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Analysis of impact of hydro-meteorological events on alluvial fans: a case study in Calabria (Southern Italy)

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INTRODUCTION

Calabria (southern Italy) is a region where alluvial fans occur widely. In this region, the presence of mountain fronts and alluvial and/or coastal plain, or deep and narrow valleys debouching into larger valleys is fundamental to the formation of this landform type. The majority of recent alluvial fans are debris-flow dominated; therefore, they must be linked with phases of increase in landsliding activity within their feeder basin and they are areas where debris-flow hazard is high. This paper presents a case study of an area along the Tyrrhenian coast of Calabria where a set of mountain front alluvial fans develops on the narrow coastal plain. In particular, in October 2010, a long rainfall event triggered shallow landslides and erosion processes in this area that caused risk conditions for the population and damage to private properties and infrastructures located on the alluvial fans. The study presents firstly a description of the morphological events that occurred in this area and the consequent damage produced along the coast. Then the paper reports a characterization of the rainfall event that triggered the phenomena. The results could be used for further future studies to plan measures for risk reduction and for emergency management in an area of high natural hazard.

The study area

The case study is a 9 km long segment on the Capo Vaticano peninsula (southern Calabria) along the Tyrrhenian seacoast of Calabria Fig. 1. In the study area, the Monte Poro granitic complex (Amodio-Morelli et al., 1976) constitutes the Paleozoic basement. The granitic rocks are characterized by deeply weathered conditions. Miocene sediments made of sandstones and sands lie in transgression on the igneous rocks. Both on the Paleozoic basement and on Miocene sediments, terraced deposits (Pleistocene), of sea origin, crop out. During Late Pliocene-Early Quaternary times, the Capo Vaticano peninsula was dissected by normal faults mainly striking NE–SW and WNW–ESE. Since the Middle Pleistocene, the extensional phase was coupled with a strong regional uplifting (Tortorici et al, 2002). This resulted in the formation of numerous marine terraces, which are the largest and most spectacular effect on the coastal landscape.
The morphology of the study area, conditioned by Quaternary tectonic uplift and cyclic sea-level changes, consists of a flight of marine terraces bounded by well-developed inner edges. The coast is characterized by narrow beaches which border paleocliffs. Moreover, narrow and deep canyons dissect the steep slopes. At the mouths of the canyons a set of recent alluvial fans extends on the narrow coastal plain. Almost all the fans are debris-flow dominated, therefore they are to be linked with phases of increase in the landsliding activity within their feeder basin. Around the second half of the last century, these fans were affected by human activities, including buildings, also seasonally used, and related infrastructures,

roads and lifelines. Moreover, this area is also one of high-impact tourism resorts, where hotels and tourist harbours have been developed on alluvial fans.

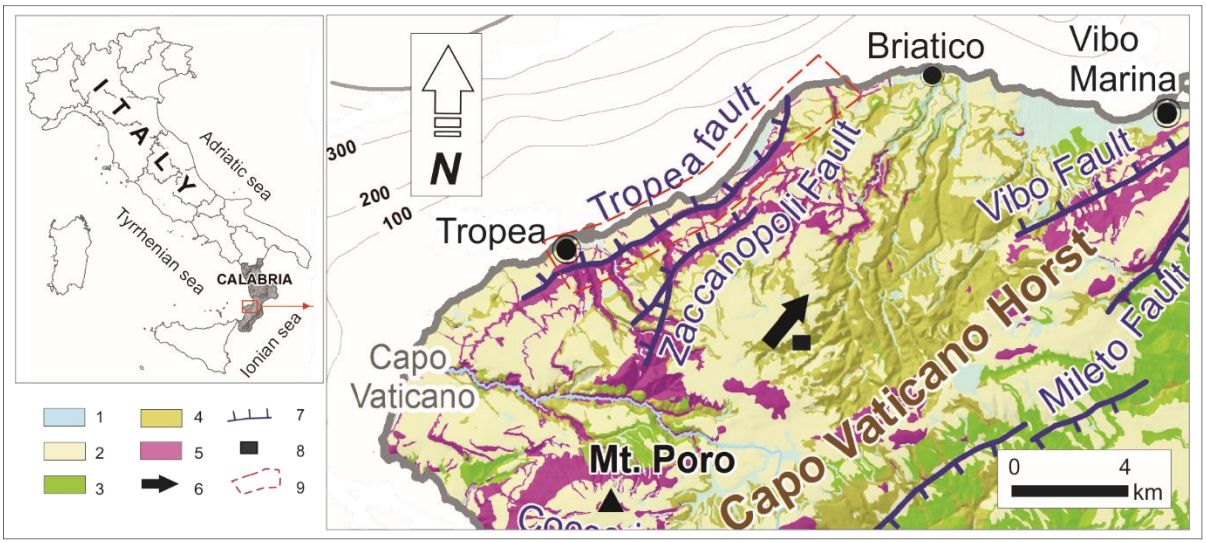

Fig.1 Geological setting of the study area (from Tortorici et al., 2002, modified). Key to the symbols: 1) alluvial and coastal deposits (Holocene); 2) conglomerates and sand (Pleistocene); 3) clayey deposits (lower Pliocene–lower Pleistocene); 4) terrigenous and evaporitic sediments (upper Miocene); 5) crystalline basement rocks (Monte Poro complex); 6) tilting direction; 7) Quaternary normal fault; 8) rain gauge of Zungri; 9) study area.

