Effect of forest presence on rockfall trajectory. An example from Greece

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Abstract
The impact of falling rocks on human activities can be hindered using protection measures such as rockfall barriers, embankments and other passive structures but also through the presence of forests. In order to study the effect of a forest on rockfall trajectory, a site neighboring a village in Central Greece was selected which has a well-recorded rockfall history in the last 50 years. The village is limited by a relatively dense forest, which lies on a limestone scree slope. An assessment of the role played by the forest stands on the site was done using the Energy Line Angle concept and conclusions on the residual rockfall risk on houses are drawn.

Keywords
Rockfall Forest Impact energy Limestone

337.1 Introduction

Based on case studies in the European Alps, a significant number of rockfalls have been stopped in forests that are upslope of many roads and settlements. These cases show that forests offer an ecologically friendly and cost efficient alternative to technical protective measures against rockfall as confirmed by Berger (2012), Bigot et al. (2009) and Dorren et al. (2005).

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337.2 Case Study in Greece

337.2.1 Introduction

The study site is located in Tithorea, which lies in the foot of mountain Parnassus. The site is appropriate for demonstration of rockfall analysis in forested slope since it fulfills the following criteria: (a) steep topography adjacent to human activities, (b) recorded rockfall history with impact on village houses, (c) high rockfall risk and (d) presence of forest. The forest surrounding the village is relatively dense and lies on the scree slope. A number of rockfall episodes have occurred in the past (1957, 1999) and a more recent one (in 2010), which caused considerable damage to houses (Papathanasiou et. al. 2011; Saroglou 2013).

337.2.2 Geomorphology—Geological Conditions

The steep slope overhanging the village is formed in karstic limestone and has a maximum height of 280 m and almost vertical slope angle. The scree slope resting at the limestone slope foot has a height of 120 m and an angle of 30 to 35°

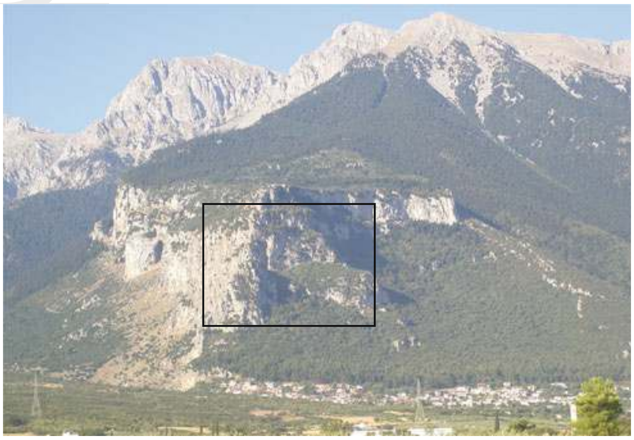

Fig. 337.1 Study site in Tithorea, Greece

(Fig. 337.1). The geological formations encountered on site are: (1) talus scree with finer texture (sandy gravel) in the area of the village (2) debris flow deposits, (3) talus scree forming the slope between the village and the foot of the steep slope, (4) fallen limestone blocks on scree slope, (5) thick bedded upper Jurassic limestones with karst forming the steep limestone slope and (6) Triassic dolomite. Large rock boulders with volumes between 30 and 60 m^3 and few with volumes up to 350 m^3 are encountered on the scree slope (Fig. 337.2). The deposited rock blocks, past rockfall impacts on houses and known trajectories are presented on the geological map in Fig. 337.2.

The limestone rock mass is intersected by three to four distinct discontinuity sets, which are mostly wide to very wide to the stress relaxation of the steep slope. The distance of discontinuities ranges between 0.5 and 2.5 m, resulting in orthogonal and tabular blocks with volumes up to 10 m^3. Based on the size distribution of detached blocks on the limestone face the majority of the blocks (35 %) have volumes smaller than 2.5 m^3 and 25 % between 2.5 and 10 m^3 (Fig. 337.3b). A certain number of very large rocks (10 %) with volumes greater than 20 m^3 and up to 140 m^3 exist, which if detached from the cliff can have a serious impact on the houses.

