravel, muddy gravel and locally breccias (Gül et al. 2013). The alluvial fan deposits have been locally deposited in front of the Gereme Formation without fault and are made up of sub-rounded/sub-angular sediments (Aktimur et al. 1996). The alluvial sediments occur as a downdip continuation of the colluviums and alluvial fans and contain moderate to poorly sorted, rounded to sub-rounded, conglomerate, sandstone and claystone alternations (Fig. 1b; Aktimur et al. 1996; Gül et al. 2013).

## Properties of the Quaternary colluviums of the Muğla

First, field observations and the results of sieve analysis are presented. Then, four facies delineated according to grain size are described.

**Table 1** Grain size percentages and statistical evaluation of the sieve analysis results of the all colluvium samples

Sample no	Northwest			Central				Southeast						
	Menteş Cooperative			Devetaş Hill (DH)				Düğerek Road (DR)						
	1- Finest part	2- Medium-grained part	3- Coarsest part	4-DH section I	5-DH section I-a	6-DH section II	7-DR Quarry finest part	8-DR Quarry coarsest part	9-DR Road Cut Slope finest part	10-DR Road Cut Slope coarsest part	11-Quarry I-coarsest part (basin margin)	12-Quarry I-finest part (basin margin)	13-Quarry II-coarsest part (extension)	14-Quarry II-finest part (extension)
Cobble 64–256 mm	0.0	0.0	42.0	0.0	0.0	20.0	0.0	23.0	0.0	46.0	0.0	0.0	10.0	0.0
Pebble 4–64 mm	68.0	87.0	54.0	83.0	50.0	76.0	61.0	71.0	66.0	52.0	93.0	64.0	81.0	75.0
Granule 2–4 mm	13.0	6.0	1.0	5.0	18.0	1.0	13.0	1.0	12.0	0.5	2.0	12.0	3.0	8.0
Very coarse sand 1–2 mm	7.0	2.0	1.0	3.0	10.0	1.0	4.0	1.0	5.0	0.5	1.0	7.0	2.0	4.0
Coarse sand 0.5–1 mm	7.0	2.0	0.5	3.0	9.0	0.5	4.0	1.0	4.0	0.5	1.0	6.0	1.0	5.0
Medium sand 0.25–0.5 mm	1.0	1.0	0.5	2.0	6.0	0.5	6.0	1.0	2.0	0.5	1.0	2.0	1.0	3.0
Fine sand 0.125–0.25	1.0	1.0	0.5	2.0	4.0	0.5	7.0	1.0	4.0	0.0	1.0	3.0	1.0	2.0
Very fine sand 0.0625–0.125	2.0	1.0	0.5	1.0	2.0	0.5	3.0	1.0	3.0	0.0	1.0	3.0	0.5	1.0
Silt + clay <0.0625 mm	1.0	0.0	0.0	1.0	1.0	0.0	2.0	0.0	4.0	0.0	0.0	3.0	0.5	2.0
Gravel %	81.0	93.0	97.0	88.0	68.0	97.0	74.0	95.0	78.0	98.5	95.0	76.0	94.0	83.0
Sand %	18.0	7.0	3.0	11.0	31.0	3.0	24.0	5.0	18.0	1.5	5.0	21.0	5.5	15.0
Silt + clay %	1.0	0.0	0.0	1.0	1.0	0.0	2.0	0.0	4.0	0.0	0.0	3.0	0.5	2.0
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Facies type	DF	CF	BF	CF	DF	BF	DF	BF	DF	BF	BF	DF	BF	DF
Graphic mean	-1.77	-2.57	-4.87	-2.73	-0.70	-4.47	-0.93	-4.27	-1.57	-4.70	-3.93	-1.73	-3.83	-1.90
Sorting	PS	PS	MWS	PS	PS	MS	VPS	PS	VPS	PS	PS	VPS	PS	PS
Skewness	SFS	SFS	NS	SFS	SFS	FS	SFS	SFS	SFS	FS	SFS	FS	SFS	SFS
Kurtosis	MK	ELK	PK	VLK	MK	VLK	LK	VLK	MK	PK	VLK	MK	VLK	LK
Sediment classification	G	G	G	G	mG	G	mG	G	mG	G	G	mG	G	G

**Table 1** continued

Sample no	Northwest		Central				Southeast						
	Menteşe Cooperative		Devetaşı Hill (DH)		Düğerek Road (DR)		Quarry						
1- Finest part	2- Medium-grained part	3- Coarsest part	4-DH section I	5-DH section I-a	6-DH section II	7-DR Quarry finest part	8-DR Quarry coarsest part	9-DR Road Cut Slope finest part	10-DR Road Cut Slope coarsest part	11-Quarry I-coarsest part (basin margin)	12-Quarry I-finest part (basin margin)	13-Quarry II-coarsest part (extension)	14-Quarry II-finest part (extension)
Modes (Ö)	-3.60	-3.60	-4.50	-3.60	-1.35	-4.5	-1.35	-3.6	-5.5	-4.5	-4.5	-4.5	-3.6

*AF* Boulder facies, *BF* Cobble facies, *CF* Granule-pebble facies, *DF* Fine-grained (Matrix Dominated) facies, *MWS* moderately well sorted, *MS* moderately sorted, *PS* poorly sorted, *VPS* very poorly sorted, *SFS* strongly fine-skewed, *FS* fine-skewed, *NS* nearly symmetrical, *PK* platykurtic, *MK* mesokurtic, *LK* leptokurtic, *VLK* very leptokurtic, *ELK* extremely leptokurtic, *G* Gravel, *mG* Muddy Gravel (based on Folk 1974)

