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EVALUATING THE TRIGGERING FACTORS OF THE ROCK FALLS OF 16TH AND 21ST DECEMBER 2009 IN NEA FOKEA, CHALKIDIKI, NORTHERN GREECE

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Abstract

This paper aims to present the characteristics of the rock falls generated on the 16th and 21st of December 2009 at the Nea Moudania – Kassandria country road in Kassandra Peninsula, Chalkidiki, Greece. Both of those events induced damages to the asphalt road and forced the local authorities to close the road to traffic until the construction of protective measures. In order to evaluate the rock fall hazard and analyze the slope instability in the area, the present study focuses on three main triggering factors: rainfall, stratigraphy and tectonic setting.

Key words: rock fall, stratigraphy, rainfall, Chalkidiki, Greece
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1. Introduction

The detachment of rock from bedrock slope is triggered by several factors such as weathering, earthquake and human activities while the fall of a rock is determined by factors like the slope morphology and the direct surrounding of the potential falling rock (Dorren, 2003).

In the study area, several rock-falls occurred and some small creeps appeared, according to historical reports, on the asphalt pavement; they were usually rapidly repaired and the road opened fr traffic in a short time. The event of 16th of December 2009 occurred during a heavy rainfall, at approximately 21:30, while few days later, on Monday 21st, a second larger rock fall close to the previous one caused the permanent closure of Nea Moudania – Kassandria road.

A few hours after the second event a field survey took place, in order to report and evaluate the rock fall hazard in the area. In this paper the triggering factors of the rock falls are analyzed and the outcome of this research is presented.

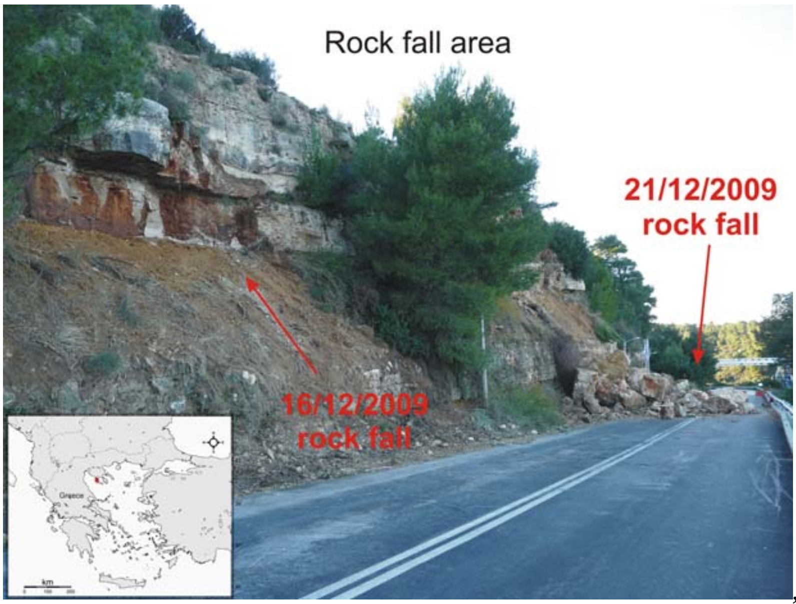

Fig. 1. Rock falling phenomena along the Nea Moudania – Kassandria road on 16th and 21st December, 2009.

2. Geomoprhological setting

Kassandra is the westernmost peninsula of Chalkidiki (fig. 1), forming an elongated strip of land. A smooth landscape consisting of very wide dry valleys and low (mean altitude 30-60 m asl) hilly terrain dominates the northern part, between Potidaea and Kassandria villages. On the contrary. the southern part of the peninsula reveals a higher (up to 333 m asl) hilly terrain, highly affected by erosion. From a tectonic point of view Kassandra peninsula can be considered as a horst (Marinos et al., 1970; Psilovikos et al., 1988; Syrides 1990).

The northern part of Kassandra reveals characteristics inherited from an older mature relief that was probably affected by a younger tectonic phase (Psilovikos et al., 1988; Syrides 1990). Criteria for identifying the tectonic effect on the relief are:

- Very steep linear coasts bordering a raised block of land with flat mature relief.
- Formation of coastal terraces in soft sediments.
- Cutoff of the mature valleys along the coast line and formation of “hanging valleys”.
- A new erosional cycle with formation of younger valleys starting from the coast.
- It is remarkable also that in northern Kassandra these mature valleys, trending from NE towards SW are also cut off along the eastern coast; as a result the watershed practically coincides with the eastern coast.

The present coastal morphology results also from the subsequent coastal processes of erosion-deposition, as well as the intensive human intervention becoming enduringly active during at least the past 3 decades (Psilovikos et al., 1988).

