ORIGINAL ARTICLE

Işık Yilmaz
Mustafa Yildirim

Structural and geomorphological aspects of the Kat landslides (Tokat—Turkey) and susceptibility mapping by means of GIS

I. Yilmaz (✉) · M. Yildirim
Department of Geology,
Faculty of Engineering,
Cumhuriyet University,
58140 Sivas, Turkey
E-mail: iyilmaz@cumhuriyet.edu.tr
Tel.: +90-346-2191010
Fax: +90-346-2191171

Abstract Kat County, which is located in a slope of hilly region and constructed in the side of a mountain along the North Anatolian Fault Zone, is frequently subject to landslides. The slides occur during periods of heavy rainfall, and these events cause destruction to property, roads, agricultural lands and buildings. In the last few decades, a lot of houses and buildings have been damaged and destroyed. Settlement areas have remained evacuated for a long time. The slope instabilities in the study area are a complex landslide extending from north to south containing a lot of landslides. Field investigations, interpretation of aerial photography, analyses of geological data and laboratory tests suggest that some factors have acted together on the slopes to cause the sliding. In the wet season, the slopes became saturated. As the saturation of the earth material on the slope causesa rise in water pressure, the shear strength (resisting forces) decreases and the weight (driving forces) increases; thus, the net effect was to lower the safety factor. Previous failures have affected the rock mass, leading to the presence of already sheared surfaces at residual strengths. The relation between the joint planes and the instability of the slope in the study area was discussed and it was found that the potential slope instabilities are mainly in the directions of NW–SE, NE–SW and N–S. The landslide susceptibility map obtained by using the geographical information system showed that a large area is susceptible and prone to landslides in the northern part of the study area.

Keywords GIS · Landslide · North Anatolian fault · Susceptibility · Tectonic

Introduction

Kat County is located in the slope of a hilly region 14 km NW of Tokat (Turkey) (Fig. 1). It is located on the side of a mountain along the North Anatolian Fault Zone. Rainfall is the significant source of water in the study area, and it is the most important element in the hydrological cycle. This area receives a mean annual rainfall of 396 mm. The minimum recorded value was 5.3 mm and the maximum, which was recorded in the wet season, was 55.4 mm. Meteorological records showed that the mean maximum temperature in August was 30.7°C, the mean minimum temperature was recorded in December and was −0.4°C. The annual mean value of temperature was 13.1°C (Table 1).

The study area was divided into the two parts, namely, down Kat County and upper Kat County. Upper Kat County is nearer the hills, and down Kat County is located in the plains of the Yesilirmak river, having slopes ranging between 0 and 5%. In the upper Kat, the slopes change from 5 to 45%, and have very steep topography, especially in the northern part of the county (Fig. 2).

This paper describes and analyses the results of the detailed study of the landslides in the Kat County of
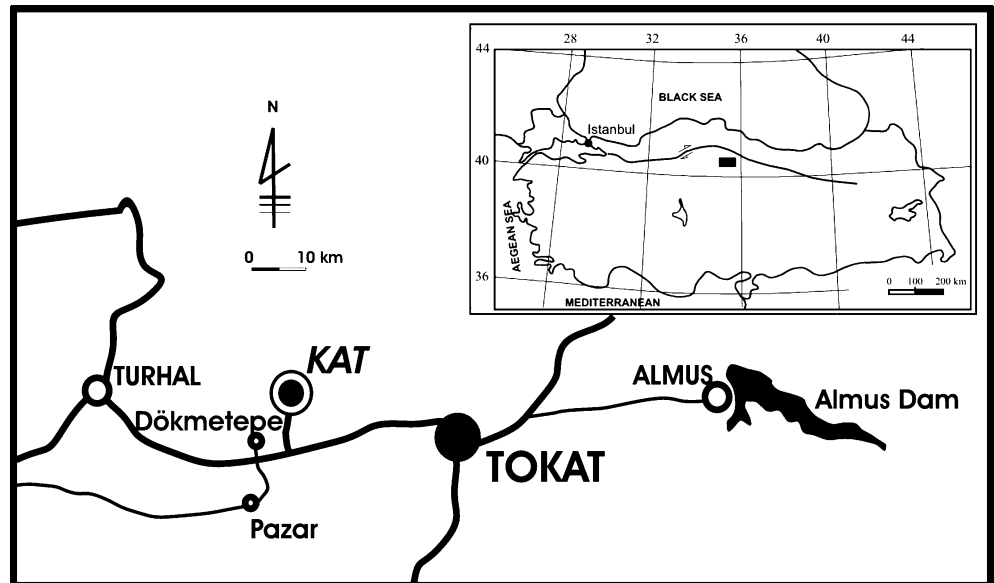
Fig. 1 Location map of the study area

Table 1 Meteorological data

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	AMV
Temperature (°C)	3.0	4.6	7.3	12.5	17.6	21.3	23.3	23.0	19.4	13.5	8.5	4.1	13.1
Rainfall (mm)	50.5	37.9	41.8	40.8	55.4	36.3	9.4	5.3	16.2	24.9	38.9	38.6	396.0

AMV annual mean value

Tokat (Turkey), based on field and laboratory measurements and the monitoring of the slide area. It has been recognized that the Kat County is frequently subject to landslides. The slides occur during periods of heavy rainfall, and these events cause destruction to property, roads, agricultural lands and buildings. In the last few decades, a lot of houses and buildings have been damaged and destroyed. Settlement areas have remained evacuatedfor a long time.

Movement of the Kat County was caused by reactivation of the pre-existing slides or activation of recent slides. Clays in the slip surfaces are highly plastic, have high swelling potential and active containing the smectite.

Also, clayey debris material in the landslide area acts like a fluid when it is saturated with water in the rainy seasons.