**Field properties of the colluviums**

*The Menteşe region*

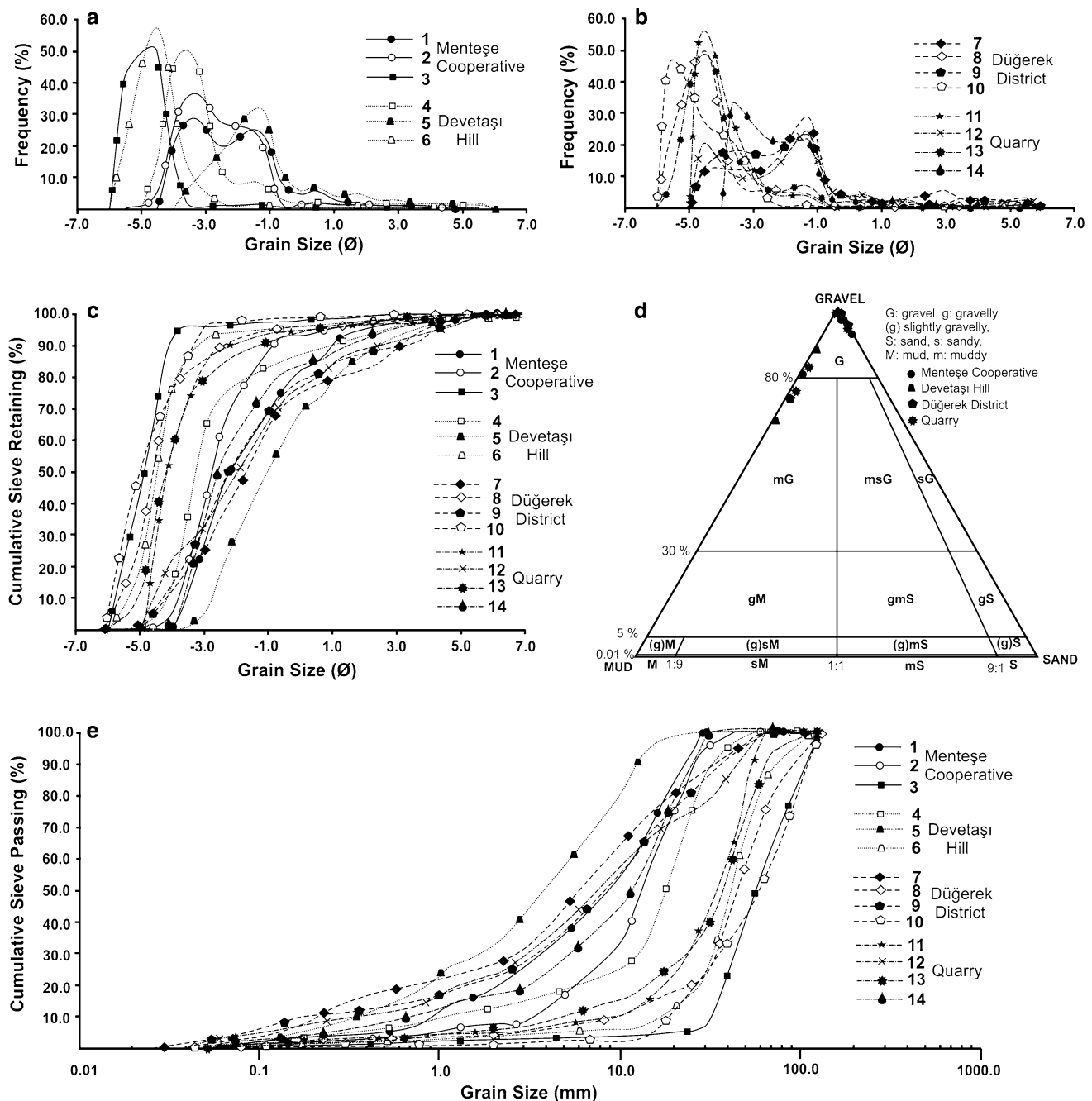
This region is a home to developing Muğla residential areas (Regions 1 and 2 in Fig. 1b). The Menteşe region is 500 m wide at its widest point, 100 m at its narrowest, and is about 2 km in length (Fig. 1b). The slope of the northern margin of the Menteşe region is 37°, and the height of host rock decreases from 970 to 720 m over a horizontal distance of 330 m. Although this section is entirely mapped as colluviums, the Gereme Formation is also observed. The Gereme Formation creates the irregular basement topography of the colluviums.

The thickness of the colluvium deposits varies from 0 to 7.0 m depending on the base topography (according to geophysical data presented in Gül et al. 2013). The coarse-grained sediment ratio of the colluviums decreases by about 100–150 m away from the edge of the basin in the downdip direction. Three representative samples were collected from the colluviums on the northern margin (Samples 1, 2, 3; Fig. 2; Tables 1, 2). Surface and ground water circulation causes cementation and the development of 1–1.5-m thick, hard, normally graded breccias at the upper part of the colluviums. Sometimes water has removed the matrix material from the coarser grain, leading to the formation of clast-supported fabrics without a matrix (sieve deposits). The groundwater and surface water in the foundations of new constructions are not taken into consideration or studied in detail. The foundation excavation for the buildings involves removing the toe of the colluviums, so that local small landslides develop.

The coarsest colluviums of the Muğla (A-Boulder facies, AF; Fig. 3) are exposed and only observed in the road cut in the south of the Menteşe Cooperative area (Region 2 in Fig. 1b). The thickness of the colluviums is about 10 m in this part. The blocks (size up to 3 m) of the fractured Gereme Formation (Fig. 3) form the main part of the colluvium. The pebbles of this formation and red-coloured sandy-muddy matrix material fill the spaces among the blocks. Very poorly sorted, normally graded colluviums laterally pass into the fine-grained colluviums.

*The Düğerek District (Central)*

This area includes three observation places: the Devetaşı Hill (Region 3 in Fig. 1b), the Düğerek Road Quarry (Region 4 in Fig. 1b), and the Düğerek Road Cut Slope (Region 5 in Fig. 1b). The Devetaşı Hill observation place is located on top of the fault step, which is bounded by two normal faults cut in the Gereme Formation (Figs. 1, 4). The other two sites are located on the northern edge of the polje along the Düğerek District Road between the northern



**Fig. 2** **a** Frequency (%) versus grain size ( $\phi$ ) diagrams of the samples from the Menteşe Cooperative and Devetaşı Hill. **b** Frequency (%) versus grain size ( $\phi$ ) diagrams of the samples from the Düğerek District and Quarry. **c** Cumulative sieve retaining a

percentage (%) versus grain size ( $\phi$ ) diagrams of the study area. **d** Classification of colluviums of the study area based on the Folk (1974) classification system. **e** Cumulative sieve passing percentage (%) versus grain size (mm) diagrams of the study area

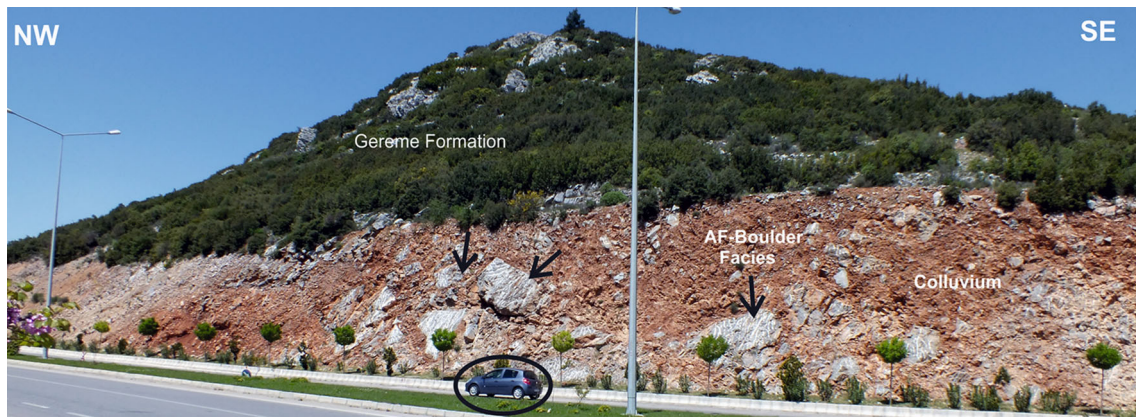
normal fault plane and southern vast plain of the polje (Fig. 1).