The potential rockfall release areas have an elevation between 650 and 880 m, while the village extremities reach

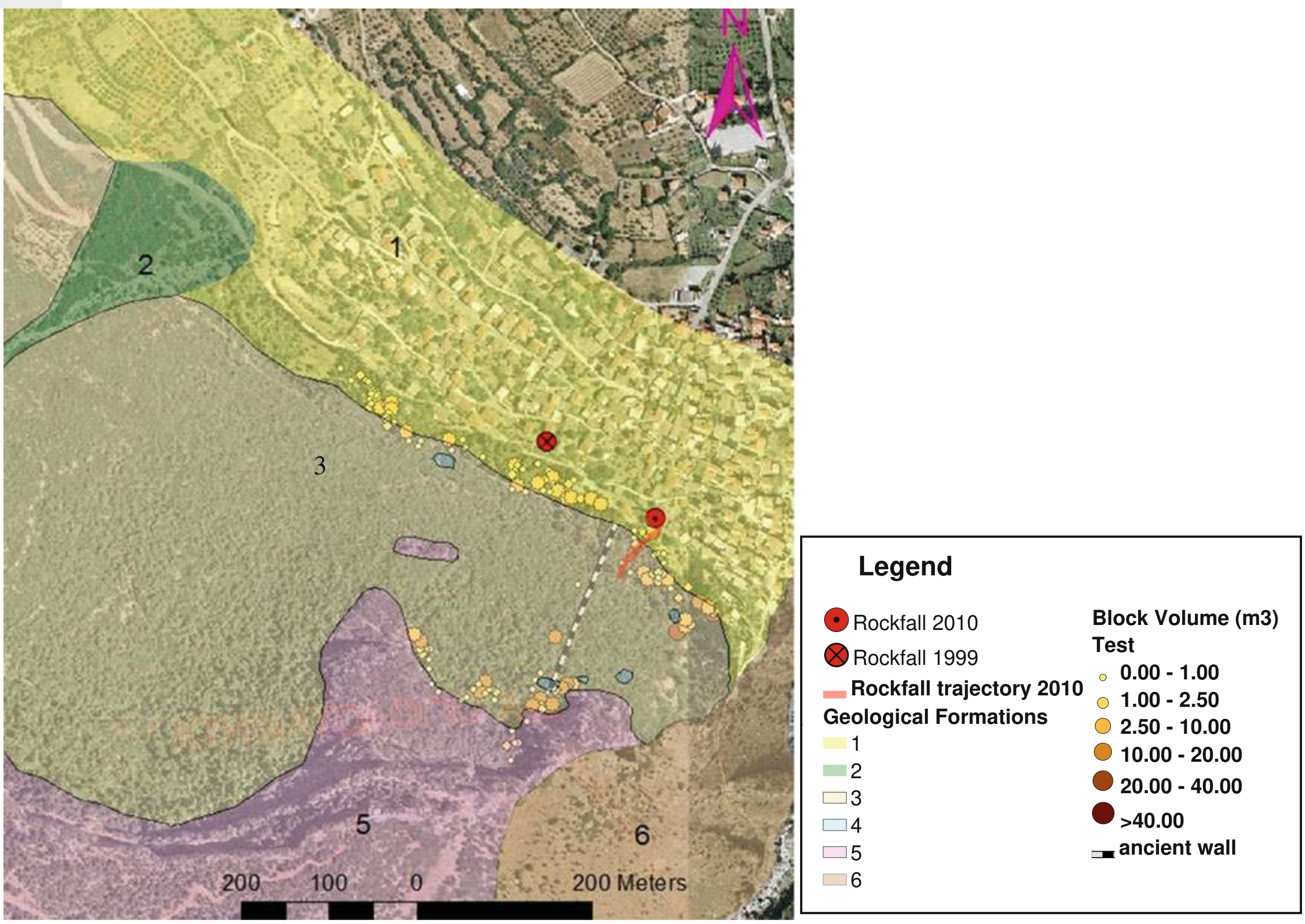

Fig. 337.2 Geological map of study site showing deposited rocks (*total* 475 *blocks*), past rockfall events and known trajectories