Geological framework and tectonic setting

Stratigraphical geology

The study area encompasses four units ranging in age from Triassic to Quaternary. From the oldest to the youngest, they are: the Triassic Tokat metamorphics, Eocene sedimentary series, alluvium and debris, respectively (Fig. 3).
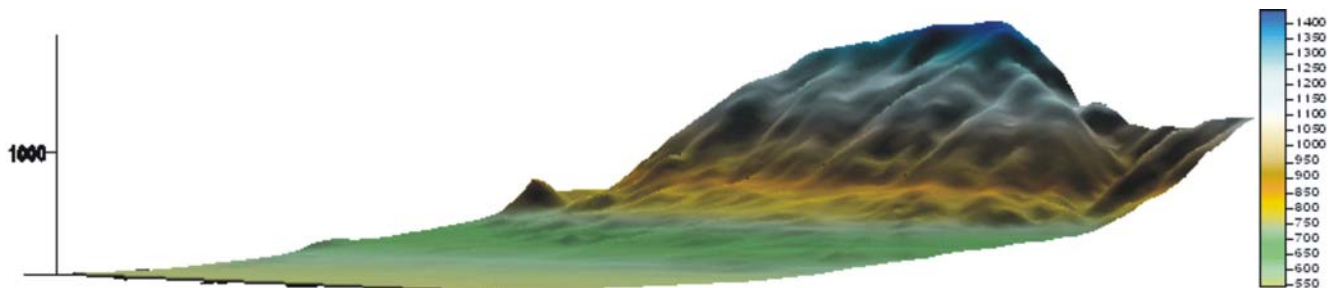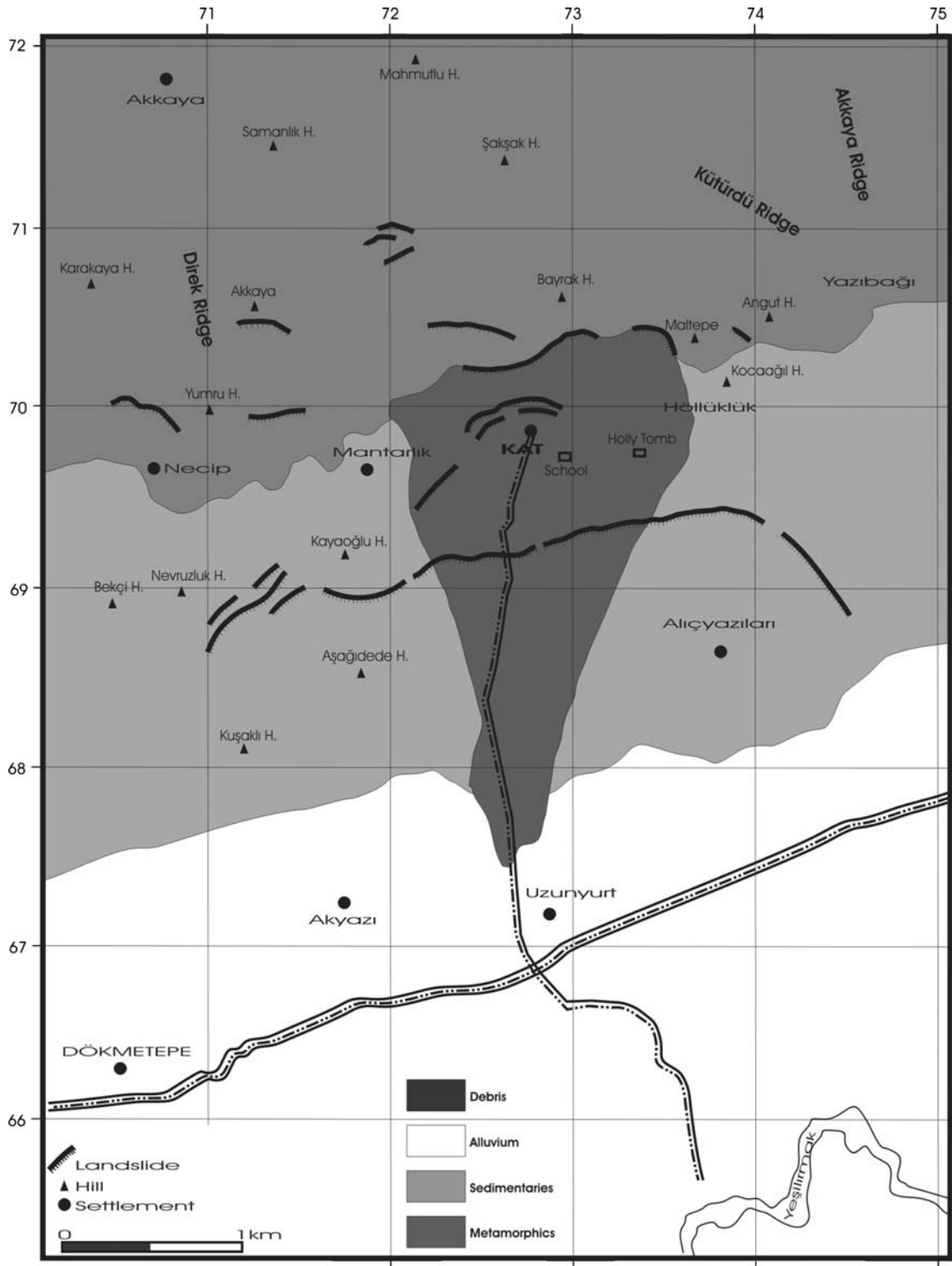

Fig. 2 Topography of the study area

Fig. 3 Geological map of the study area

Crushed and jointed, greyish green Tokat metamorphics crops out widespread in the northern part of the study area. This unit consists of metabasalts and is of the Triassic age. Yellowish brown, bedded sedimentary series occurs as an alternation of conglomerates, sandstone and claystone.
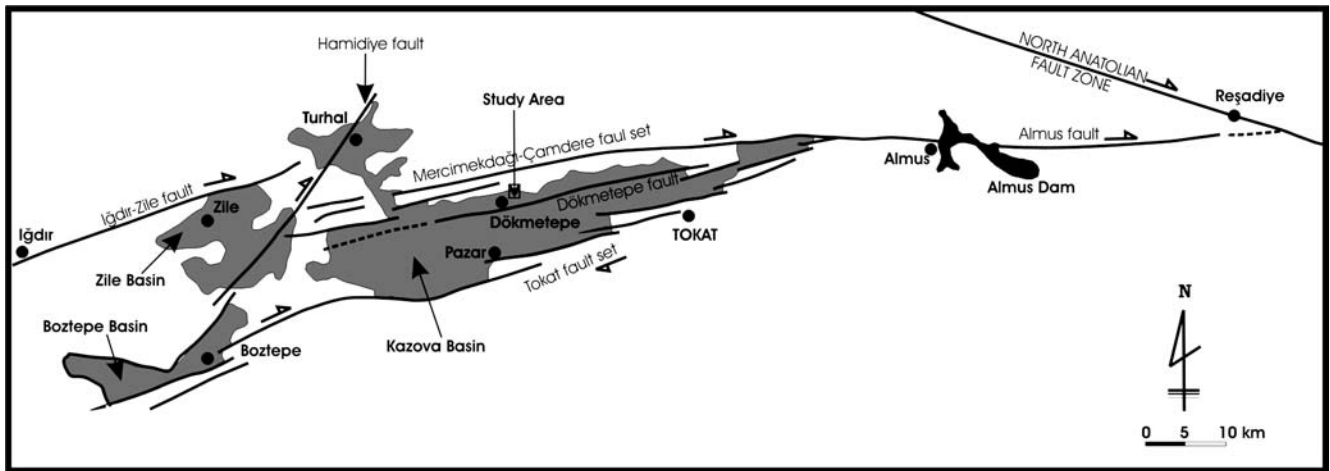
Fig. 4 Tectonic situation of the study area and its environment