The colluviums in front of the Devetaşı Hill (974 m) form a narrow strip 1100–1200 m in length and 200 m in width (Fig. 1). The inclination of the slope is  $35.7^\circ$ , while the height decreases from 974 m (summit of the hill) to 830 m (road on fault step). Three sedimentary sections

were measured to show the lateral and vertical lithological changes of the colluviums (Figs. 4, 5). The Devetaşı Hill section I (10 m) was measured at the centre of the colluvium (from the small aggregate quarry) (Figs. 4a, b, 5). Two samples were collected from this section (Samples 4, 5; Tables 1, 2; Figs. 4a, b, 5). The coarse-grained facies (AF, BF and CF) have limited distribution in this section,

**Table 2** Facies separation of the study area based on sediment grain size

Facies	Boulder	Cobble (%)	Total gravel (%)	Sand + mud (%)
AF-Boulder facies	Dominant	–	–	–
BF-Cobble facies	None	10–46	≥94.0	<6.0
CF-Granule–pebble facies	None	None	83.0–94.0	6.0–17.0
DF-Gravelly fine-grained (matrix dominant) facies	None	None	<83.0	>17.0



**Fig. 3** Boulder facies (AF) bearing colluvium crops out southeast of the Menteşe Cooperative Region. *Black arrow* shows the blocks in 3 m size (height of a car: 1.5 m)

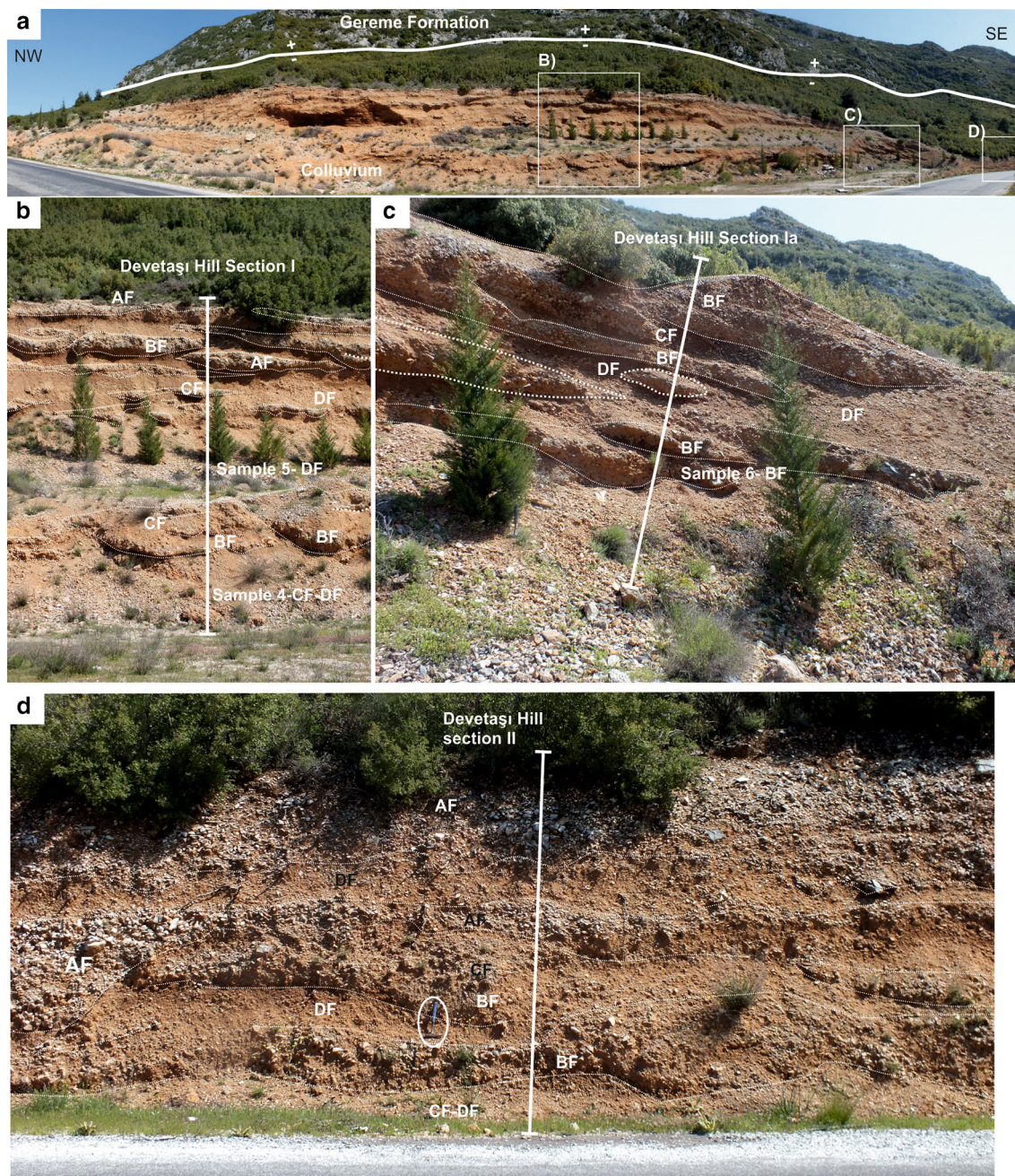
while the fine-grained matrix (DF) facies is the dominant facies (Figs. 4b, 5). The Devetaşı Hill section I (6 m) contains mainly laterally pinching out, cobble-bearing gravels with an erosive base (BF-Sample 6, CF) and to a lesser extent muddy gravel (DF) that inclines to the south as 18° (Figs. 4a, c, 5). The Devetaşı Hill section II (5 m) includes muddy gravel (DF) and cobble-bearing facies (BF), normal and reverse-graded cobble-bearing gravels (BF), then massive boulder-bearing gravels (AF) (Figs. 4a, d, 5). All three sections start at roughly the same level; however, their facies contents differ significantly. These observations emphasize that local factor (such as sediment type, means of transportation, sediments accumulated at the top of a slope, etc.) strongly affect the properties of the colluviums.

The Düğerek Road Quarry slope is 36.5°, and the altitude of the area decreases from 830 to 630 m over a horizontal distance of 270 m. The colluvium strip of this region is 1300 m in length and 300 m in width. The apparent thickness of the colluvium is 18–20 m in the centre of the aggregate quarry (150 m in length, 75 m width). The inclination of the colluvium beds is 20°–22° (to SE) towards the polje at the edge of the quarry. Normal-graded, 20–30-cm thick, cobble-boulder bearing, laterally pinching out, clast-supported gravel (breccias) form the colluviums in this quarry. Two samples were collected in this quarry (Samples 7, 8; Table 1).

The colluviums create a 150–200-m wide and maximum 15-m-thick narrow strip along the Düğerek Road Cut (2 km long) (Fig. 1). The slope of this area is 32.1°, and the height decreases from 820 to 650 m over a horizontal distance of 270 m. Two samples were collected from this colluvium wedge (Samples 9, 10; Tables 1, 2). The toe of this colluvium wedge was removed for road construction. Rock falls (from the AF–BF facies) and sediment flows (from the BF and CF facies) are observed from time to time, depending on excess water entry during the wet season, or due to seismic activities and sediment weathering. These rock falls and debris flows are threatening the road and public life. Small springs and surface runoff evolve inside the colluvium during the wet season. They cause flooding of the neighbouring lowland field. Sometimes the flooding area increases and affects houses in the district. The amount of clast-supported, coarse fractions at this site is greater than at the Düğerek Road Quarry.

*The aggregate quarry (Southeast)*

This quarry is about 300 m long and 150 m wide (Fig. 1). The slope of the source rocky surface is 26.2°, the height of the slope decreases from 1060 to 690 m over a 750 m horizontal distance. The apparent thickness of the quarry is about 10–12 m, while it increases 20 m to the polje interior according to geophysical data (Gül et al. 2013). The upper



**Fig. 4** **a** Three sections measured from colluvium accumulated on the fault step located in front of the Devetaşı Hill. The Devetaşı Hill section I was measured from the thickest colluvium exposure. The Devetaşı Hill section I a located on the southeastern side of the same exposure. Devetaşı Hill section II was measured from the lateral

continuation of the colluvium. **b** Field view of the Devetaşı Hill Section I. **c** Field view of the Devetaşı Hill Section I a. **d** Field view of the Devetaşı Hill Section II. Coarse-grained facies have an erosive base. *AF* Boulder facies, *BF* Cobble facies, *CF* Granule-pebble facies, *DF* Fine-grained (matrix-dominated) facies

part of the remnant hill contains a low inclined, 1.5-m-thick hard and cemented layer, while it contains 7–8-m-thick cross-bedded layers in its lower part. Two samples were obtained from this part (Samples 11, 12; Table 1). The colluviums contain sub-angular/sub-rounded, matrix-abundant sediments to the south (Samples 13, 14; Table 1).

