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A PECULIAR HISTORY OF DESTRUCTION IN THE OLD VILLAGE OF CASTEL FRENTANO, CENTRAL ITALY, FROM RECONSTRUCTION OF LANDSLIDE EFFECTS FOLLOWED BY EARTHQUAKE DAMAGE IN 1881.

Simone Racano[1], Sara Amoroso[2-3], Matteo Del Nobile[4], Fabrizio Galadini[3]

[1] Universität Potsdam, Institute für Geowissenschaften, Potsdam, Germany.
[2] Department of Engineering and Geology, University of Chieti-Pescara, Pescara, Italy.
[3] Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.
[4] Writer and journalist, Castel Frentano, Italy.

Corresponding author: Simone Racano < racano@uni-potsdam.de >

ABSTRACT: Anthropogenic modifications of the landscape (e.g. urbanization, deforestation and agricultural activities) act as geomorphic processes, producing fast changes and instabilities, which often lead to landslides along hillslopes and floodings in lowlands. Anthropogenic modifications have increased with the progress of civilization; therefore, coupling historical information and geomorphological data can provide key information to determine the anthropogenic impacts on landscape evolution. The case of Castel Frentano, a village in the Abruzzo Region (Central Italy), has been analysed to shed light on the causes of its destruction in 1881: during the summer of that year, the village was heavily damaged by a peculiar succession of paroxysmal events, i.e. a massive landslide followed by a strong earthquake. This earthquake induced additional damages to the buildings, due to seismic shaking and slide reactivation. This study involved geomorphological and geological surveys, which were aimed at mapping and defining the main presently active geomorphic processes in the area of interest; moreover, we researched 19th-century historical documents to reconstruct the genesis and evolution of the events that led to landsliding in 1881. Although the study area has always been prone to instability phenomena (due to its local geological and geomorphological characteristics), our results revealed that sliding was most likely triggered by human activities that had strongly modified the hillslope. Historical sources revealed a general hillslope instability that progressively evolved in the 1881 landslide because of deforestation. That deforestation had been carried out for agricultural exploitation on a previously stable territory. In this view, the case of Castel Frentano exemplifies the relationship between human activities, landscape modifications and their consequences in Italy in terms of risks to both natural and anthropogenic environments. This is particularly important to assess at present: in a historical period characterized by economic growth, strong demographic expansion and the consequent fast colonization of natural spaces.

Keywords**:** historical geology, human impact, natural hazards, urban changes, landscape response.

1. INTRODUCTION

The integration of History and Earth Sciences can lead to the production of datasets useful for understanding the impacts of past geological processes on human communities. The collection of historical information has always been of great importance for reconstructing climatic, environmental and landscape changes, and particularly to determine the evolution of flood and landslide risks (Guzzetti et al., 2005; 2012). Four basic pieces of information were identified by van Westen et al. (2006) to support landslide risk assessment and management: (1) landslide inventories, (2) information on the environment surrounding the landslides, (3) information on the landslide triggers and (4) information on the elements at risk (in the past or in the present). The integration of several methods is necessary to produce reliable information that can be combined with geotechnical quantitative data in view of modelling (e.g. remote sensing and photogrammetry, Soeters & van Westen, 1996; geomorphological field investigations, Brunsden, 1985) and public reporting/interviews and archival research for historical contribution (Tropeano & Turconi, 2004; Salvati et al., 2009).

In general, landslide occurrence is controlled by several predisposing factors (e.g. topography, geology and human activities, Arca et al., 2018) and trigger processes (e.g. rainfall, glacial melting, stream and coastal erosion, earthquakes and volcanic eruptions, Lichkov, 1938; Crandell et al., 1984; Keefer, 1984; Mathewson et al., 1990; McInnes, 1996; Suarez, 1996). Moreover, several researchers have argued that urbanization impacts landslide risk by influencing the severity and frequency of landslides, as well as the extent and value of building exposure and the degree of vulnerability to damage (Smyth & Royle, 2000; Douglass et al., 2005; Fedeski & Gwilliam, 2007; Mandasari et al., 2016; Zope et al., 2016). If the fragility of a territory depends on the interrelation of natural and anthropogenic factors, then historical knowledge about landscape changes caused by human action and land use is necessary to completely understand the predisposing factors (Dapples et al., 2002; Glade, 2003; Alcántara-Ayala et al., 2006; Beguería, 2006; Gariano et al., 2018).