Fig. 5 General view from land-slides

The age of this unit is Eocene, and overlies the Tokat metamorphics with an unconformity. The sedimentary series extensively outcrops in the middle part of the study area, having a bedding plane of 15/30. Red-coloured clays derived from this unit were observed overlying the sedimentary series, and some of the landslides occur in these clayey levels.

Alluvium crops out most extensively in the southern part of the study area. They consist of gravel, sand, silt and clay. The alluvium consists of stratified material of heterogeneous grain sizes, derived from various geo-logical units in the vicinity. Their continuity cannot be established laterally and vertically. Alluvium is also covered by thick (~1–1.5 m) organic topsoil.

There is a widespread cropping out of debris materials in the central part of the study area, and it lies from north to south. They comprise materials having varied grain-size from clay to block especially derived from the metamorphic units in the vicinity. Debris materials having a thickness of 30 m have a poor grading, and grains and block were angular and semi-rounded.
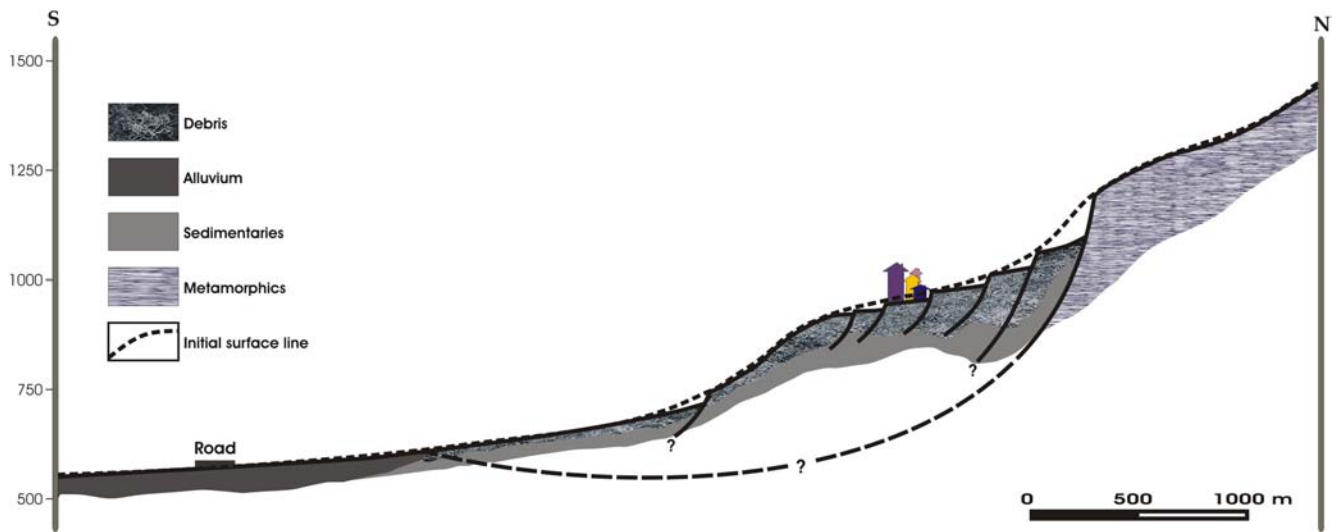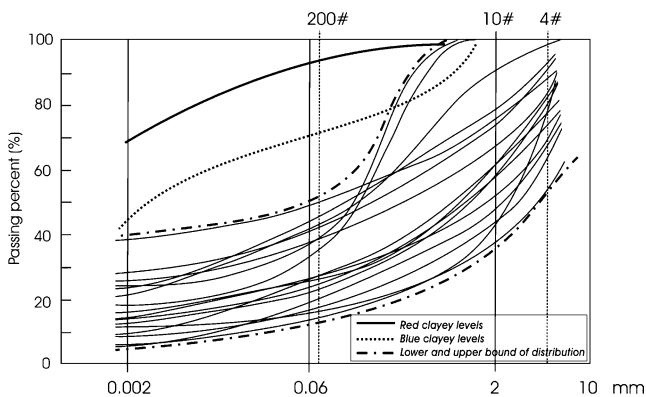
Fig. 6 Cross-section from north to east

Fig. 7 Grain size distribution of the soils from landslide materials

Tectonic setting

The Kazova basin is a 0.7–10-km-wide, 60-km-long, active, right-lateral strike-slip depression with its long axis oriented in a 077° direction. The basin is a typical wedge-shaped depression along the Almus Fault zone (AFZ) and becomes wider from east to west. AFZ has mostly an E–W-trending, single fault trace character for about 50 km from the southeast of Reşadiye in the east, where it branches off the North Anatolian Fault Master Strand, and Bakımlı village in the west. AFZ bifurcates from the west of Bakımlı village into numerous parallel to subparallel smaller fault segments resulting in a simple horse-tail strike-slip fault pattern. The kazova basin is bounded by the Mercimekdağı-Çamdere fault set on the north and the Tokat fault set in the south, while the active Dökmetepe fault, the master strand of the AFZ, lies within the basin. The two fault sets control and

bound both the margins, the Turhal block in the south, and are composed of numerous parallel to subparallel fault segments. The ground ruptures of the Erzincan earthquake of 1939 moved the fault sets, and the southern blocks were moved relatively downwards (Bozkurt and Koçyigit 1996). The landslide in the Kat County occurred between the Mercimekdağı-Çamdere fault set in the north and the Dökmetepe fault in the south (Fig. 4).