3. Geological setting

Kassandra peninsula is almost entirely covered by Neogene – Quaternary sediments. Only in the southern part older rocks appear (Mesozoic limestones, ophiolites & Paleogene sandstones), forming the pre-Neogene basement.

According to Syrides (1990) Kassandra peninsula is situated along the eastern side of the extensive Axios – Thermaikos basin that was formed during early Miocene and gradually filled up by mainly clastic Neogene and Quaternary sediments. Total thickness of these sediments exceeds 5 km in the centre of the basin, gradually diminishing towards the margins. In the area of western Chalkidiki and Kassandra peninsula these sediments are classified into six (6) sedimentary formations:

1. Antonios Fm (?Lower - Middle up to Upper Miocene). Fluviolacustrine sediments, alternating lenses of loose Sands, cobbles and gravel.
2. Triglia Fm (Upper Miocene, Vallesian – Early Turolian). Continental sediments, Red beds.
3. Trilophos Fm (Uppermost Miocene, "Pontian", Turolian). Well stratified beds of fossiliferous sands, sandstones, clays, limestones, containing a brackish mollusc fauna of Paratethyan origin.
4. Gonia Fm (Pliocene, Ruscinian). Fluviolacustrine sediments consisting of lenses and beds of sand, clay, sandstone, marl and massive marly limestone.
5. Moudania Fm (Villafranchian and later). Continental sediments, Red beds.
6. Eleochoria Fm (Pleistocene – Holocene). Tuffaceous limestones and travertines deposited by the action of carstic or thermal springs, with a restricted occurrence south of Katsika mt.

The above sediments dip ~2-3^o towards SSE in the area of West Chalkidiki, but in Kassandra the dip direction is generally opposite, towards NNW. In northern Kassandra 4 of the above sedimentary formations appear:

- Moudania Fm covers the area from Nea Potidea up to Kallithea and Kassandria villages.
- Gonia Fm appears only in the west side of the peninsula at Sani area.
- Trilophos Fm appears as a hard fossiliferous limestone along the east coast while at the west coast (Sani) it outcrops as sands, clays and sandstones.
- Triglia Fm is exposed just below the Trilophos Fm which actually covers and protects the softer red beds.

The steep coastal terrace along the east coast, from Nea Potidaea up to Kallithea villages, forms a natural section ~ 15 km long that allows a good view of these sediments. Red beds of both Triglia & Moudania Fms dominate the whole section. The limestone of Trilophos Fm is interbedded between them, allowing the distinction between each other. Due to the slight NNW dipdirection, this limestone firstly appears at sea level in Nea Fokea village but southwards gradually rises up the top of the terrace.
Coastal erosion undercuts the terrace, favouring rock fall of large blocks of limestone; the latter is very characteristicsouth of Nea Fokea.

A stratigraphic column (Fig 2a) for the sediments exposed in the area of Nea Fokea – Athytos villages is given by Syrides (1990),

1. Red beds of Moudania Fm
2. Fossiliferous limestone consisting of numerous badly preserved shells of Limnocardiids and Dreissenids. 2a is oolithic with sparitic cement, 2b contains sand, 2c is a thin(~20cm)

bed of cohesive grey-white clay, 2d contains more sand that increases towards the base and contains also small pebbles and gravel the last well visible embedded at the base of this layer.

3. Reddish brown sandy loam. 3a is more sandy with thin lenses of gravel, 3b is more fine grained with thin bedding.
4. Fossiliferous sandy limestone contains also numerous badly preserved shells of Limnocardiids and Dreissenids. 4a reddish-brownish sandy limestone, 4b grey-whitish limestone more sandy at the base, 4c lose sand with sandstone concretions, 4d yellowish-grey to reddish yellow sandy limestone with Limnocardiids and Melanopsidae with more sand and embedded large cobbles at the base.
5. Red beds of Triglia Fm