The Castel Frentano landslide (CFL) represents a case study in Central Italy (Fig. 1). In this study, it was investigated through a combination of geological and historical approaches to clarify the evolution of natural processes and their impacts on surrounding buildings. During the summer of 1881, Castel Frentano, a typical Italian hillside village of medieval origin, suffered the effects of a massive landslide that occurred on its eastern hillslope. This event was followed a few weeks later by a 5.4-magnitude earthquake that struck the central Periadriatic sector, as reported in Nature Notes (1881): "*On Thursday (September 10th) last, at noon, further shocks of earthquake alarmed the inhabitants of Orsogna, Lanciano, and Castel Frentano, where a landslip did serious damage*" (Nature Notes, 1881).

Differently from many other landslide cases in Italy, which were triggered by earthquakes (e.g. Agnesi et al., 1983; Chiodo et al., 1999), the CFL occurred before a seismic event and was sufficient to cause significant building collapses and damages. The successive earthquake induced further significant damages and the reactivation of the slide about 40 days after its first trigger. This peculiar combination of slope sliding and seismic shaking determined a "continuous" building damage through a period of several months.

Although the CFL has been already studied from a geotechnical point of view (Mancini et al., 2001), the genesis and evolution of the event, as well as the predisposing factors and triggers, are still not clear. Through this study, we investigated the factors that conditioned the CFL in 1881: we combined geological, geomorphological and topographic information about the eastern hillslope of Castel Frentano with historical information (not limited to the events of that year, but extending to preceding times). After defining the geological framework and describing the 1881 earthquake event,