Mercimekdağı-Çamdere fault set

The Mercimekdağı-Çamdere fault set is approximately 70 km long and 4 km wide. It is composed of numerous parallel to subparallel fault segments together with synthetic R-shears and antithetic R′-shears, which are oblique to the general trend of the fault set. The fault set clearly defines and controls the northern margin of the Kazova basin.

Dökmetepe fault

The Dökmetepe fault is composed of 075° trending and en-echelon fault segments and is well exposed at the northern margin of the Kazova basin. The ground ruptures of the 1939 Erzincan earthquake also moved this fault. Although it is not in the catalogues, this fault was reactivated two or three times in the past (Bozkurt and Koçyigit 1995). The activity of the Dökmetepe fault is indicated by a active tectonic creep along which a concrete bridge is dextrally offset by about 1.6 cm (Bozkurt and Koçyigit 1996).

The ground ruptures of the 1939 Erzincan earthquake affected the following fault segments: the Merci-

Fig. 8 Distribution of the soil samples on the plasticity chart
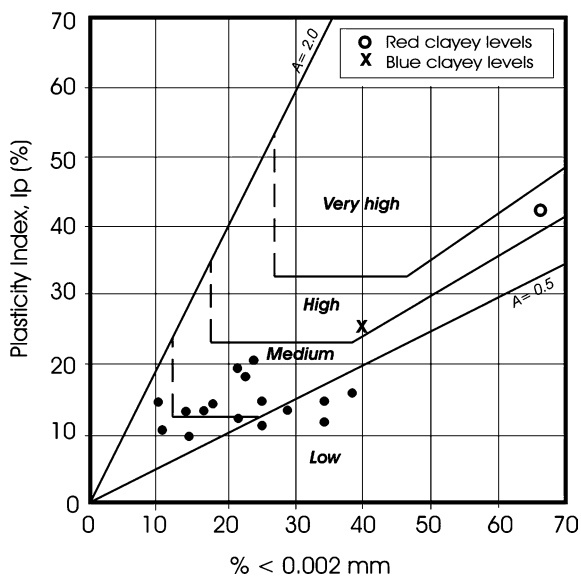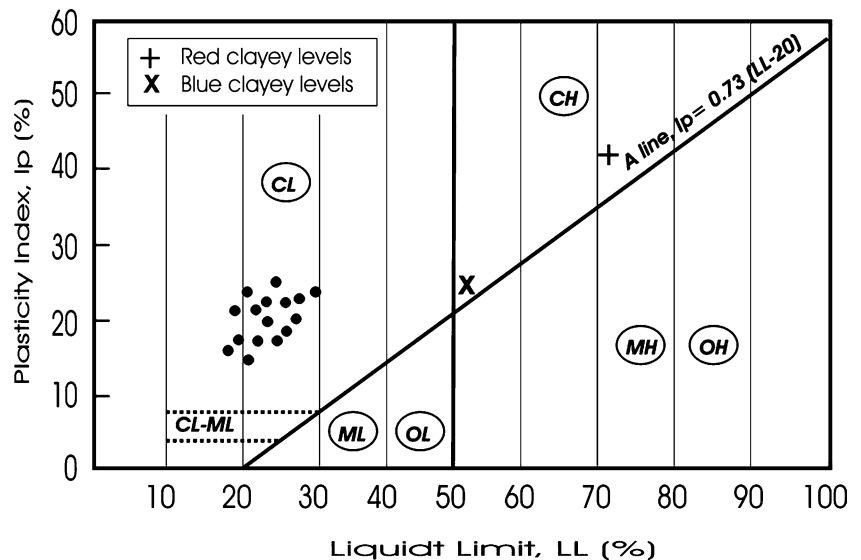

Fig. 9 Distribution of the soil samples on the swelling potential chart

mekdağı-Çamdere fault set, the Tokat fault set and the Dökmetepe fault. However, the maximum destruction and movement took place along the Dökmetepe fault (personal communication with local people). Evidence relating to this deformation is being obscured by agricultural activities and recent sedimentation in the Kazova basin (Bozkurt and Koçyigit 1996).

Descriptions of the landslides

It has been recognized that the Kat County is frequently subjected to landslides (Fig. 5). The slides occur during the periods of heavy rainfall. The events cause destruction to property, roads, agricultural lands and buildings. In the last few decades, a lot of houses and buildings have been damaged and destroyed. Settlement areas have remained evacuated for a long time. Constructed cross-section from north to south by the continuous surface investigations and borehole works had shown that there were a lot of landslides connected to each other (Fig. 6).

Soil mechanic tests were carried out on samples collected from the debris material in accordance with the American Standards Testing of Materials standards (Bowles 1992). Conventional coarse sieve, fine sieve and hydrometer methods were used for grain size analyses. These analyses revealed that the soils are composed of 5% block, 25% gravel, 40% sand, 10% silt and 20% clay size material. The range of grain size is shown in Fig. 7. Most of the clays tested were of low plasticity, and according to the plasticity chart, 100% of the samples are of the CL group (low plasticity, inorganic clay) soils (Fig. 8). The soils of the debris material possess low to medium swelling potentials according to the Williams and Donaldson's (1980) swelling potential chart modified from Van Der Merwe (1964) (Fig. 9).

Also, red-coloured clays were observed in the contact of the sedimentary series and debris material, and blue clays were observed between the metamorphics with sedimentary series where there was a widespread occurrence of the landslides (Fig. 10). Both of those clays were of the CH group (high plasticity, inorganic clay) soils (Fig. 8), and have high swelling potentials (Fig. 9). Clays in the contacts of the units reduce the friction and driving forces. Thus, the sliding was to be easy and fast especially in the steep slopes. In the rainy season, an increase in the saturation degree of the sliding material facilitated the landslide. Water could be

Fig. 10 Views from the red and blue clayey levels of the land-slide area

reached to the clayey levels because of the permeable characteristic of the debris and the jointed structure of the rocks.