Rock falls and debris flows also develop in this region; fortunately, the quarry area is far away from the road and district. The colluviums are laterally passed into the horizontally bedded alluviums in this region. Flooding due to excess water entry also has affected this region similar to the Dügerek region.



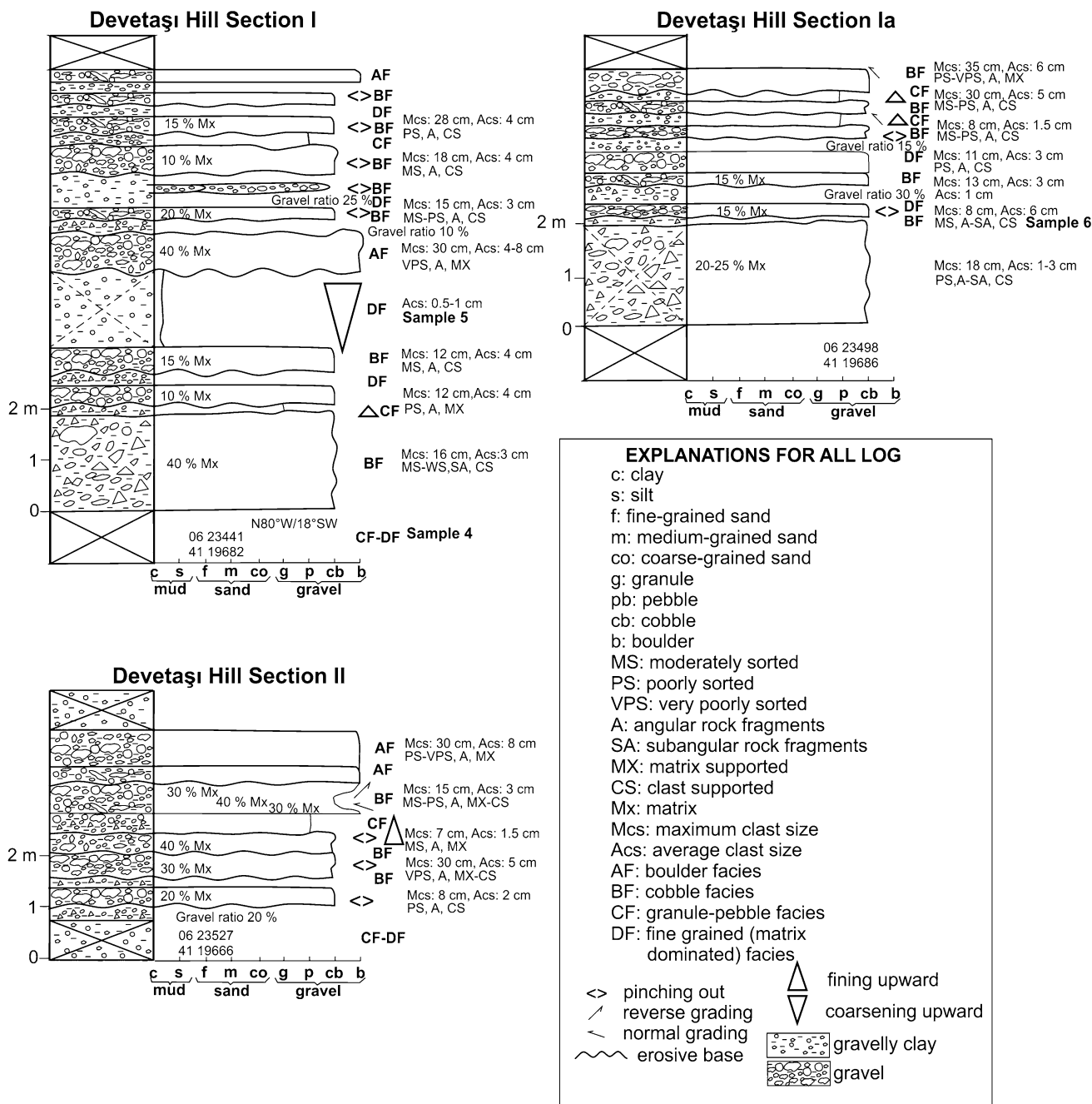


Fig. 5 Three representative sections measured from the Devetaşı Hill

**Sedimentary facies of the colluviums**

The colluviums include four main facies separated according to sediment size with varying ratios (Table 2). These are; A-Boulder facies (AF), B-Cobble facies (BF), C-Granule-pebble facies (CF), and D-Gravelly fine-grained (matrix-dominant) facies (DF). Each facies may also include several sub-facies that can be separated based on detailed sedimentary properties (such as normally graded A-Boulder facies).

*A-Boulder facies (AF)*

This coarsest facies of the study area is generally found in the lower part of the colluviums in contact with the host rock, comprising 2–3-m-sized boulders bearing disorganized, matrix-supported facies bounded by pebble-granule and fine-grained sediments in the Menteşe region with an erosive base (Fig. 3). It contains 50-cm and 1-m-thick sediments with block sizes of 30 cm to 2 m in other regions (Figs. 4, 5).

Faulting and orientation of cracks in the host rocks lead to block formation and a local distribution of colluviums. When the blocks inside this facies are released from the matrix, they cause rock falls especially in high-slope areas. Previous studies also emphasize a similar interpretation for this type of colluvium, such as local rock disintegration and rock falls (Boggs 1987; Nemeč and Kazancı 1999). They were found in the proximal part of the steep rocky areas (Nichols 2005).

#### *B-Cobble facies (BF)*

This most common, coarse-grained facies contains matrix/clast-supported, poorly to well sorted, fine to strongly fine-skewed and very leptokurtic, erosive-based, and laterally pinching out (inside DF-type facies) often disorganized and imbricated gravels (Figs. 4, 5; Tables 1, 2). The thickness of this facies is around 0–2 m (Fig. 5). The sieve deposits of this facies include angular/sub-angular cobble and pebble without or with a very small amount of matrix.

Characteristically a poorly sorted boulder and cobble-bearing sediment without a sedimentary structure is interpreted as the product of debris flows (Nichols 2005; Pope and Wilkinson 2005). Inversely graded cobble–pebble-bearing gravels were interpreted as a product of the grain flows (Nemeč and Kazancı 1999). ‘Sieve deposits’ point out the freely moving water among the grains (Boggs 1987) and are interpreted as water-laid sediments (Bull 1972). Clast-supported sediments are products of non-cohesive debris flows (Hartley et al. 2005), while the clast-supported breccia is interpreted as a product of cohesive debris flows (Sanders 2010). The matrix-supported breccia is interpreted as the product of grain flow (Sanders 2010). The thicker coarser polymodal debris flow has been interpreted as a gravitational failure of weathered bedrock at the higher mountain level (Nemeč and Kazancı 1999). A channelized, erosive base of the coarse-grained facies develops in gullies where the surface flow gathers and exceeds the resistance of the bottom sediments (Nemeč and Kazancı 1999). This facies causes debris flow (also a threat to public life) associated with CF facies during the wet season.

#### *C-Granule–pebble facies (CF)*

This second dominant coarse-grained facies does not include the cobble and boulder size sediments (Figs. 4, 5; Tables 1, 2). The facies (0–2 m thick) contains an erosive-based, matrix-supported, clast-supported, very poorly

sorted, strongly fine-skewed, often disorganized, laterally pinching out (inside the DF), crudely imbricated and normally graded breccia (Tables 1, 2).