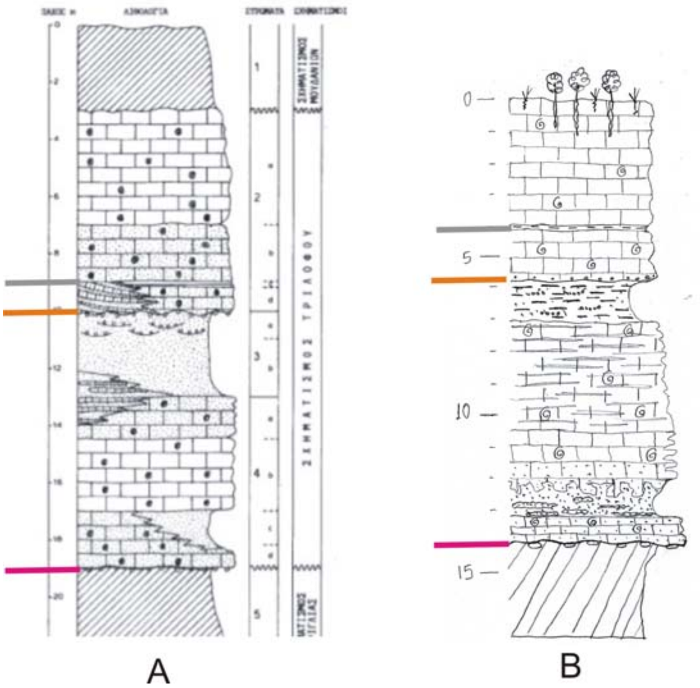

Fig 2. A) Stratigraphic column of the sediments in Nea Fokea – Athytos area (Syrides 1990) and b) stratigraphic column of the study area

4. Evaluating the triggering factors of the rock falls

On Wednesday 16th and Monday 21st of December 2009, rock falling took place on the Nea Moudania – Kassandria country road, between the 20th and 21st kms. Both of these slope instabilities fortunately caused only structural damages and no casualties.

More specifically, on Wednesday, December 16 at 21:30, two large size boulders of 6-8 m^3 detached from a height of 8 m and fell onto the road. This rock fall event forced the local authorities to temporally close the road for few hours in order to remove the fallen blocks and construct a new protective metal barrier along the steep slope of the road cut.

Fig 3. Source area of the rock falls occurred on December 16, 2009.

However, few days later, on Monday morning of December 21st, a larger scale slope failure happened. As shown in figure 4, boulders with volume ranging from 2 to $15m^3$ fell on the road form a height of 10 meters, causing the permanent closure of the country road. A few hours after the second slope failure, a field survey took place in order to examine the rock falls and evaluate the triggering factors.

Fig 4. Source area of the December 21, 2009 rock falls.

The present study focuses on the heavy rainfall activity that took place on 15th and 16th of December, a few hours before the first event, as well as on the rainfall that was recorded during Sunday, 20th of December. Furthermore, the stratigraphy of the site was studied, since a soil layer (sandy loam) is present beneath the source area of rock falls and finally, the structural status of the area and the discontinuities that created the blocks of limestone are analyzed.

5. Rainfall activity

Initially, the monitored precipitation at the Kassandra weather station was examined. The weather station of Kassandra (40º03'N, 23º 25'E, altitude = 37 m) was established by the Aristotle University of Thessaloniki (AUTH) only very recently (since 2007), thus the precipitation records of the period under investigation in Kassandra were compared with the normal values of the same parameter for the period 1961-1990 of AUTh (40º37'N, 22º57'E, altitude = 32 m). In particular, the monthly total rainfall in Kassandra in December 2009 was 68 mm (distributed in 15 days) (Fig. 5), 28% more than the normal amount (53 mm) AUTh received for this month during 1961-1990. The relatively wet December followed the severely dry months of October (6 mm vs. the normal value of 40 mm) and November (3 mm vs. the normal value of 56 mm) of 2009. However, from the above mentioned total amount Kassandra received in December, more than 81% of rainfall (or 56 mm) dropped in one single day (16/12/2009). Although this specific rain episode lasted all day (Fig. 6), more than 80% (45mm) of rain was measured from 21:00 to 22:00 local time.

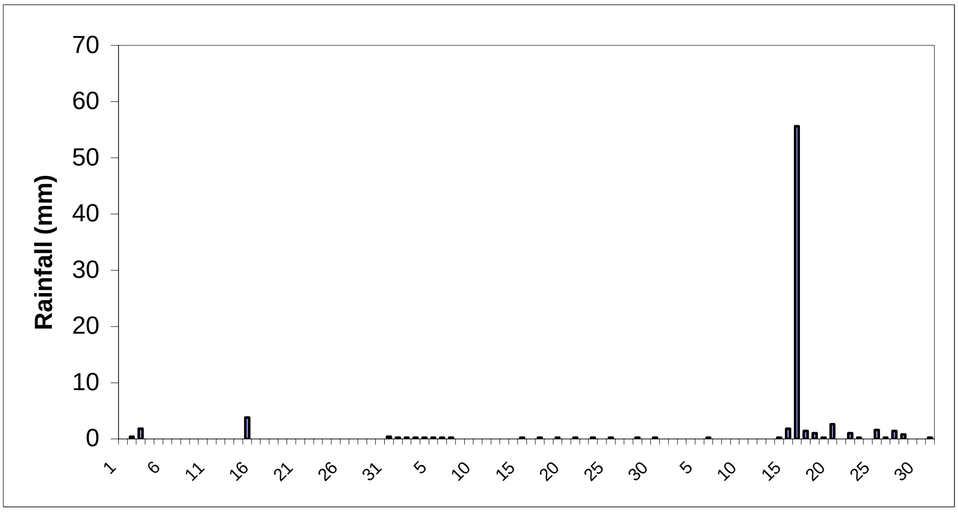

Fig. 5. The daily precipitation in Kassandra from October 1st to December 31st 2009. The normal precipitation values (1961-90) of the weather station in AUTh are also presented.