Mineralogical determinations

Basement-rock mineralogy

Basementrock in the landslide area is metabasalt. Pyroxenes were observed as phenocrysts, and in some samples, there were transformations to tremolite and amphibole. In all the samples, chloritization after groundmass is common and epidote group minerals were observed. Although cataclasm was not observed in the thin sections, sometimes a non-clear cataclasm and orientation were observed (Fig. 11). As the result of thin-section determination, it was determined that the basementrock has basic characteristic and metamorphized in the green-schist facies.

Slide material mineralogy

Mineralogical determinations were carried out in two stages, which included whole-rock powder diffraction determination and oriented samples of clay-size fraction by X-ray diffraction. Quantities of the minerals were calculated as proposed by Yalçın and Bozkaya (2002). The results of the mineralogical determinations showed that the soils were composed of clay, calcite, feldspar, pyroxene and hornblende minerals, the average semi-quantitative quantity of clay minerals being 48.8% (Fig. 12, Table 2). The mineralogical content thus ob-

tained largely supports the fact of the source rock of metabasalts. Chlorite and smectite appear to be the dominant clay minerals (Fig. 13, Table 2).

Geostructural aspects

The rocks in the study area are intensively fractured by the effect of the faulting. Two to four sets of joints have been recognized. The measured average strikes of the joints are 60°. The extensions of these joints range from a few centimetres to tens of metres. Some joints are wide open, others are filled with residual material formed mainly of clay. The Joints make the circulation of groundwater possible and are probably the most critical feature. Discontinuities are generally parallel to the slope face.

Discontinuities have been described according to I.S.R.M. (1978); their orientations as well as slope faces have been plotted on equatorial equal-area diagrams (Figs. 14, 15). The obtained projection implies that a

Table 2 Semi-quantitative results of X-ray diffraction determinations

Minerals	Minimum	Maximum	X	Sx
Clay (%)	38	53	48.8	4.31
Calcite (%)	0	6	4.1	2.73
Hornblende (%)	15	21	17.0	3.02
Pyroxene (%)	±	35	30.0	8.12
Feldspar (%)	19	30	24.1	3.44
Clay Minerals				
Smectite (%)	45	60	55.0	3.91
Chlorite (%)	55	40	45.0	3.74

number of significant pole concentrations are present and indicates the range of strikes and dips of the joints as well as their mean directions.

According to Hutchinson (1988) and Goodman (1989), the presence of the fractures, joints, their extensions, attitudes and their intersections all affect the stability of the slope in an area because they form pre-existing surfaces along which sliding may take place (Abderahman 1998). The orientations of the joints and the slope faces were presented as great circles. These circles show different intersections between themselves. They represent the intersection of joints. These planes influence the stability of the slope.

The connection between the dominant strike of discontinuities and the dominant slope directions were represented in Fig. 16. Different intersections between fractures indicated some potential failure directions of NE–SW, NW–SE and N–S. These directions are similar to the principle slope directions in the study area. In the kinematical analyses, geometrical conditions were satisfied according to Hoek and Bray (1981).

Landslide susceptibility mapping

The methodology of susceptibility mapping included the making, the inventory and the database of slope movements, analyses of the factors that determine susceptibility, and the production of the susceptibility maps.

First, the slope movements were identified according to their mechanism, involved materials and sizes by the use of aerial photography and ground surveys. Identified