This facies is also interpreted as a product of debris flows, like the previous facies, but in a lower energy environment (Bull 1972). Very poorly sorted gravel with mud <10 % in the Cordillera Coastal area of Chile was interpreted as a debris flow product and lobe deposits that evolved far away from the source (Hartley et al. 2005). The thinner pebbly debris flow was interpreted as a product of the failure of sediments on the fan head (Nemeč and Kazancı 1999).

#### *D-fine-grained (matrix-dominant) facies (DF)*

This fills the spaces between the coarse-grained facies (Figs. 3, 4, 5). The sand ratio of this facies is higher than that of the others (Tables 1, 2). This facies is made up of poorly to very poorly sorted, matrix-supported, fine-skewed to strongly fine-skewed, mainly mesokurtic, bimodal (pebble and granule) muddy gravel (Table 1).

The DF facies is interpreted as the product of the lowest energy debris flow (Boggs 1987). However, Hartley et al. (2005) mentioned that sheet flow deposits contain angular, clast-supported gravel and gravelly sand (as in the Muğla colluviums). This facies evolves as an upper and lateral continuation of AF–BF–CF facies, depending on a decrease in the energy level in the downslope direction.

### **Factors controlling the deposition of the colluviums**

The talus, colluvium or alluvial sedimentation is influenced by several effects such as tectonism, climatic changes, base level changes, bottom topography, drainage network, source area, size of the rock, weathering characteristics, amount and type of sediment (Nemeč and Kazancı 1999; Harvey et al. 2005; Sanders 2010).

#### *Tectonism*

Tectonic processes control the formation of the sediment, sediment transportation, sediment geometry and the morphology of the region (Harvey et al. 2005). Dense tectonic activities cause the easily disintegration of rocks, and increase the weathering effect (Pope and Wilkinson 2005). Fidolini et al. (2013) suggested that a fining upward sequence was deposited during tectonically stable periods, while a coarsening upward sequence was deposited during active tectonic periods with a low subsidence rate.

Muğla Province is located in a first-degree seismic zone. 767 earthquakes with a magnitude greater than 4 occurred between 1900 and 2000 AD, while since 1940 AD, 10 earthquakes with a magnitude of 5 or more have affected the region (Sezer 2003). The ground shaking has triggered the movement of the unstable-loose sediments on slopes and led to the formation of coarse-grained facies. Subsequent quiet periods led to fine-grained, matrix-supported sediments. The orientation of the normal fault plane forms smooth, long, plain slope surfaces without gullies. So, loose sediments on top of this slope may lead to the formation of unchanneled coarse-grained sediments (Düğerek Road Cut). The orientation of the normal fault alignment controls the accommodation space of strip-wedge-shaped colluvium.

#### *Climatic condition*

Colluviums carry important information about past climatic conditions (Mackel et al. 2003; Löwner et al. 2005). Rock fall during a debris flow event in Mallorca designates a period of intense rainfall (Clemmensen et al. 2001).

If we consider the present-day climate conditions of Muğla, the winter and spring seasons are rainy. Daily and seasonal temperature differences accelerate the disintegration of rock due to the enlargement of joint surfaces, and actively control the quantity of sediment. The loose-unstable sediments on top of the slopes move downward depending on surface water flowing in gullies after heavy rain falls. The sediments create channelized deposits with an erosive base during the deposition (Fig. 1b). Fine-grained sediments can evolve during the dry season. Some seasonal surface runoff and springs cause to excess water entry. Water floods especially the agricultural area, and some houses basement. Urbanization (preventing easy infiltration) and rapid heavy short-term precipitation has increased the flooding effects in the last two decades.

#### *Gravity*

Sanders (2010) examined the colluviums under the proximal portions (30°–35°) and distal portions (10°–20°) based on sediment inclinations. Gray and Gardner (1977) mentioned that the large number of landslides in West Virginia is partly related to the steep topography. Meanwhile, Kaya and Kwong (2007) reported that the landslides in the Hawaiian colluviums are located in gentle slopes

(9–30 %), where highly plastic colluviums and smectite led to landslide development.

The slope of the host rock of studied colluviums varies between 32.1° and 37°. The loose sediments on these slopes move in the downdip direction under the effect of gravitational forces. If we look at the slope of colluvium sediments in the colluvium wedge, it varies between 18° and 22°. The sediment inclination decreases towards the centre of the basin and passes into the nearly horizontal alluvial sediments. Loose grains with various sizes at the top of colluviums have moved down the slope depending on gravity (depending on high sediment accumulation) or subsequent tectonic activity or rainfall. Rock falls are observed at the top of the colluviums, cohesive debris flow and grain flow products, and mostly grain flow deposits are observed towards the basin (Sanders 2010). Road excavation and basement excavation at the toes of the colluviums have increased the slope height and slope angle. This situation is increasing the instability problem.

#### *Host rock properties, weathering rate, sediment type and quantity*

The tectonic history and recent tectonic activities led to formation of a lot of fractures in the Gereme Formation. These fractures and the moderate-to-high strength (Gül et al. 2013) characteristics of host rock promote the weathering of the formation. Over time, the quantity of angular and sub-angular limestone fragments on the slope has increased and moved in the downdip direction. The boulder-bearing facies-AF may develop at the beginning of the colluviums deposition (Sanders 2010). The thicker coarser polymodal debris flow (BF) was interpreted as a gravitational failure of weathered bedrock at the higher mountain level, while the thinner pebbly debris flow (CF) was interpreted as a product of the failure of sediments on the fan head (Nemec and Kazancı 1999). The DF, with a maximum percentage of mud and sand, is interpreted as the product of a low-energy debris flow and sheet flow. The width of these colluvium wedges depends on the quantity of weathered material. A greater quantity of sediment leads to thicker and wider colluvial deposits.

#### *Accommodation space, basin morphology*

Schulz et al. (2008) worked on the spatial distribution of colluviums and slope morphology. They defined two different slope types, a regular planar slope after escarpment,

and a step-type slope including a bench and downslope of the bench in Seattle (USA).

The older structural properties and recent normal faults restrict the Muğla Polje, and control the basin geometry and slope development. The small faults in front of the Devetaşı Hill form the fault step. Thus, a small depocentre has evolved on this step (equivalent to the bench in the study by Schulz et al. 2008). The longer faults on the northern margin of the basin created a high, steep rocky cliff. The colluviums in front of these faults form a narrow strip.

## Results and discussions

Colluviums and related slope deposits of varying thickness can be found worldwide and evolve under different climatic conditions (Harvey et al. 2005; Gradziński et al. 2014). These types of deposit can be found in Spain (Clemmensen et al. 2001; Baeza et al. 2010), Lithuania (Bauziene 2002), China (Du et al. 2013; Xu et al. 2014), Germany (Mackel et al. 2003; Zolitschkaa et al. 2003; Leopold and Völkel 2007; Emadodin et al. 2011), Italy (Fidolini et al. 2013), Poland (Gradziński et al. 2014), the USA (Gray and Gardner 1977; Kaya and Kwong 2007; Schulz et al. 2008), Chile (Hartley et al. 2005; Lara and Sepulveda 2010) and Turkey (Nemec and Kazancı 1999; Topsakal and Topal 2014). Colluvial deposits are attracting attention in different branches of scientific study, including geomorphology, sedimentology, paleoclimatology, geography and engineering geology.