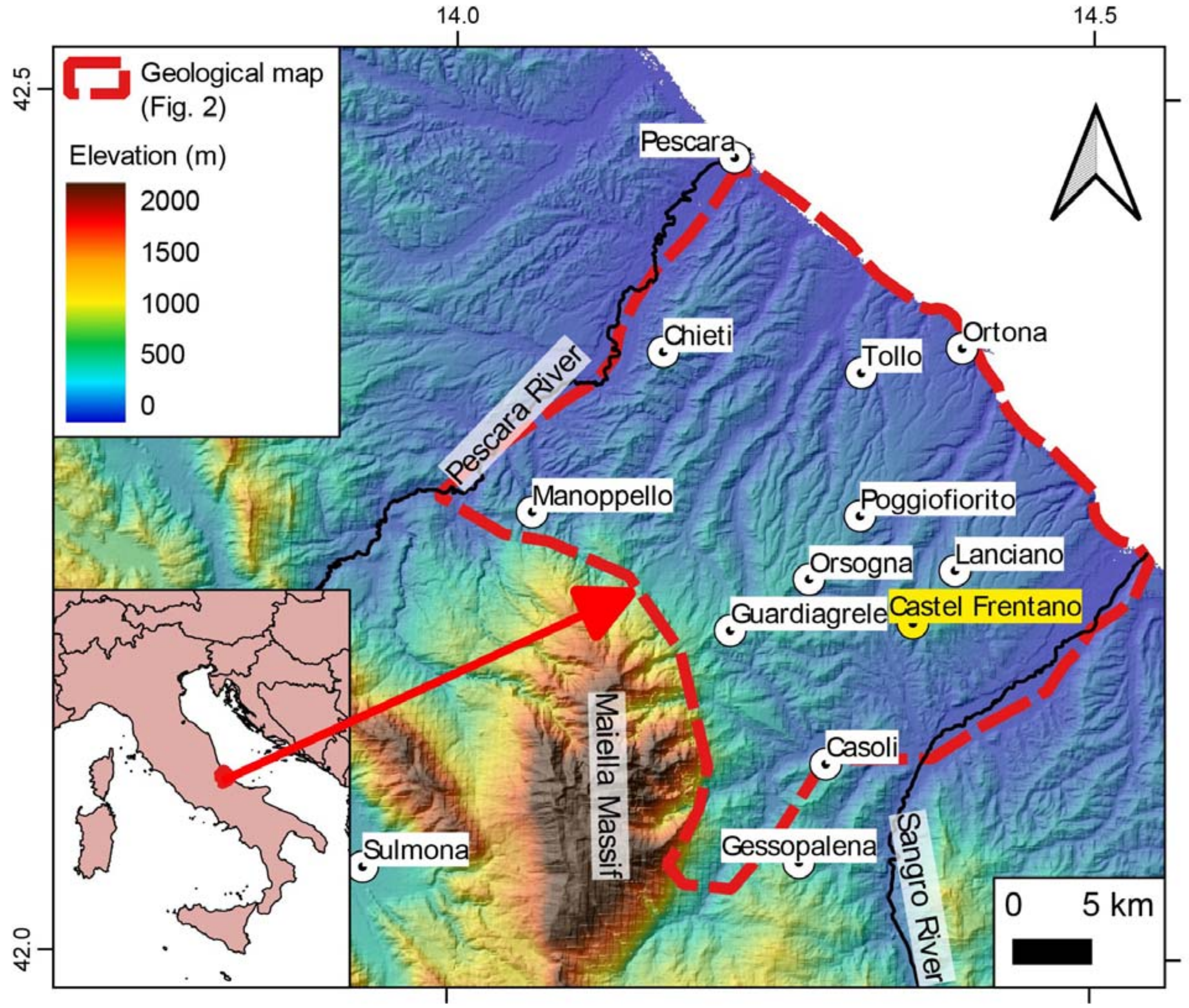

Fig. 1 - Location of Castel Frentano (yellow) and extent of the geological map of the area shown in Fig. 2 (red).