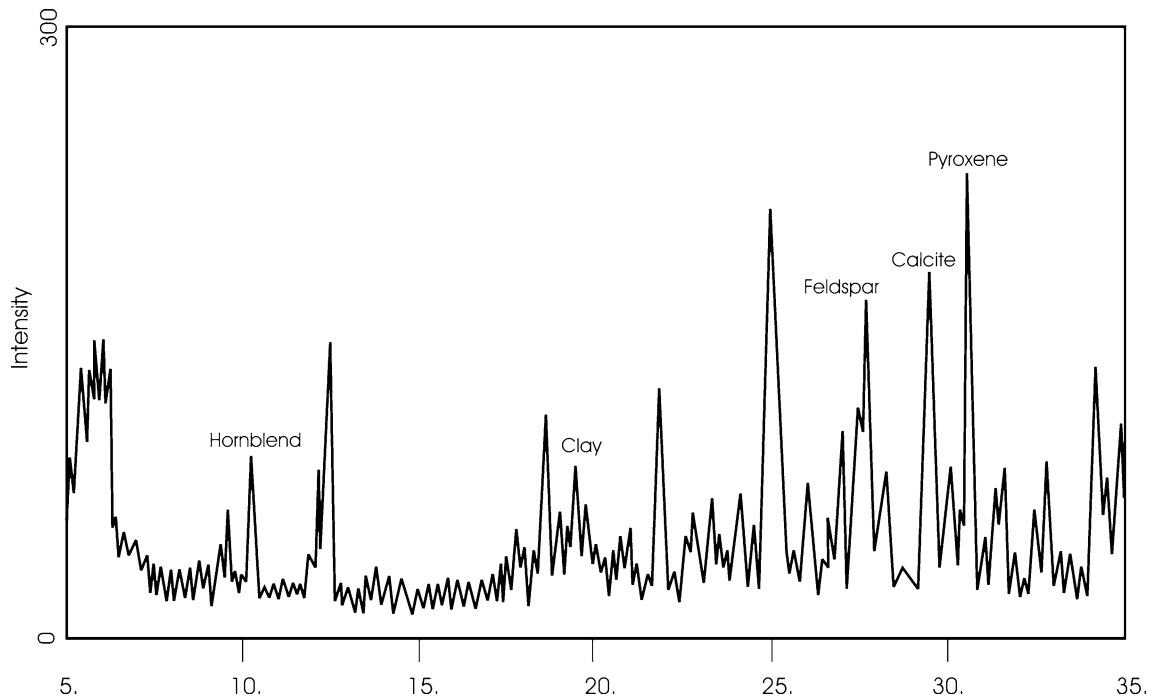Fig. 11 Thin sections of the metamorphics
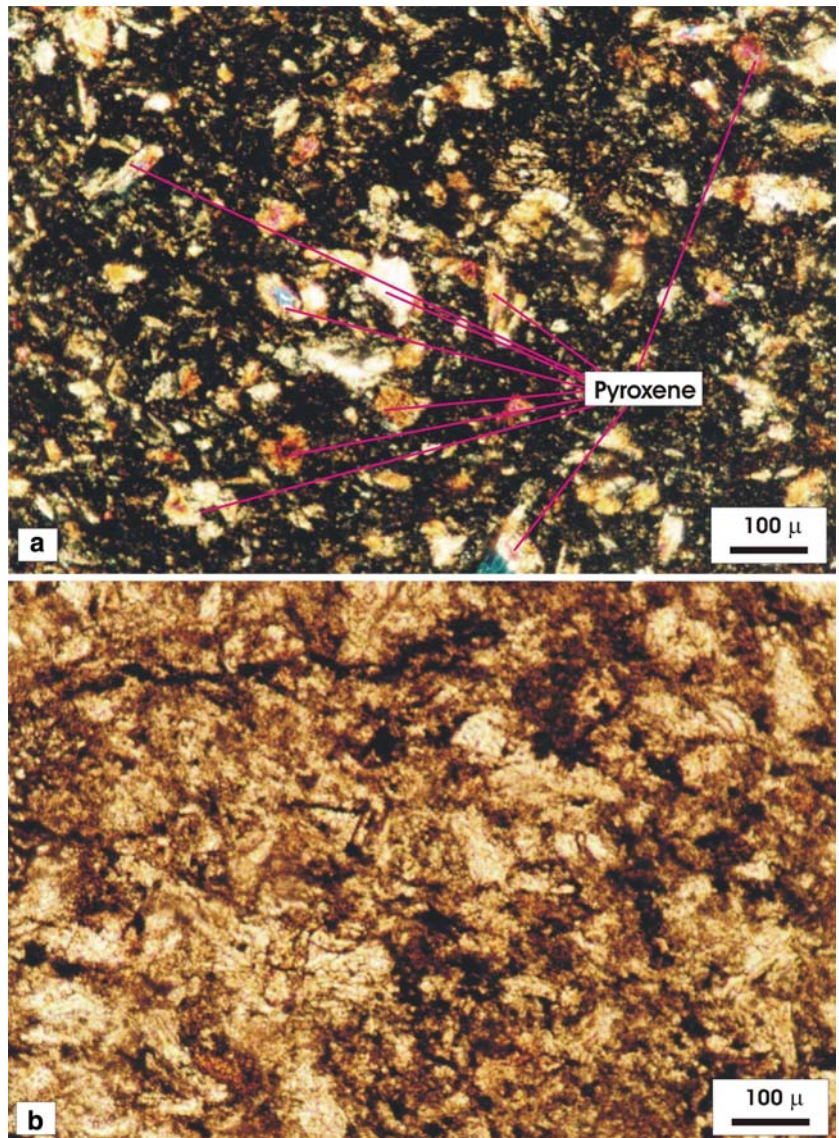
Fig. 12 Characteristic X-ray diffraction diagram of whole-rock powder
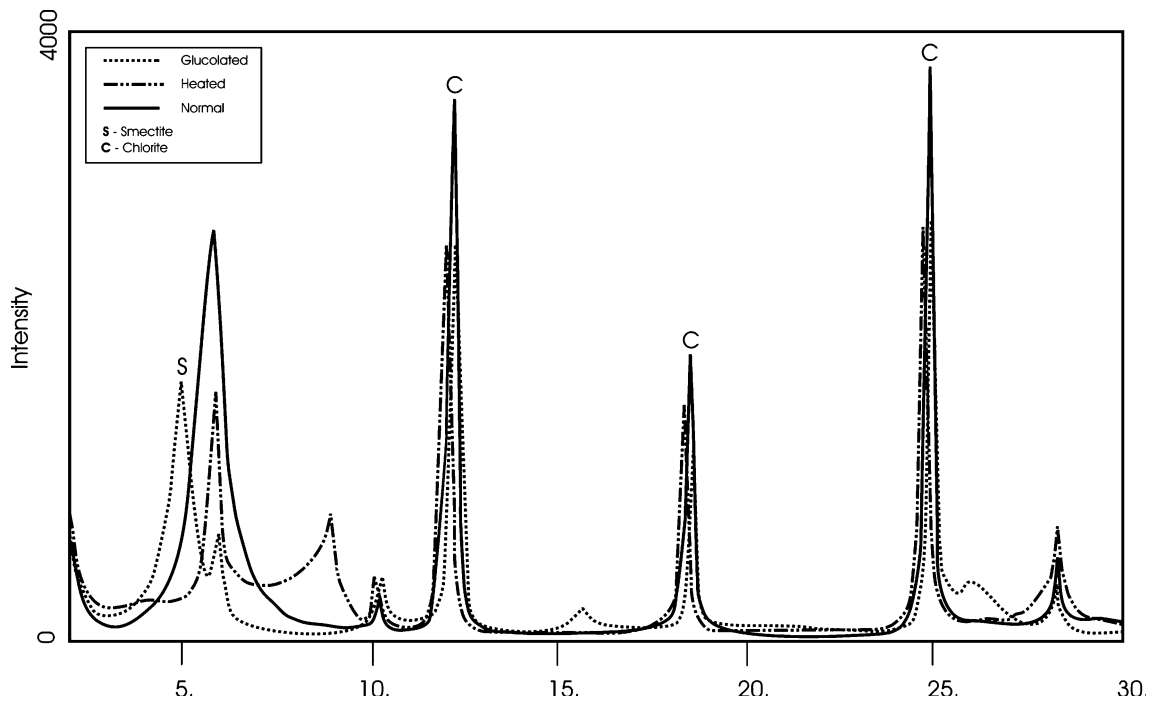

Fig. 13 Characteristic X-ray diffraction diagram of oriented clay-size material

slope movements were then grouped into a series of basic types (Varnes 1978). The field inventory was then put on the 1:25,000 topographic maps, digitized and entered into a geographical information system (GIS).