The colluviums of the Muğla contain gravel (AF, BF, and CF) and muddy gravel (DF), as well as breccia. BF–CF, BF–CF–DF, BF–DF and CF–DF-type facies associations are the fining upward sequences and may evolve during tectonically stable periods, while a coarsening upward sequence evolves during tectonically active periods (Fidolini et al. 2013). Facies differentiations develop depending on local factors including faults, joints, orientation of gullies, local high slopes, high weathering rate, etc.

Environmental issues of the Muğla colluviums may be evaluated in terms of agriculture, ground–surface water and mass wasting. Colluviums affect soil properties, including their chemistry such as the pH (McEntee 1998). Bauziene (2002) proposed that the water content and nutrient level of the colluviosols (related with colluviums) are higher than the eroded alluvial soil. If we look at the Muğla Polje, the agriculturally used soil is located at the centre of the polje and on the colluviums at the margin (Fig. 1b). The alluvial

sediment in the polje is located in the continuation of the colluviums. The colluvium-covered area is decreasing because of the new settlements (Menteşe Cooperative and enlargement of the main city), road excavation and construction. So, the colluviosols-covered area is decreasing, and the central alluvial sediments source is being lost. This situation is threatening the future of agriculture in the Muğla region.

Sun et al. (2013) emphasized that loose Quaternary geologic units have higher porosity and permeability values than the underlying weathered and jointed rocks. Karikari-Yeboah and Gyasi-Agyei (2000) reported that the colluviums are wet and have many springs flowing through. Baeza et al. (2010) reported that slope failures in the Eastern Pyrenees follow the convergence of groundwater flow. Partially saturated colluvium materials in Seattle (USA) led to the development of landslides (Schulz et al. 2008). The Xintan Landslide (1985) in the Three Gorges Reservoir region of the Yangtze River (China) was related to the dynamic parameters of rainfall (Keqiang et al. 2008). In the Muğla, rainwater after heavy rainfalls does not have sufficient time for percolation. This excess water invades neighbouring roads, buildings and agricultural fields during the winter time. If the rain is slow, the water has sufficient time for infiltration. The groundwater removes the matrix material and leads to the formation of sieve deposits in the Muğla colluviums. So the circulation of groundwater may affect the basements of buildings in the Menteşe Cooperative.

The absence of suitable regions for urbanization is one of the main problems in mountainous regions (Karikari-Yeboah and Gyasi-Agyei 2000). Colluviums are usually associated with potential stability problems (Karikari-Yeboah and Gyasi-Agyei 2000). Landslides, rockfalls and similar mass wasting movements are common in regions with steep slopes (Australia, Karikari-Yeboah and Gyasi-Agyei 2000). Slope failures of colluvium in the Eastern Pyrenees include translational slides and debris flow (Baeza et al. 2010). Similarly, Lara and Sepulveda (2010) reported that debris flow and slides are the main geological hazards observed in colluviums in Central Chile. Sun et al. (2013) reported that stability problems in colluvium slopes generally evolve depending on toe removal. Some creep or landslide of colluvium is related to seismic activity (Xu et al. 2014). A great many colluvium landslides in different parts of the world evolve as a result of the combination of its layering structure on the bedrock and the soil characteristics (USA, Gray and Gardner 1977; USA, Kaya and Kwong 2007; USA, Schulz et al. 2008;

Turkey, Topsakal and Topal 2014). These slides can cause extensive economic damage and many casualties (Schulz et al. 2008; Du et al. 2013). Human activities are another factor controlling colluvium sedimentation and are closely related to climatic conditions. Clearing of woodland or deforestation, and land use lead to easy erosion and the transportation of coarse-grained sediment by surface runoff, while after this period, depending on dense vegetation development, erosion can be prevented and soil or fine-grained sediments start to form (Zolitschka et al. 2003; Leopold and Völkel 2007; Emadodin et al. 2011). Small landslides in the Menteşe Cooperative and rock fall and debris flow in the Düğerek Road Slope are the main instability problems of the colluviums in Muğla. Road excavation leads to toe removal of the slope, increasing the slope height and slope angle. So, large blocks of the colluviums (in the AF and BF facies) are falling on to the road. Loose debris on top of the slope is flowing in the down-dip direction towards the road (BF and CF). Heavy rainfall and the seismicity of the Muğla region also trigger debris flows and block falls.

Colluviums are one of the most common Quaternary deposits in the SW Turkey–Aegean Region (Nemec and Kazancı 1999; Sözbilir 2005) and similar normal-faulted grabens. The environmental issues surrounding the Muğla colluviums summarized in the previous paragraphs may also apply in these regions. This colluvium-covered region must be protected from erosion, and road and housing construction. If this is not feasible, the local properties of the colluvium must be studied in detail. The facies characteristics of the colluvium have a strong effect on the type of instability problems of the colluviums. The relation between the engineering geological properties of the colluvium and the sedimentary facies must be investigated in detail, and necessary precautions must be applied before any engineering applications.

## Conclusions

Colluviums, which have deposited in SW Anatolia grabens, serve as the main residential and agricultural areas. The recent colluviums of Muğla form a narrow wedge-shaped strip that extends along the normal-faulted Liassic Limestone Mountains. Those colluviums contain poorly to very poorly sorted, angular to sub-angular, fine-skewed, clay to boulder size Liassic limestone fragment-bearing breccia. The A-Boulder facies (including boulder), B-Cobble facies (including cobble, 10–46 %) and C-Granule–pebble facies (pebble–granule, 83–94 %; mud + sand, 6–17 %) are surrounded by D-Fine-grained (matrix dominated) facies (gravel, <83 %; mud + sand, >17 %) in the colluviums. The colluviums pass laterally into the alluviums. Both of them are important for agriculture. The instability problems of the colluvium are challenging for engineers and municipalities. Construction of new residential areas and roads of Muğla may cover or destroy the colluviums, and increase the flood risk in lowland fields. Deterioration of the spreading area of the colluvium especially in the toe (due to its removal) is triggering instability problems such as landslides, rock falls, slides and debris flow. The facies characteristics of colluvium affect the type of stability problem. The detailed properties of the colluvium, the factors controlling sedimentation, and the factors triggering the main instability problems must be adequately researched before any engineering design application.

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## Appendix

See appendix in Tables 3, 4, 5, 6, and 7.