Because of its geographic position and mountainous nature, Calabria is characterized by a high variability of climate, known as Mediterranean climate, with a typically dry subtropical summer. The study area, as with the whole Tyrrhenian side of the region, is influenced by western air currents, and it presents considerable orographic precipitation. The yearly rainfall of the area ranges within 300-600 mm (Ferrari et al., 2013) and it is much lower than the average regional value that is about 1,100 mm.

October 2010 event

In October 2010 consecutive rainfall events occurred in several parts of Calabria. Figure 2a shows the rainfall event distribution in 2010 observed at Zungri rain gauge, located about 4 km away to the North from the study area. In particular, a long rainfall event was registered, starting on 9 October and ending on 21 October (Fig. 2b). The cumulative rainfall height was 272.4 mm and the maximum daily rainfall of the event (127.2 mm) was registered on 18 October. Considering all the rainfall events registered at the Zungri rain gauge from 2008 to 2010, a very rainy period for the whole Calabrian territory (Antronico et al., 2013; Gullà et al., 2009), the highest cumulative rainfall height was registered during the event of October 2010. Moreover, Figure 3 shows the distribution of the yearly maximum values of the daily rainfall registered at Zungri station in the period 1951-2013, not considering the years with missing values (about 8% of the whole data set). Almost all the values range within 40-100 mm. Only 4 years present maximum daily data greater than 100 mm: 1954, 1959, 1973 and 2010: the maximum values of 1954 (148.4 mm) and of 1973 (139.1 mm) were higher than the value registered on 18 October 2010 (127.2 mm). Moreover, a statistical interpretation of historical maximum yearly values of daily rainfall was carried out using a Gumbel distribution, with parameters β and μ equal to 18,955 and 56,850, respectively, estimated by means of the sampling data. According to this distribution, the return period (expressed as the frequency that a certain rain event would be exceeded) corresponding to the 18 October 2010 rainfall value results about 42 years.

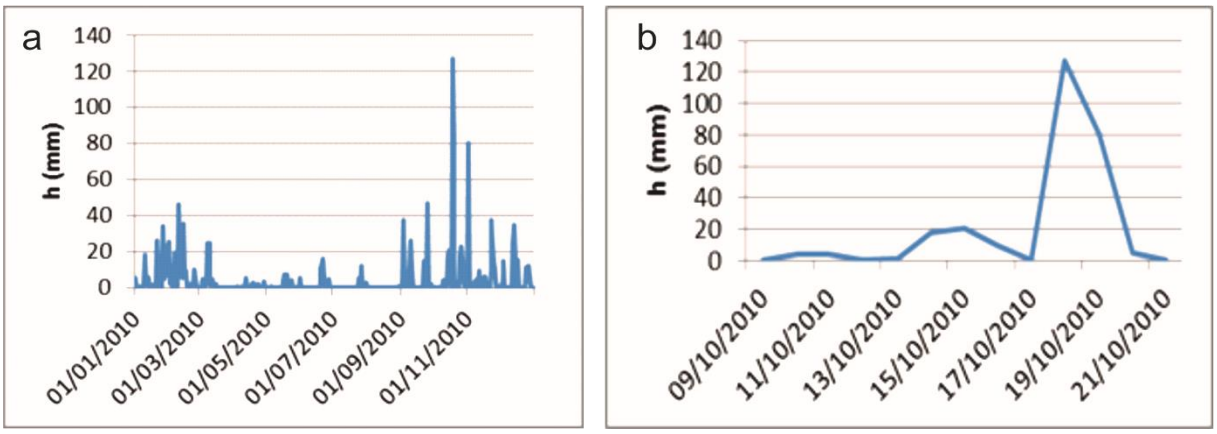

Fig. 2 Distribution of daily rainfall heights in the year 2010 (a) registered at Zungri rain gauge and in particular during the event of 9-21 October (b).