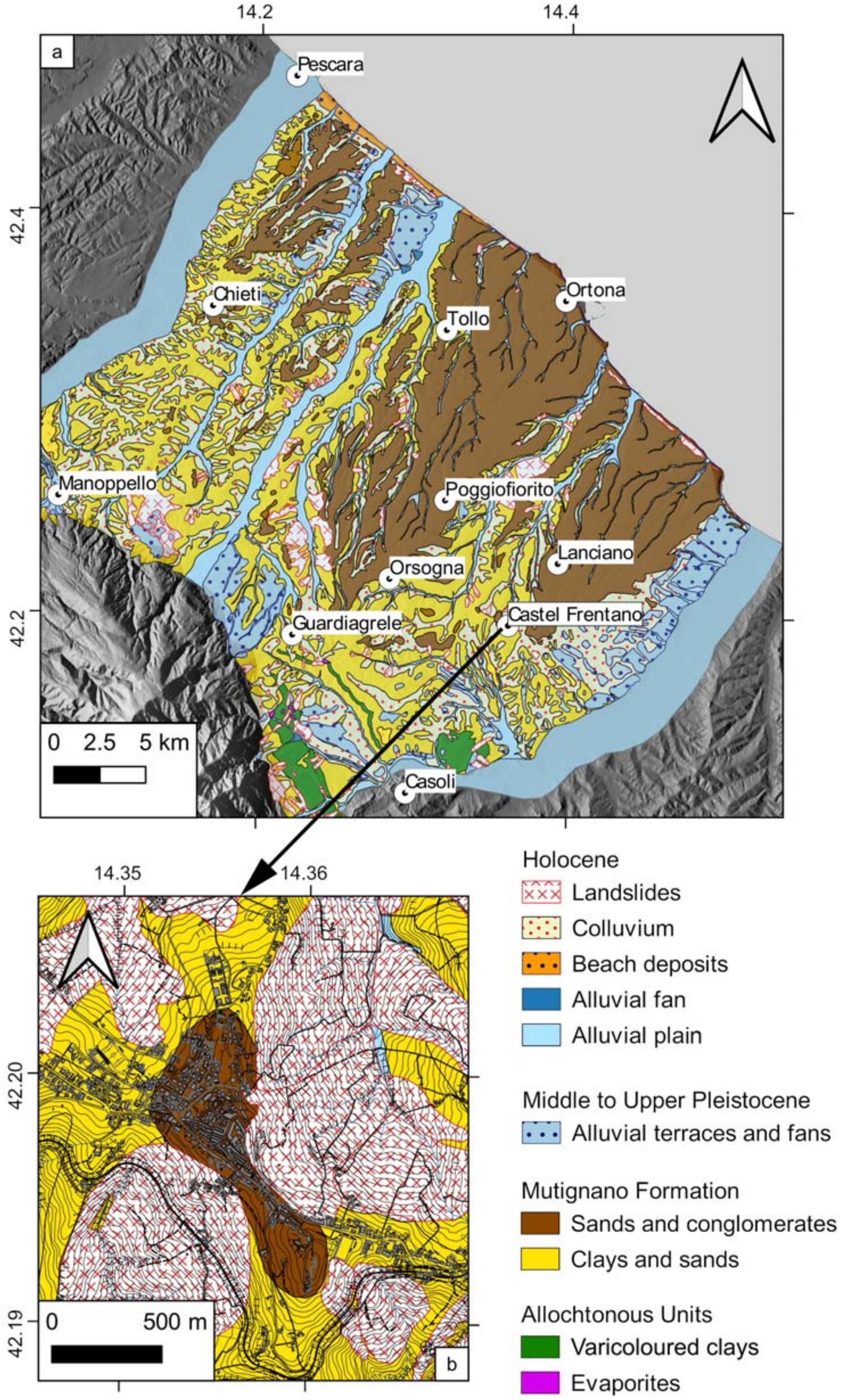

Fig. 2 - (a) Synthetic geological map of the central Abruzzo Periadriatic area; (b) sketch of Castel Frentano's geology (modified from Racano et al., 2020).

we discuss the available geomorphological and historical data to provide a realistic interpretation of the landslide origin.

2. GEOLOGICAL, GEOMORPHOLOGICAL AND SEISMOLOGICAL FRAMEWORK OF THE CASTEL FRENTANO AREA

The hill of Castel Frentano is located on Plio-Pleistocene marine to coastal units characteristic of the entire Periadriatic sector (Fig. 2a,b). The relief, whose altitude gradually decreases from the Maiella piedmont to the Adriatic coast, was produced by a regional uplift during the Quaternary (Centamore & Nisio, 2003; Centamore & Rossi, 2009; Racano et al., 2020). The main lithology outcropping in the area consists of bluish clays, sometimes interbedded with silty-sandy layers, that gradually upward to yellow silty-sandy levels and finally to sands interbedded with conglomerates, which mark the end of marine sedimentation (Bigi et al., 1997; Centamore & Nisio, 2003; Racano et al., 2020). The hill is bounded by steep slopes, which have been formed by the linear incisions of creeks draining the area. The main stream channel is the Feltrino Creek (Fig. 2b), which drains the eastern slope of the hill. One of the main geomorphological consequences of the recent geological evolution of the area is its predisposition to large landslides. Due to the recent uplift and the weakness of superficial lithologies, the drainage system has produced narrow and steep valleys carved into a highly erodible substratum. These are evident landslide predisposing conditions that can explain the recent/present landscape evolution (Centamore et al., 1996).

The AVI (Italian Vulnerable Areas for landslides and floods, developed by the National Research Council of Italy) and PAI (Hydrogeological Plan, provided by the Abruzzo Region) catalogues list rotational landslides, earth flows and "rill erosion" phenomena on clays (which produce badlands just below the urban centre). In terms of hazard, the Castel Frentano area is classified as a P3 zone (i.e. a high hazard zone: affected by active or seasonally reactivated instability phenomena).

The most important gravitational movement (i.e. a rotational landslide) has been detected along the eastern slope of Castel Frentano's hill (Mancini et al., 2001). The main activation of this landslide occurred on the 31st of July, 1881, generating the collapse of the village's eastern sector. On the 10th of September, 1881, the landslide was reactivated by an earthquake (Savarese et al., 2011) (Fig. 3a,b). Foreshocks of this seismic event, which preceded the main landslide motion, are not reported in seismic catalogues (e.g. Rovida et al., 2022) and historical sources (Savarese et al., 2011), nor mentioned in the literature published after the occur-