In the second stage, the determinant factors for each type of movement were defined and analysed. The analysed factors were slopes, altitudes, aspects, slope curvature and roughness, slope area and hillshading
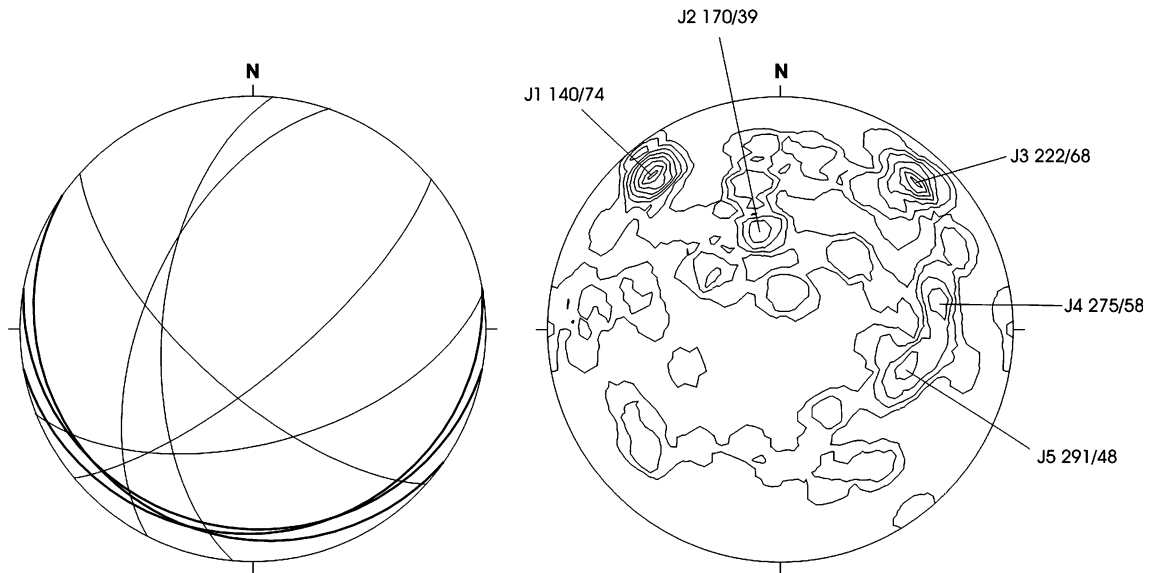
Fig. 14 The significant pole concentrations, and their great-circles (sedimentary series)
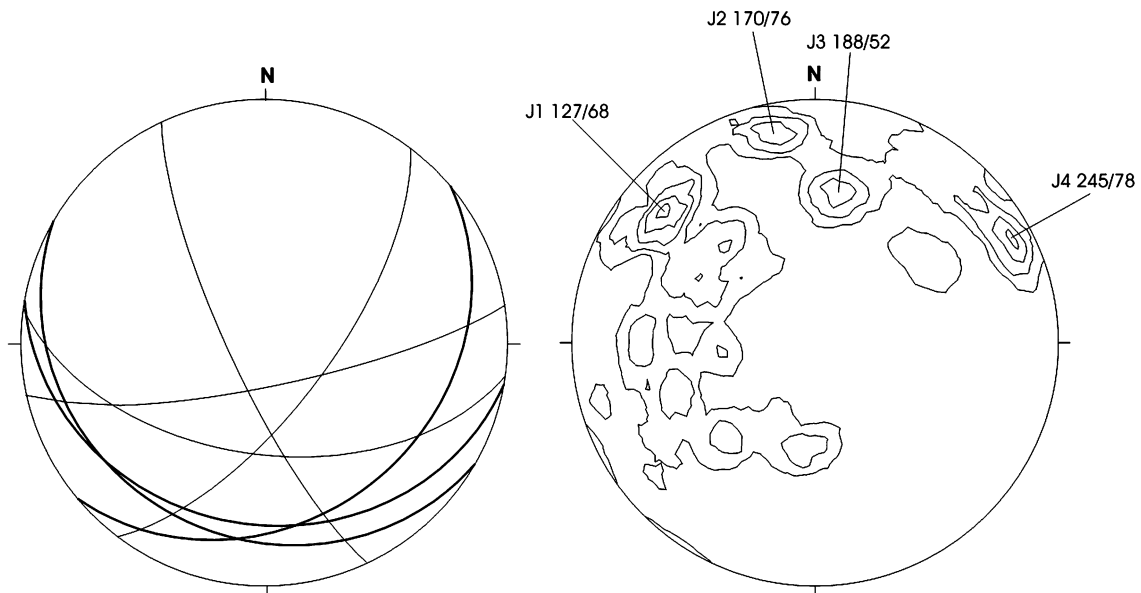

Fig. 15 The significant pole concentrations, and their great-circles (metamorphics)

derived from the digital elevation model, which was obtained by the digitization of the contour lines of the topographic map at scale 1:25,000. Thematic maps such as geology, soils, vegetation, hydrology, drainage basins and structural conditions were entered into the system by digitizing polygonal, linear and point data. These were then rasterised by means of polygon-raster transformation. And then, discontinuities, potential instability planes and proximity to the faults were entered into the system as linear or point data.

Finally, the susceptibility map was produced by using the matrix method. The first matrix was the area of each of the combinations of classes of factors that determine each type of movement. The second one was the area of each of the combinations occupied by the rupture zones for the different types of movements. And, the third matrix was established from these data as the matrix of susceptibility (Fernández et al. 2003). The susceptibility map of the study area can be seen in Fig. 17.
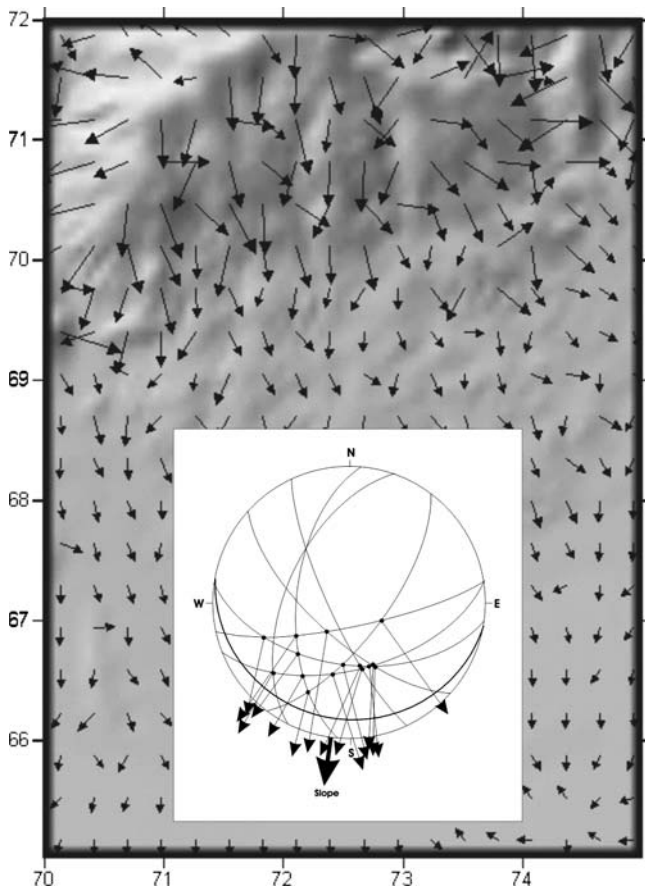
Fig. 16 Stereoplot of structural conditions (intersection of joints) likely to give rise to failure (landslides) in the study area