**Table 3** Weight of retained material (g) on each sieve

Grain size (mm)	Central										Southeast															
	Northwest					Düğerek Road (DR)					Quarry															
	Menteşe Cooperative		4-DH section I		5-DH section I-a		6-DH section II		7-DR Quarry finest part		8-DR Quarry coarsest part		9-DR Road Cut Slope finest part		10-DR Road Cut Slope coarsest part		11-Quarry I-coarsest part (basin margin)		12-Quarry I-finest part (basin margin)		13-Quarry II-coarsest part (extension)		14-Quarry II-finest part (extension)			
128	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
64	0	0	1643.6	0	0	533.9	0	706.1	0	1639.5	0	706.1	0	1639.5	0	706.1	0	0	0	0	0	0	0	0	0	0
31.5	0	87.6	1976.1	336.3	0	1544.2	233.5	1442.1	157.1	960.8	1475.5	1442.1	157.1	960.8	1475.5	1442.1	157.1	407.8	407.8	1488.6	1488.6	0	0	0	0	0
15.5	449.8	586.2	109.5	1168.4	127.4	417.1	244.7	302.9	223.9	714.8	707.7	302.9	223.9	714.8	707.7	302.9	223.9	212.6	212.6	563.7	563.7	492	492	0	0	0
9.5	326.6	459.4	52.4	280.3	396.7	55.2	267.5	165.1	209.9	84.3	152.3	165.1	209.9	84.3	152.3	165.1	209.9	227.9	227.9	192	192	315.4	315.4	0	0	0
3.35	401.5	383.3	41.8	198.3	704	43.6	571.3	131.4	292.5	53.2	119.2	131.4	292.5	53.2	119.2	131.4	292.5	475.2	475.2	226.2	226.2	319.6	319.6	0	0	0
2	143	33.5	20.1	73.8	285.4	18.7	154	31.7	84.7	12.2	20.1	31.7	84.7	12.2	20.1	31.7	84.7	142.3	142.3	58.6	58.6	62.9	62.9	0	0	0
1.19	76	20.1	15	41.5	131.8	13.2	65	10.1	42.6	8.2	13	10.1	42.6	8.2	13	10.1	42.6	79.9	79.9	30.5	30.5	35.9	35.9	0	0	0
0.85	93.8	29.2	14	52.9	150.4	13.5	45	8.4	44.6	8.4	18.4	8.4	44.6	8.4	18.4	8.4	44.6	87.7	87.7	36.3	36.3	41.9	41.9	0	0	0
0.6	37.7	16.2	15	31.5	88.5	9.1	30.9	6.3	20.2	3.2	9.5	6.3	20.2	3.2	9.5	6.3	20.2	45	45	22.5	22.5	33.5	33.5	0	0	0
0.355	34.5	15.2	15.3	35.5	105.7	11.6	59.8	13.4	22.3	3.6	10.6	13.4	22.3	3.6	10.6	13.4	22.3	44.3	44.3	23	23	37.5	37.5	0	0	0
0.25	14.8	6.8	8.1	48.2	65.3	5.9	76.1	17.5	13.7	1.9	7.1	17.5	13.7	1.9	7.1	17.5	13.7	26.3	26.3	14	14	23.2	23.2	0	0	0
0.15	15.7	7.9	9.8	25.3	66.5	8.7	109.2	26.2	23.1	2.4	13.4	26.2	23.1	2.4	13.4	26.2	23.1	32.7	32.7	14	14	22.2	22.2	0	0	0
0.106	7.2	4.3	5.9	14.6	29.7	6.1	47.5	12.5	46.2	2	11.1	12.5	46.2	2	11.1	12.5	46.2	33.2	33.2	8.2	8.2	14.7	14.7	0	0	0
0.063	12.5	10.1	7.1	16.9	25.9	9.5	45.1	12.9	26.1	2.4	21	12.9	26.1	2.4	21	12.9	26.1	35.6	35.6	7.4	7.4	8.9	8.9	0	0	0
Pan	16.2	12.2	5.9	20.1	21.9	10.8	34.3	10.6	38.9	5.7	38.4	10.6	38.9	5.7	38.4	10.6	38.9	63.3	63.3	16.3	16.3	22.5	22.5	0	0	0
Total	1629.3	1672	3939.6	2343.6	2199.2	2701.1	1983.9	2897.2	1245.8	3502.6	2617.3	2897.2	1245.8	3502.6	2617.3	2897.2	1245.8	1913.8	1913.8	3008.9	3008.9	1430.2	1430.2	0	0	0

**Table 4** Frequency percentage (%) of each sieve

Ø	Frequency percentage (%)																		
	Northwest							Central							Southeast				
	Menteşe Cooperative							Devetaşı Hill (DH)							Düğerek Road (DR)			Quarry	
	1- Finest part	2- Medium-grained part	3- Coarsest part	4-DH section I	5-DH section I-a	6-DH section II	7-DR quarry finest part	8-DR Quarry coarsest part	9-DR Road Cut Slope finest part	10-DR Road Cut Slope coarsest part	11-Quarry 1-coarsest part (basin margin)	12-Quarry 1-finest part (basin margin)	13-Quarry II-coarsest part (extension)	14-Quarry II-finest part (extension)					
-7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
-6.0	0.0	0.0	41.7	0.0	0.0	19.8	0.0	24.4	0.0	46.8	0.0	0.0	10.2	0.0					
-5.0	0.0	5.2	50.2	14.3	0.0	57.2	11.8	49.8	12.6	27.4	56.4	21.3	49.5	0.0					
-4.0	27.6	35.1	2.8	49.9	5.8	15.4	12.3	10.5	18.0	20.4	27.0	11.1	18.7	34.4					
-3.2	20.0	27.5	1.3	12.0	18.0	2.0	13.5	5.7	16.8	2.4	5.8	11.9	6.4	22.1					
-1.7	24.6	22.9	1.1	8.5	32.0	1.6	28.8	4.5	23.5	1.5	4.6	24.8	7.5	22.3					
-1.0	8.8	2.0	0.5	3.1	13.0	0.7	7.8	1.1	6.8	0.3	0.8	7.4	1.9	4.4					
-0.3	4.7	1.2	0.4	1.8	6.0	0.5	3.3	0.3	3.4	0.2	0.5	4.2	1.0	2.5					
0.2	5.8	1.7	0.4	2.3	6.8	0.5	2.3	0.3	3.6	0.2	0.7	4.6	1.2	2.9					
0.7	2.3	1.0	0.4	1.3	4.0	0.3	1.6	0.2	1.6	0.1	0.4	2.4	0.7	2.3					
1.5	2.1	0.9	0.4	1.5	4.8	0.4	3.0	0.5	1.8	0.1	0.4	2.3	0.8	2.6					
2.0	0.9	0.4	0.2	2.1	3.0	0.2	3.8	0.6	1.1	0.1	0.3	1.4	0.5	1.6					
2.7	1.0	0.5	0.2	1.1	3.0	0.3	5.5	0.9	1.9	0.1	0.5	1.7	0.5	1.6					
3.2	0.4	0.3	0.1	0.6	1.4	0.2	2.4	0.4	3.7	0.1	0.4	1.7	0.3	1.0					
4.0	0.8	0.6	0.2	0.7	1.2	0.4	2.3	0.4	2.1	0.1	0.8	1.9	0.2	0.6					
5.0	1.0	0.7	0.1	0.9	1.0	0.4	1.7	0.4	3.1	0.2	1.5	3.3	0.5	1.6					
6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0					
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0					