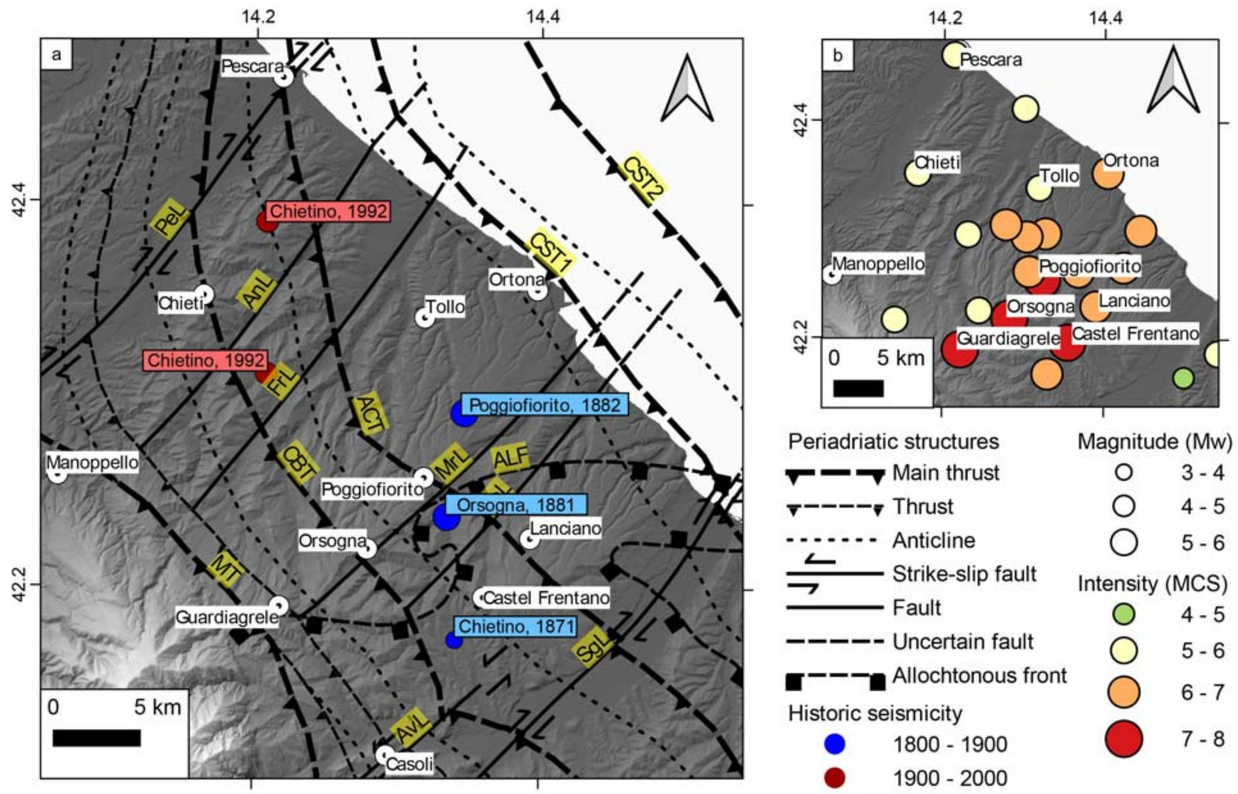

Fig. 3 - (a) Structural map of buried structures (from Racano et al., 2020) and historic seismicity between 1800-2000 (from Rovida et al., 2022): MT (Maiella Thrust); CBT (Casoli-Bomba Thrust); ACT (Abruzzo Citeriore Thrust); CST1-2 (Coastal Thrusts 1-2); PeL (Pescara Line); AnL (Alento Line); FrL (Foro Line); MrL (Moro Line); FeL (Feltrino Line); AvL (Aventino Line); SgL (Sangro Line); (b) damage distribution of the 1881 Orsogna earthquake (from Locati et al., 2022).

rence of the paroxysmal events (Niccoli, 1882). Although the occurrence of foreshocks cannot be completely excluded, it is at least highly improbable, since potential precursors are typically reported in the literature and reports coeval to strong historical earthquakes.

The seismic event that occurred in 1881 was reported to have a 5.4-magnitude (Fig. 3a,b) (CPTI15 catalogue; Rovida et al., 2022) and was attributed to the activation of a blind reverse fault related to the Abruzzo Citeriore thrust system (De Nardis et al., 2011), which represents the external and younger expression of the Central Apennines. The epicentre of that seismic event was located at about 5 km NNW from the study area (Fig. 3a). The mainshock was responsible for moderate damages to Castel Frentano (Mercalli-Cancani-Sieberg Intensity, MCS = 7-8) and nearby villages (Poggiofiorito, MCS = 8; Guardiagrele and Orsogna, MCS = 7-8; Lanciano, MCS = 7) according to the DBMI15 macroseismic database (Locati et al., 2022) (Fig. 3b). The earthquake-induced damages added to those caused by the July and September landslide movements. Therefore, the estimation of the effects strictly induced by seismic shaking is very difficult and affected by uncertainties: the present topography and urban setting of the eastern hillslope of Castel Frentano are the overall product of an earthquake and of one main landslide event that occurred in 1881.

Traces of slope instability related to continuous superficial slow movements (creep) and earth flows have been detected along the western flank of the hill. These events have also affected the urban centre (Buccolini et al., 2000), although they have not evolved in paroxysmal events comparable to the 1881 landslide.