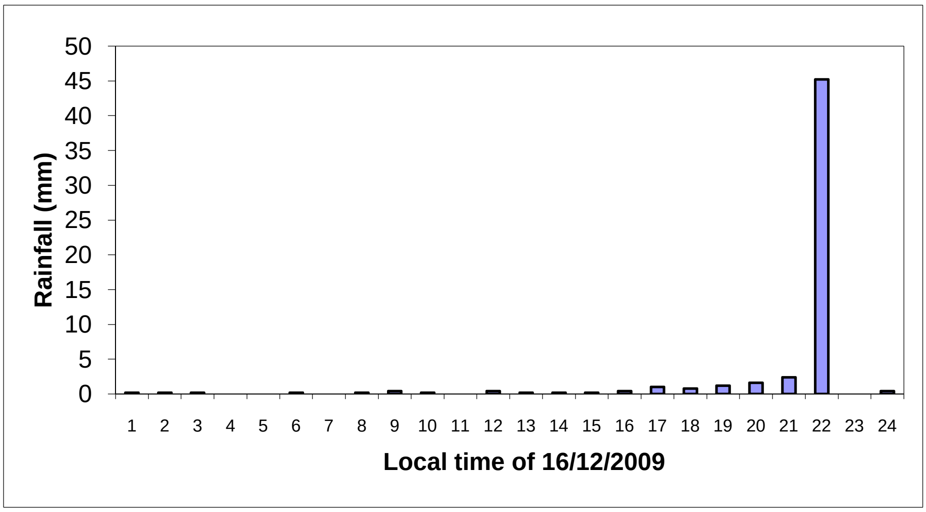

Fig. 6. The hourly precipitation in Kassandra at 16/12/2009.

6. Stratigraphy

The stratigraphy (fig 2b) of the sediments along the rock falls is very similar with that (fig 2a) of Syrides (1990) for the wider area, while differences are observed due to the lateral changes of the various beds.

From a stratigraphic point of view, three "weak horizons" of low strength are defined in this column (fig 2b); a thin layer of grey-whitish cohesive clay (bed 2c) pointed as grey line, a second layer of reddish-brown sandy loam (bed 3) (red line depicts the contact between 2 and c beds) and a third layer defined as the contact (violet line) between the base of the Trilophos Fm limestone and the Triglia Fm red beds.

It is remarkable that within the limestone numerous vertical cracks allow the percolating water to pass downwards, but the intercalation of reddish-brown sandy layer (bed 3) between the limestone beds causes the drying up of the water from the superimposed limestone along this contact. As a result, thick reed vegetation appears along and below the contact. It is also remarkable that this bed of reddish sandy loam prevents water from percolating in the lower strata, resulting to the dryness of contact between the base of the limestone (Trilophos Fm.) and the top of the red beds (Triglia Fm.).

Regarding the influence of stratigraphy to the triggering of rock falls, Kotze (2007) stated that any soil stratum that intercalates between or appears below a thick hard rock bed can be considered as a "weak horizon" that is subject to preferential weathering and erosion with ongoing exposure to the elements. Thus, the overlying more resistant limestone beds become undercut. As undercutting advances, the overlying limestone eventually collapses, due to sudden brittle failures occurring along prevalent rock mass defects that act as release planes.

In our cases, the above conclusion precisely describes one of the triggering factors (stratigraphy) and the unstable conditions that were created these specific two days (16th and 21st of December 2009), thus concluding that in both cases the rock falls were generated by the undercut of the reddish brown sandy loam bed.

Fig 7. The layer of reddish-brown sandy loam is slowly washed out by the percolating water from the overlying limestone (note the beginning of undercutting). The water favors thick reed vegetation. It is a matter of time this slow process to undercut the limestone causing a rockfall in this place in the future.