**Table 5** Cumulative Retained Weight Percentage of all sample

Grain size (mm)	Cumulative retained weight percentage (%)														
	Northwest					Central					Southeast				
	Menteşe Cooperative					Devetaşı Hill (DH)					Düğerek Road (DR)				
	1- Finest part	2- Medium-grained part	3- Coarsest part	4- DH section I	5- DH section I-a	6- DH section II	7-DR Quarry finest part	8-DR Quarry coarsest part	9-DR Road Cut Slope finest part	10-DR Road Cut Slope coarsest part	11-Quarry I-coarsest part (basin margin)	12-Quarry I-fineest part (basin margin)	13-Quarry II-coarsest part (extension)	14-Quarry II-fineest part (extension)	
-7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
-6.0	0.0	0.0	41.7	0.0	0.0	19.8	0.0	24.4	0.0	46.8	0.0	0.0	10.2	0.0	
-5.0	0.0	5.2	91.9	14.3	0.0	76.9	11.8	74.1	12.6	74.2	56.4	21.3	59.7	0.0	
-4.0	27.6	40.3	94.7	64.2	5.8	92.4	24.1	84.6	30.6	94.6	83.4	32.4	78.4	34.4	
-3.2	47.7	67.8	96.0	76.2	23.8	94.4	37.6	90.3	47.4	97.1	89.2	44.3	84.8	56.5	
-1.7	72.3	90.7	97.1	84.6	55.8	96.0	66.4	94.8	70.9	98.6	93.8	69.2	92.3	78.8	
-1.0	81.1	92.7	97.6	87.8	68.8	96.7	74.1	95.9	77.7	98.9	94.6	76.6	94.3	83.2	
-0.3	85.7	93.9	97.9	89.5	74.8	97.2	77.4	96.3	81.1	99.2	95.1	80.8	95.3	85.7	
0.2	91.5	95.7	98.3	91.8	81.7	97.7	79.7	96.6	84.7	99.4	95.8	85.3	96.5	88.6	
0.7	93.8	96.6	98.7	93.1	85.7	98.1	81.2	96.8	86.3	99.5	96.1	87.7	97.2	91.0	
1.5	95.9	97.5	99.1	94.7	90.5	98.5	84.3	97.2	88.1	99.6	96.5	90.0	98.0	93.6	
2.0	96.8	97.9	99.3	96.7	93.5	98.7	88.1	97.9	89.2	99.6	96.8	91.4	98.5	95.2	
2.7	97.8	98.4	99.5	97.8	96.5	99.0	93.6	98.8	91.1	99.7	97.3	93.1	98.9	96.8	
3.2	98.2	98.7	99.7	98.4	97.8	99.2	96.0	99.2	94.8	99.8	97.7	94.8	99.2	97.8	
4.0	99.0	99.3	99.9	99.1	99.0	99.6	98.3	99.6	96.9	99.8	98.5	96.7	99.5	98.4	
5.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
6.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	



**Table 6** Cumulative weight passing percentage of all sample

Grain size (mm)	Cumulative weight passing (%)															
	Northwest								Southeast							
	Menteşe Cooperative				Devetaşı Hill (DH)				Düğerek Road (DR)				Quarry			
	1- Finest part	2- Medium-grained part	3- Coarsest part	4-DH section I	5-DH section I-a	6-DH section II	7-DR Quarry finest part	8-DR Quarry coarsest part	9-DR Road Cut Slope finest part	10-DR Road Cut Slope coarsest part	11-Quarry I-coarsest part (basin margin)	12-Quarry I-finest part (basin margin)	13-Quarry II-coarsest part (extension)	14-Quarry II-finest part (extension)		
128.000	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
64.000	100.0	100.0	58.3	100.0	100.0	80.2	100.0	75.6	100.0	53.2	100.0	100.0	89.8	100.0	100.0	100.0
31.500	100.0	94.8	8.1	85.7	100.0	23.1	88.2	25.9	87.4	25.8	43.6	78.7	40.3	100.0	100.0	100.0
15.500	72.4	59.7	5.3	35.8	94.2	7.6	75.9	15.4	69.4	5.4	16.6	67.6	21.6	65.6	65.6	65.6
9.500	52.3	32.2	4.0	23.8	76.2	5.6	62.4	9.7	52.6	2.9	10.8	55.7	15.2	43.5	43.5	43.5
3.350	27.7	9.3	2.9	15.4	44.2	4.0	33.6	5.2	29.1	1.4	6.2	30.8	7.7	21.2	21.2	21.2
2.000	18.9	7.3	2.4	12.2	31.2	3.3	25.9	4.1	22.3	1.1	5.4	23.4	5.7	16.8	16.8	16.8
1.190	14.3	6.1	2.1	10.5	25.2	2.8	22.6	3.7	18.9	0.8	4.9	19.2	4.7	14.3	14.3	14.3
0.850	8.5	4.3	1.7	8.2	18.3	2.3	20.3	3.4	15.3	0.6	4.2	14.7	3.5	11.4	11.4	11.4
0.600	6.2	3.4	1.3	6.9	14.3	1.9	18.8	3.2	13.7	0.5	3.9	12.3	2.8	9.0	9.0	9.0
0.355	4.1	2.5	0.9	5.3	9.5	1.5	15.7	2.8	11.9	0.4	3.5	10.0	2.0	6.4	6.4	6.4
0.250	3.2	2.1	0.7	3.3	6.5	1.3	11.9	2.1	10.8	0.4	3.2	8.6	1.5	4.8	4.8	4.8
0.150	2.2	1.6	0.5	2.2	3.5	1.0	6.4	1.2	8.9	0.3	2.7	6.9	1.1	3.2	3.2	3.2
0.106	1.8	1.3	0.3	1.6	2.2	0.8	4.0	0.8	5.2	0.2	2.3	5.2	0.8	2.2	2.2	2.2
0.063	1.0	0.7	0.1	0.9	1.0	0.4	1.7	0.4	3.1	0.2	1.5	3.3	0.5	1.6	1.6	1.6
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7 Statistical values obtained from Fig. 2

Sample no	Central												Southeast				
	Northwest			Devetası Hill (DH)			Düğerek Road (DR)			Quarry			Quarry				
	Mentesë Cooperative			4-DH section I	5-DH section I-a	6-DH section II	7-DR Quarry finest part	8-DR Quarry coarsest part	9-DR Road Cut Slope finest part	10-DR Road Cut Slope coarsest part	11-Quarry I-coarsest part (basin margin)	12-Quarry I-finest part (basin margin)	13-Quarry II-coarsest part (extension)	14-Quarry II-finest part (extension)			
Ø 5	-3.7	-4.0	-5.8	-4.6	-3.0	-5.8	-4.5	-5.8	-4.5	-6.0	-5.0	-4.7	-5.4	-3.8			
Ø 16	-3.4	-3.6	-5.6	-4.0	-2.6	-5.2	-3.6	-5.3	-3.8	-5.7	-4.6	-4.3	-4.8	-3.4			
Ø 25	-3.0	-3.4	-5.4	-3.7	-2.2	-4.9	-2.9	-5.0	-3.3	-5.5	-4.5	-3.7	-4.7	-3.2			
Ø 50	-2.2	-2.8	-4.8	-3.2	-1.0	-4.5	-1.6	-4.5	-2.1	-4.9	-4.2	-1.9	-4.2	-2.6			
Ø 75	-0.6	-2.9	-4.4	-2.5	0.6	-4.1	0.0	-4.0	0.5	-4.0	-3.4	0.3	-3.4	-1.0			
Ø 84	0.3	-1.3	-4.2	-1.0	1.5	-3.7	2.4	-3.0	1.2	-3.5	-3.0	1.0	-2.5	0.3			
Ø 90	1.0	-0.8	-4.1	0.7	2.4	-3.2	3.2	-2.4	3.2	-3.3	-2.2	2.2	-1.4	1.4			
Ø 95	2.0	0.8	-3.8	2.4	3.3	-2.0	4.0	-1.0	4.2	-3.0	0.4	4.2	0.4	3.0			
Graphic mean (M)	-1.77	-2.57	-4.87	-2.73	-0.70	-4.47	-0.93	-4.27	-1.57	-4.70	-3.93	-1.73	-3.83	-1.90			
Sorting (SD)	1.79	1.30	0.65	1.81	1.98	0.95	2.79	1.30	2.57	1.00	1.22	2.67	1.45	1.96			
Skewness (Sk)	0.41	0.40	-0.07	0.53	0.29	0.19	0.33	0.38	0.38	0.27	0.60	0.23	0.53	0.61			
Kurtosis (K)	0.97	3.93	0.82	2.39	0.92	1.95	1.20	1.97	0.94	0.82	2.01	0.91	1.83	1.27			
Modes (Ø)	-3.60	-3.60	-4.50	-3.60	-1.35	-4.5	-1.35	-4.5	-3.6	-5.5	-4.5	-4.5	-4.5	-3.6			
	-1.35								-1.35			-1.35					

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