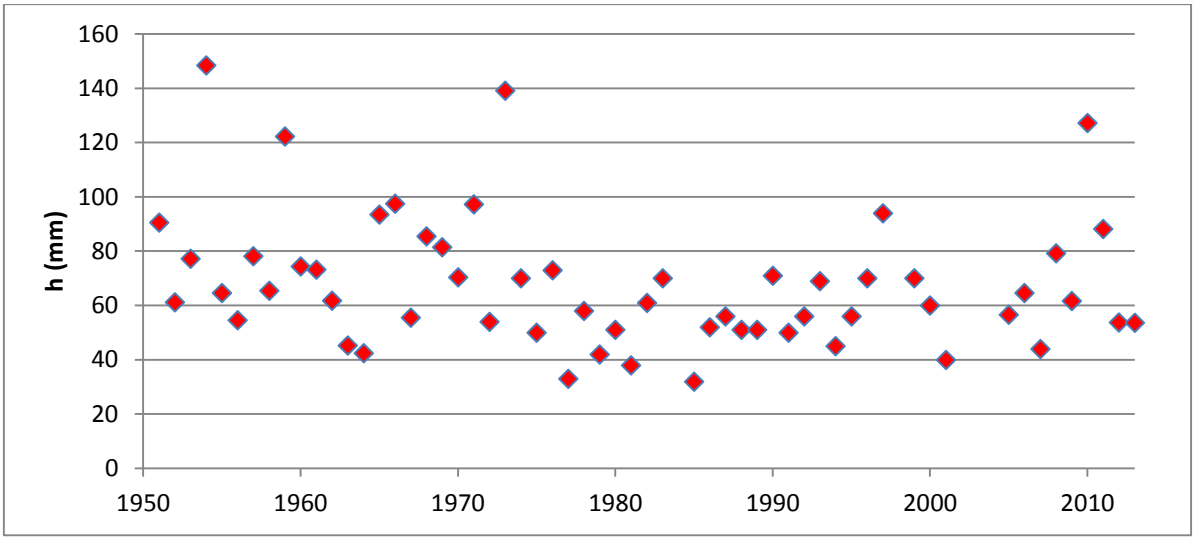

Fig. 3 Yearly maximum values of the daily rainfall registered at Zungri station for each year of the observation period (1951-2013).

From 18 to 19 October the rainfall event produced extensive and strong effects on the southern Tyrrhenian coast between the villages of Tropea and Zambrone (province of Vibo Valentia). Shallow landslides and erosion processes, triggered by the rainfall event described above, produced relevant debris volumes that, including further water, travelled with considerable velocity along the deep canyons (Fig, 4). Moreover, diffused erosion phenomena of the stream beds occurred. The detrital material was deposited on the terminal reach and on alluvial fans reaching a thickness of a few meters. Shallow instabilities occurred mainly on steep slopes along the incisions and involved granitic rocks that in the study area are reduced to residual and saprolitic soils even for significant thickness.
Consequently, risk conditions for the population and damage to private properties and infrastructure located on the alluvial fans occurred. At the outlet of the canyons, the mixture of coarse sediment (including boulders) and water, covering the surface of the alluvial fans, partly buried the roofs of some buildings, roads and underpasses. Figure 5 shows the damage caused by debris flows to buildings situated on the fans present at the mouths of the incisions of T. Zinzolo and Petosa.