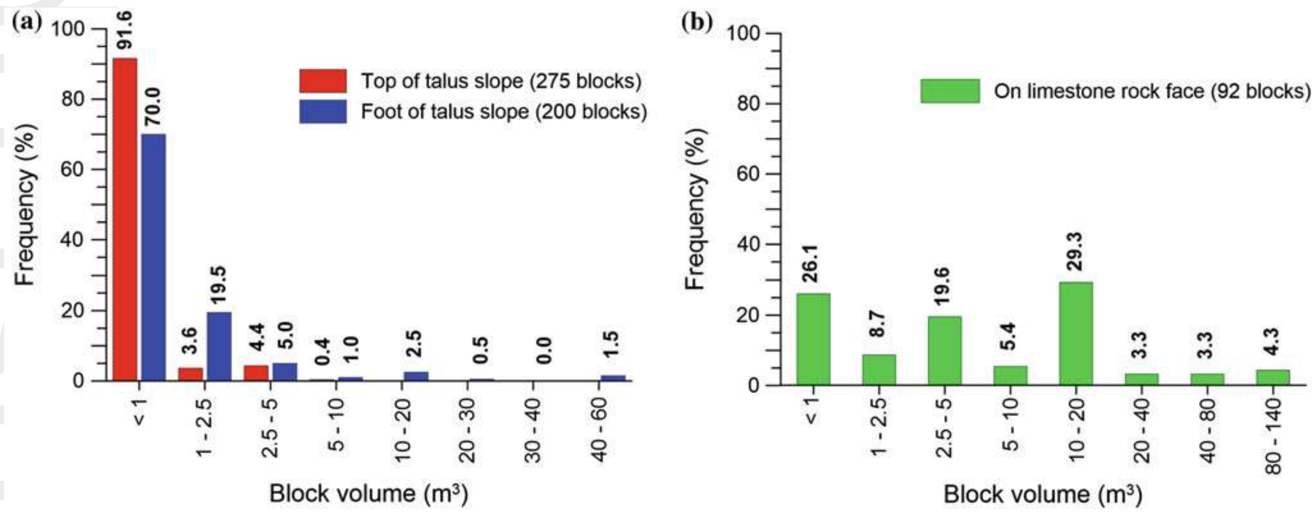

Fig. 337.3 Distribution of volume of rock blocks **a** fallen at the top and foot of talus slope, **b** unstable on the limestone slope

an elevation of 470 m. The most prone area of the cliff is its southeast side, where the 2010 episode has occurred.

337.2.3 Rockfall History

The distribution of fallen rocks in recent and historical times was depicted during field survey and emphasis was given in two areas: (a) at the foot of the limestone steep slope and (b) down slope near the houses, as shown in Figs. 337.2 and 337.3. The majority of blocks at the slope foot (85 %) have a volume less than 0.5 m^3 while a 5 % has a volume between 2 and 10 m^3 (Fig. 337.3a). Considering the size of potentially unstable blocks on the slope, it can be concluded that falling rocks break during the first impact at the foot of the slope before continuing their downslope movement. This is further supported by the fact the volume of blocks reaching the outskirts of the village is primarily less than 2.5 m^3 with a percentage of 90 % (Fig. 337.3a). The large rock boulders with volumes between 30 and 60 m^3 and up to 350 m^3 encountered on the scree slope are probably connected with historical extreme rockfall events. Evidence from impact on houses exists only for the episodes during 1957, 1999 and more recently in 2010, which are all triggered by intense rainfall during the winter period. The rockfall impacts on the ground and trees during the 2010 episode are presented in Fig. 337.2. Rockfalls of medium sized blocks (up to 1 m^3) occurred during a near field earthquake on the 7th of August 2013 with a magnitude of 5.2 Richter and were arrested by trees at the upper part of the scree slope.

337.3 Rockfall Analysis

A first analysis was performed using with Rockfor^{NET} (Beger & Dorren). This tool gives a first evaluation of the residual risk above a forested slope. Four different boulders volumes have been used according to the past events deposit boulders volumes present on the slope. These volumes are 2.0, 1.0, 0.5 and 0.125 m^3. The shape of the boulders is a rectangle one. The results are presented in Table 337.1.

The minimal percentage of residual risk has been fixed by construction to 1 %.The rockfall trajectory model Rockyfor 3D (Dorren 2012) has been used in order to have a better assumption of the risk generated by the most productive release areas for the study site of Tithorea. This productivity has been defined using the spatial distribution of past events deposit boulders, the number and spatial distribution of injured trees, and a geomorphologic analysis of the cliffs. The rockfall analysis was based on a digital elevation model of the site.