7. Structural setting

The main structure of the study area is a WSW – ENE trending normal fault, which causes the displacement of the strata by about 12-15 metres. The amount of displacement is not clear, because of the lack of outcrops. The fault dips towards the NNW and the visible fault zone has a width of about 20 m. The actual fault zone however is much wider, as is indicated by the intense relief just on the north of the site: a transverse valley of the same WSW – ENE trend is formed due to the erosion of the main fault zone, which is probably located along this valley. The observed normal fault is therefore a synthetic footwall secondary fault, and it is characterized as possibly active since its strike is perpendicular to the extensional axis of the local stress field.

The strata appear to have a gentle dip towards the SSW (fig. 8), while their strike is similar to the road cut direction; dip direction however is opposite to the road cut's one, reducing the possibility of water saturation to the road cut. The dip direction of the strata can be associated to footwall rebound backtilting, which is typical in areas adjacent to a fault zone.

The dominant joint system has a strike of 075^o - 080^o, parallel to the above mentioned normal fault, while a conjugate secondary system of much less importance trends at about 030^o. All joints are of high angle (>75^o) and most of them almost vertical (fig. 8). They are open joints, typically filled with fine-grained material and calcite, while at their uppermost part they sometimes appear eroded and have a heave of up to 3 cm.

The joints appear to affect the pavement of the connecting road to the nearby hotel. A set of cracks is aligned in deformation zones in *en échelon* and overlapping pattern. These zones are parallel to the main fault and they have formed as a result of both the pre-existence of joints, as well as the soil creep towards the road cut (hence their “strike-slip” appearance).

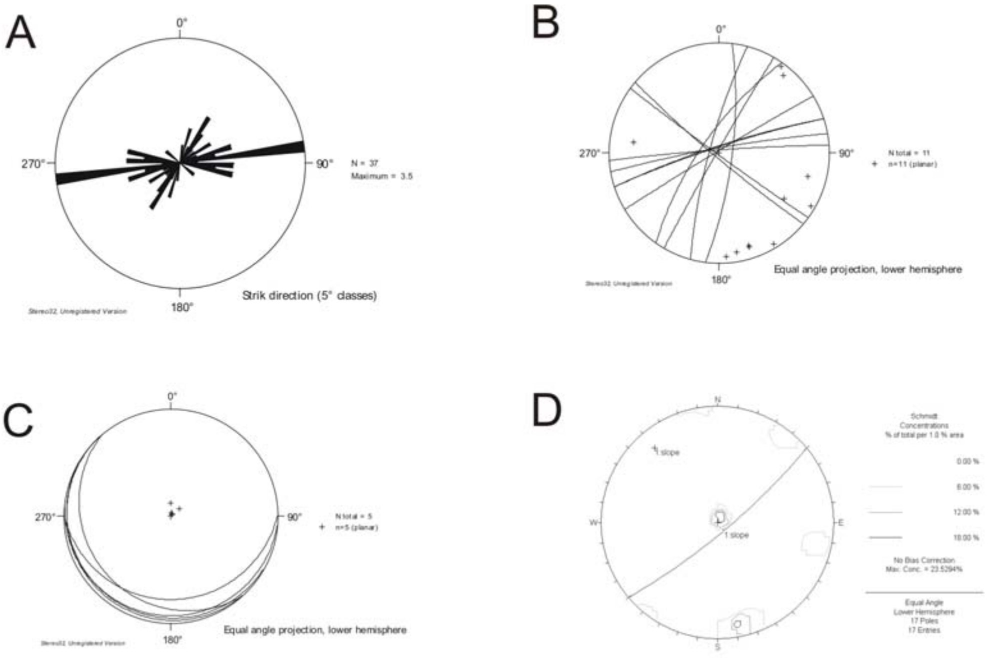

Fig 8. a) Rose diagram, b) joints stereoplot, c) bedding stereoplot and d) contour plot in the source area of the rock falls. The *bold line* in the contour plot represents the general orientation of the slope

8. Conclusions-Results

On the 16th and 21st December 2009, rock falls 0ccured at the eastern coastal area of Kassandra peninsula in northern Greece. This study aims to describe the characteristics of the slope failures and evaluate their triggering factors. In particular, we examined the rainfall activity, the stratigraphy and the tectonic regime in the area. According to data from the weather station in Kassandra, more than 81% of rainfall (or 56 mm) of the total amount for December, dropped in one single day (16/12/2009). Moreover, the dense system of discontinuities in combination with the subhorizontal bedding plane, under the effects of weathering, divided the limestone bed into a series of contiguous blocks or slabs. All the fallen blocks of rocks originate from the layers above a layer of reddish sandy loam. The outcome provided by this study is that the rock falling phenomena in Nea Fokea were generated due to the undercut of a specific layer of reddish brown sandy loam bed, as consequence of extremely high precipitation.

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