Fig. 17 Landslide susceptibility map of the study area

Discussion and conclusions

The analyses showed that the potential slope instabilities are in the main directions of NW–SE, NE–SW and N–S, these directions are the same with the dominant slope directions in the study area. All of the landslides in the study area were observed between the Dökmetepe fault in the south and the Mercimekdagi-Çamdere fault set in the north. It is possible to explain that the slope instabilities in the study area are a complex landslide extending from the north to the south containing a lot of landslides (Fig. 6).

Field investigations, interpretation of aerial photography, analyses of geological data and laboratory tests suggest that some factors have acted together on the slopes to cause the sliding. Previous failures have affected the rock mass, leading to the presence of already sheared surfaces at residual strengths. In addition, the
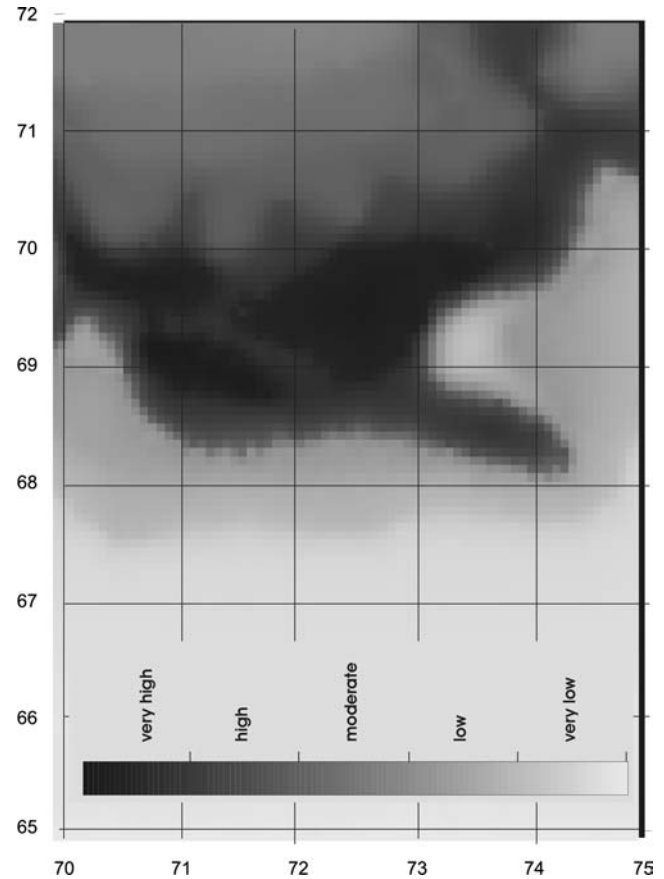
old mass movements have caused a loosening of the rock mass and tensional fractures to stress relief. The relation between the joint planes and the instability of the slope in the study area was discussed above. In the wet season, the slopes became saturated. As the saturation of the earth material on the slope had caused a rise in the water pressure, the shear strength (resisting forces) decreased and the weight (driving forces) increased; thus, the net effect was to lower the safety factor. At the toe of the landslides, springs from the infiltrated water were observed.

The landslide susceptibility map obtained by using the GIS showed that a large area is susceptible and prone to landslides in the northern part of the study area.

References

Abderahman NB (1998) Landslides at km 56.4 along the Irbid–Amman highway, Northern Jordan. AAPG Div Environ Geosci 5(3):103–113

Bowles JE (1992) Engineering properties of soils and their measurement. McGraw-Hill Inc., New Jersey, pp 241

Bozkurt E, Koçyigit A (1995) Almust fault zone: its age, total offset and relation to the North Anatolian fault zone. Turk J Earth Sci 4:93–104

Bozkurt E, Koçyigit A (1996) The Kazova basin: an active negative flower structure on the Almus Fault Zone, a splay fault system of the North Anatolian Fault Zone, Turkey. Tectonophysics 265:239–254

Fernández T, Irigaray C, Hamdouni RE, Chacón J (2003) Methodology for landslide susceptibility mapping by means of a GIS. Application to the Contraviesa Area (Granada, Spain). Nat Hazards 30:297–308

Goodman RE (1989) Introduction to rock mechanics, 2nd edn. Wiley, New York

Hoek E, Bray J (1981) Rock slope engineering. Institution of mining and metalurgy, London

Hutchinson JN (1988) General report: morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. Landslides 1:3–35

I.S.R.M. (1978) Suggested methods for the quantitative description of the discontinuities in rock masses. Int J Rock Mech Min Sci Geomech Abstr 15:319–368

Van Der Merwe DH (1964) The prediction of heave from the plasticity index and percentage clay fraction of soils. Civil Eng S Afr 6(6):103–106

Varnes DJ (1978) Slope movement types and processes. In: Schuster RL, Krizek RJ (eds) Landslides analysis and control. Special report, vol 176. Transportaion Research Board, National Academy of Sciences, New York, pp 12–33

Williams AAB, Donaldson G (1980) Building on expansive soils in South Africa. In: Proceedings of 4th International Conference, vol 2. Expansive Soils, Denver, pp 234–238

Yalçın H, Bozkaya Ö (2002) Hekimhan (Malatya) çevresindeki Üst Kretase yaşlı volkaniklerin alterasyon mineralojisi ve jeokimyası: denizsuyu-kayaç etkileşimine bir örnek. C.Ü. Mühendislik Fakültesi Dergisi Seri-A Yerbilimleri 19:81–98