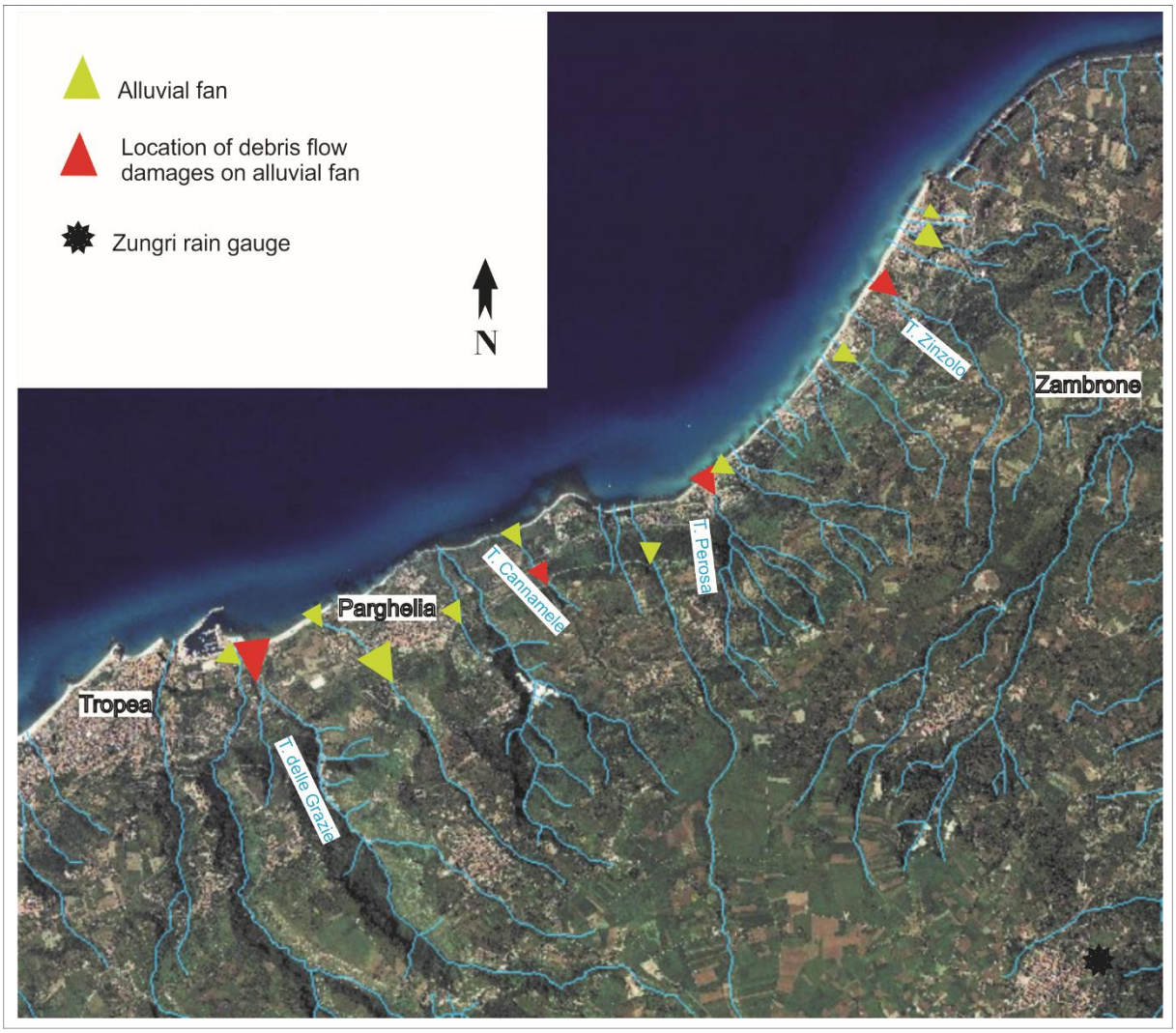

Fig. 4 Map of recent alluvial fans in the study area and indication of the locations where debris flow damage occurred during the October 2010 event (red). Google Earth® 2011 images.

Fig. 5 Examples of the debris flow damage caused by the October 2010 event to private property (a) and hotel (b) building on alluvial fans. Imagery from http://www.youtube.com.

Massive amounts of sediment, moving rapidly through the steep narrow incision of the T. delle Grazie, also invaded the tourist harbour of Tropea and the adjacent roads (Fig. 6). The tourist harbour of Tropea is located near the distal part of the T. delle Grazie alluvial fan. Historical records indicate that the fan was formed owing to the collapse of a natural dam caused by a landslide around 1873 (Antronico and Sorriso, 1996).

Fig. 6 Alluvial fan of the T. delle Grazie. In the box, damage to Tropea harbor are shown. *Google Earth® 2011 images.*

Following these events, some safety measures were adopted including the evacuation of more than 100 inhabitants and tourists.

Discussion and conclusions

In the international literature, it is now widely recognized that alluvial fans are areas of high geomorphic activity. Debris flows and flash floods occur episodically in these environments, and place many communities at high risk during intense and prolonged rainfall (Larsen, 2001).

The analysis of this study case evidenced that the risk due to the debris flow and the vulnerability of the area are increasing as a consequence of both the reactivation of construction processes in the alluvial fan feeder basin and the intense development of human activities on the same areas. In fact, historical and archaeological records indicate that the alluvial fans present in the study area, and along the Tyrrhenian coast of Calabria, experienced periods of intense activity of construction processes (mainly debris flows) during 18th and the end of 19th century (Antronico and Sorriso-Valvo, 1996). Moreover, population expansion on alluvial fans increased the risk for people. Consequently, a non-extreme pluviometric event, like the one that occurred in October 2010 with rainfall heights characterised by a return period of about 42 years, can cause damage to buildings and

infrastructures. Lastly, in the study area, the steep slopes where weathered and fractured granitic rocks crop out are areas of potential and dangerous debris sources.
The results obtained could be used for further future studies with the following aims: a) to assess the variation of the social and economic impact of hydro-meteorological events on the alluvial fan; b) to identify potential rainfall thresholds triggering landslide phenomena and debris flows in the study area; c) to define rainfall scenarios involving the generation of extreme hydro-meteorological events, d) to plan measures aimed at risk reduction and at emergency management.

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