3. MATERIALS AND METHODS

This study integrates pieces of information collected through field geological and geomorphological surveys with the results of bibliographic and archive research on historical sources. The aim was to reconstruct the genesis and sequence of events related to the 1881 CFL.

The collected field investigations allowed the production of a map depicting the landslide area (on the eastern slope of the Castel Frentano hill), in order to highlight the main geomorphic processes acting on it and the lithologies involved. This map was used as a base to define the geometries of the landslide scarp and body, as well as the lithologies involved in the movement and the main geomorphic processes that might have triggered it. The field data were digitised in a GIS environment using the open-source software QGIS (https://www.qgis.org). The base map was developed from the regional cartography of the Abruzzo Region at scale 1:5000 (in ESRI shapefile format) and the Digital Elevation Model (in TIFF format) of the region with a resolution of 10 m/px. The GIS data are freely available on http://geoportale.regione.abruzzo.it/Cartanet.

Several archives were consulted to determine the sequence of events related to the landslide that occurred in 1881. In particular, we searched for descriptions of the landslide (i.e. geometry and extension, magnitude of the phenomenon and involved lithologies), its impact on the landscape (i.e. portion of involved hillslope, temporal evolution of the phenomenon), the extent of damage caused to the village (i.e. involved buildings) and any indication related to the possible triggers of the CFL (i.e. geological active processes, climate, seismicity and anthropogenic changes of the landscape). Most of the data were derived from the Historical Archive of the Castel Frentano Municipality. Many documents produced by the City Council in the 19th century were found to contain suitable information; in particular, the documents archived in folder *B9*, file *F168* (1861-1881) and folder *B10,* file *F169* (1881-1926) focus on land use activities on the eastern slope of Castel Frentano's hill and on the evolution of the landslide. These bibliographic data were integrated with documents from the Italian State Archives (State Archive of Chieti, Chieti-Section Lanciano, Pescara, L'Aquila-Section Sulmona and the Diocesan Archive of Lanciano), which consisted mostly of telegrams, newspaper reports and climatic reports. The information gathered from the archive research was combined with that from published studies on climate and meteorological trends (Giraudi, 1990; Maugeri et al., 2004) and from the local literature (mainly books on Castel Frentano's history; Del Nobile, 2011; Scioli, 1981, 1998).

4. RESULTS

4.1. Geomorphological features of Castel Frentano's hill

The Plio-Pleistocene deposits representing the substratum of Castel Frentano's hill are sub-horizontal or gently dip eastwards from the ridge towards the valley bottom. The village is located at the top of the hill: it seats on a narrow plateau composed of consolidated sands and conglomerates, which represent the stiffer lithology of the study area and have a maximum thickness of about 20 m (Fig. 4a). An 8-10-m-thick layer of fine sands and silts marks the downward transition to the blue clays of the Mutignano Formation, which pervasively outcrop in the study area.

The hillslopes were and are still exploited by pervasive agricultural activities, which have led to the development of soil from the thick silty colluvium covering the bedrock. These colluvial deposits have derived from extensive weathering processes and gravitational deformations that have affected all the slopes. Evidence of slow earthflow movements in the absence of large paroxysmal events was detected along the SW flank of the hill; however, landslides are widespread on the eastern flank. Similarly to the earthflows of the western flank, the landslides on the eastern flank mainly involve the colluvium cover. This has led to the generation of terraces and sub-circular scarps typically associated with rotational landslides. Moreover, the presence of water springs characterized by ephemeral flows, mostly located in correspondence of the landslide terraces (where the slide planes intersect the surface), indicates a shallow water circulation influenced by seasonal rainfall variations. The erosional processes are highlighted by linear and V-shaped incisions triggered by run-off and mainly related to the Feltrino Creek catchment, which deeply