Table 337.1 Results obtained with Rockfor^{NET}

Boulder volume [m^3]	Residual risk [% of rocks not stopped within the forested zone]
2	75
1	50
0.5	5
0.125	1

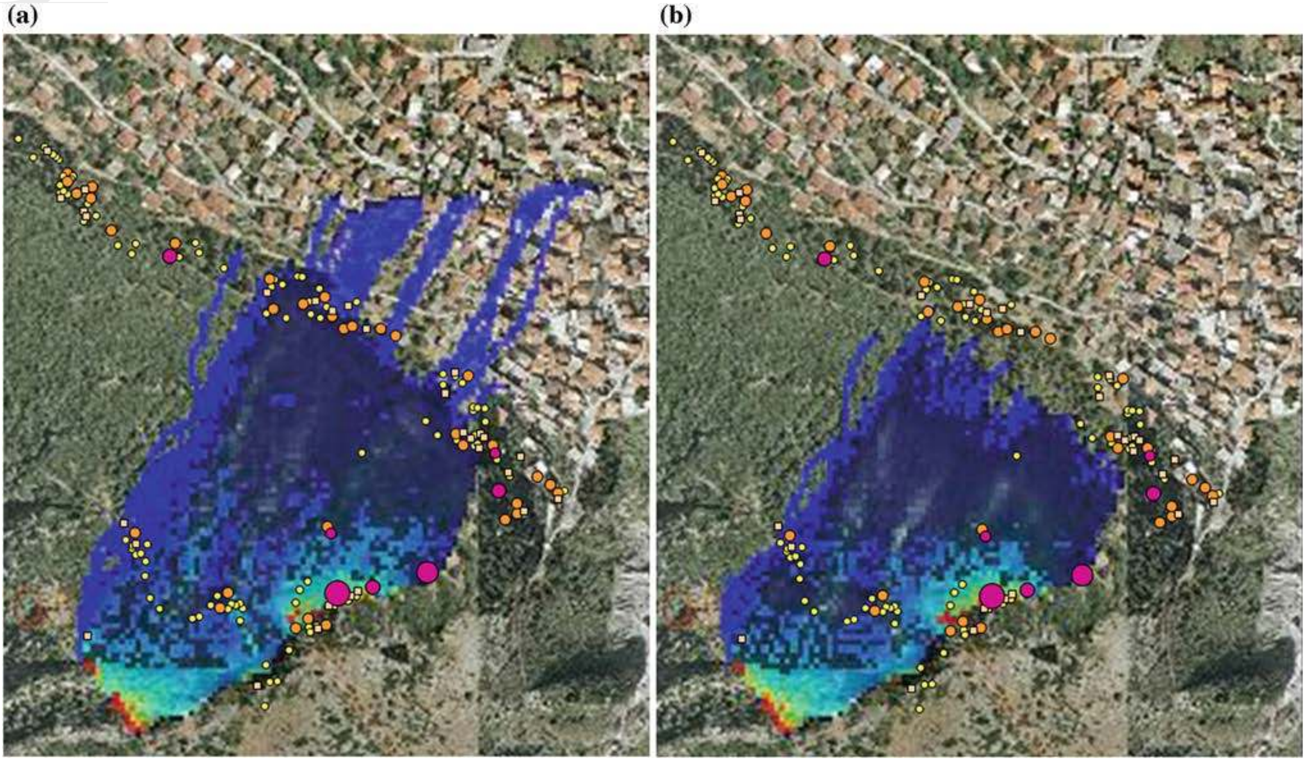

Fig. 337.4 Maps of the reach probability with the draping of the number of deposit for boulders of 0.5 m^3. **a** without taking into account the presence of forest stands, **b** with the action of forest stands. For scale and legend refer to Fig. 337.2

Figure 337.4a, b presents the results obtained for the reach probability and the number of deposit. The info coming from the number of deposit has been draped on the map of the reach probability. The simulations have been done without and with taking into account the presence of the forest stands.

In conclusion, the upper part of the village of Tithorea is endangered by rocks having a volume equal or superior to 1 m^3. Up to this volume of 1 m^3 the current forest stands are able to provide an efficient protection by reducing from 99 to 50 % the number of rocks with a volume of less or equal to 1 m^3.

The following conclusions are evident:

1. The upper part of the village of Tithorea is endangered by rockfalls.
2. If the current forest stands are very efficient (the majority of the deposit points are located in the last down slope forested band or the versant) there is still a residual risk proofed by the 3 rocks, which have reached the village.
3. The residual risk below the forest area is about 1 % (3 rocks in the village for 275 deposit points under the forest canopy).

337.4 Conclusions

The effect of forest presence on rockfall was performed for Tithorea site using three-dimensional rockfall analysis. The analysis showed that the upper part of the village is endangered by rockfalls having a volume equal or superior to 1 m^3. Up to this volume of 1 m^3 the current forest stands are able to provide an efficient protection by reducing from 99 to 50 % the number of rocks with a volume of less or equal to 1 m^3. In order to increase this protection, the main objective of the sylvicultural actions to be done is to increase the value of the basal area of the stands.

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