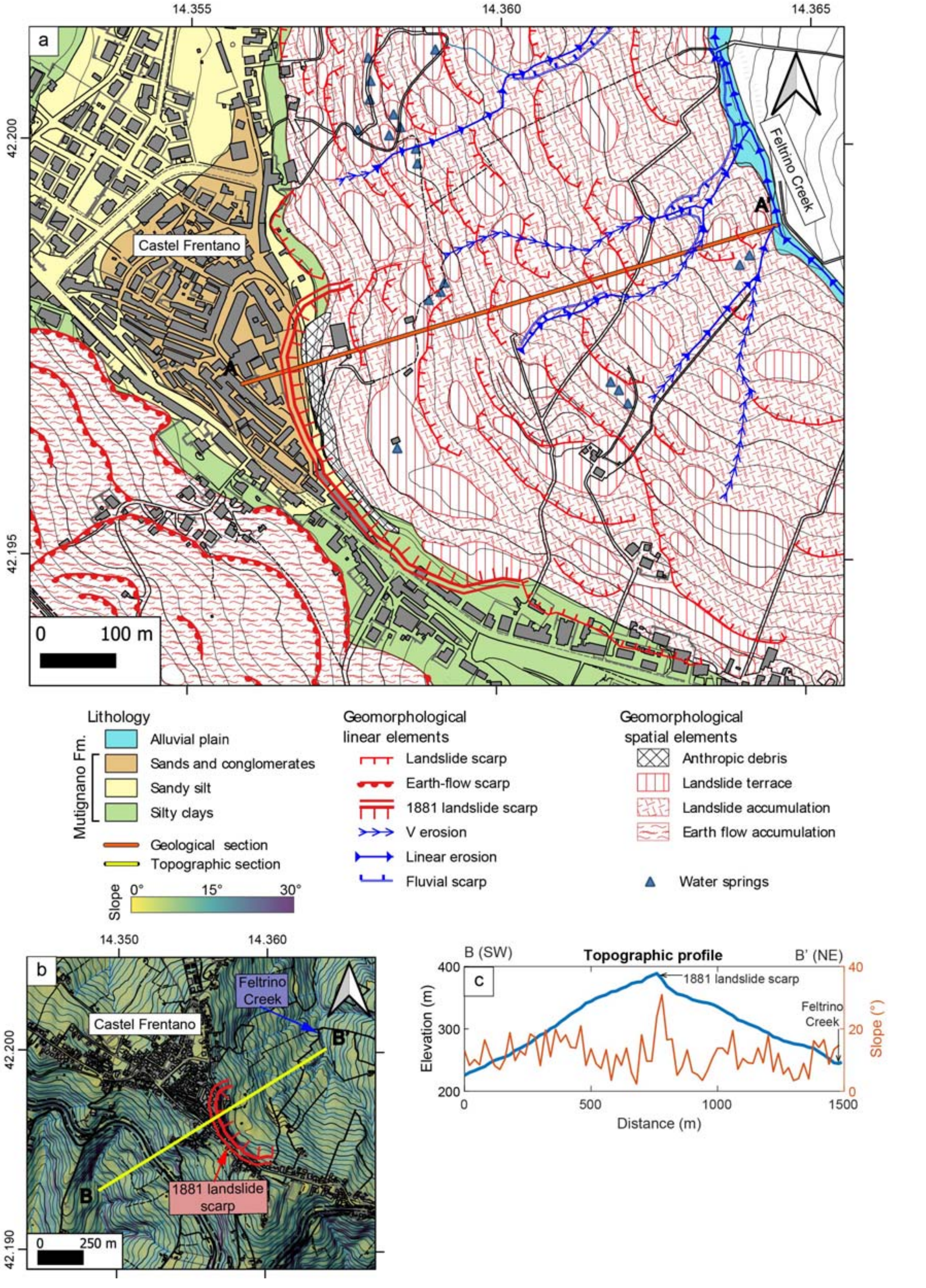

Fig. 4 - (a) Geological and geomorphological map of Castel Frentano; (b) slope map of Castel Frentano's hill; (c) topographic and slope profiles.

and linearly cuts the eastern hillslope.

Despite the differences in slope-movement between the western and eastern flanks of Castel Frentano's hill, the slope values of the two flanks are not significantly different (Fig. 4b,c). The most significant feature in this regard is a prominent scarp located at the southeastern edge of the village (Fig. 4b), which corresponds to the area with the highest slope values in the topographic profile (Fig. 4c) and is located at the northeastern top of the hill. In top view, the scarp has a subcircular shape, typical of rotational landslides. Moreover, it represents the boundary between the bedrock units of the hilly top and the slope deposits (Fig. 6a,b). The maximum thickness of the landslide deposits, based on our field observations, and the numerical analysis of Mancini et al. (2001) should be approximately 15 m. A large landslide terrace was detected just below the scarp. Altogether, the above features represent morphological evidence of the large gravitational movements that occurred in 1881.

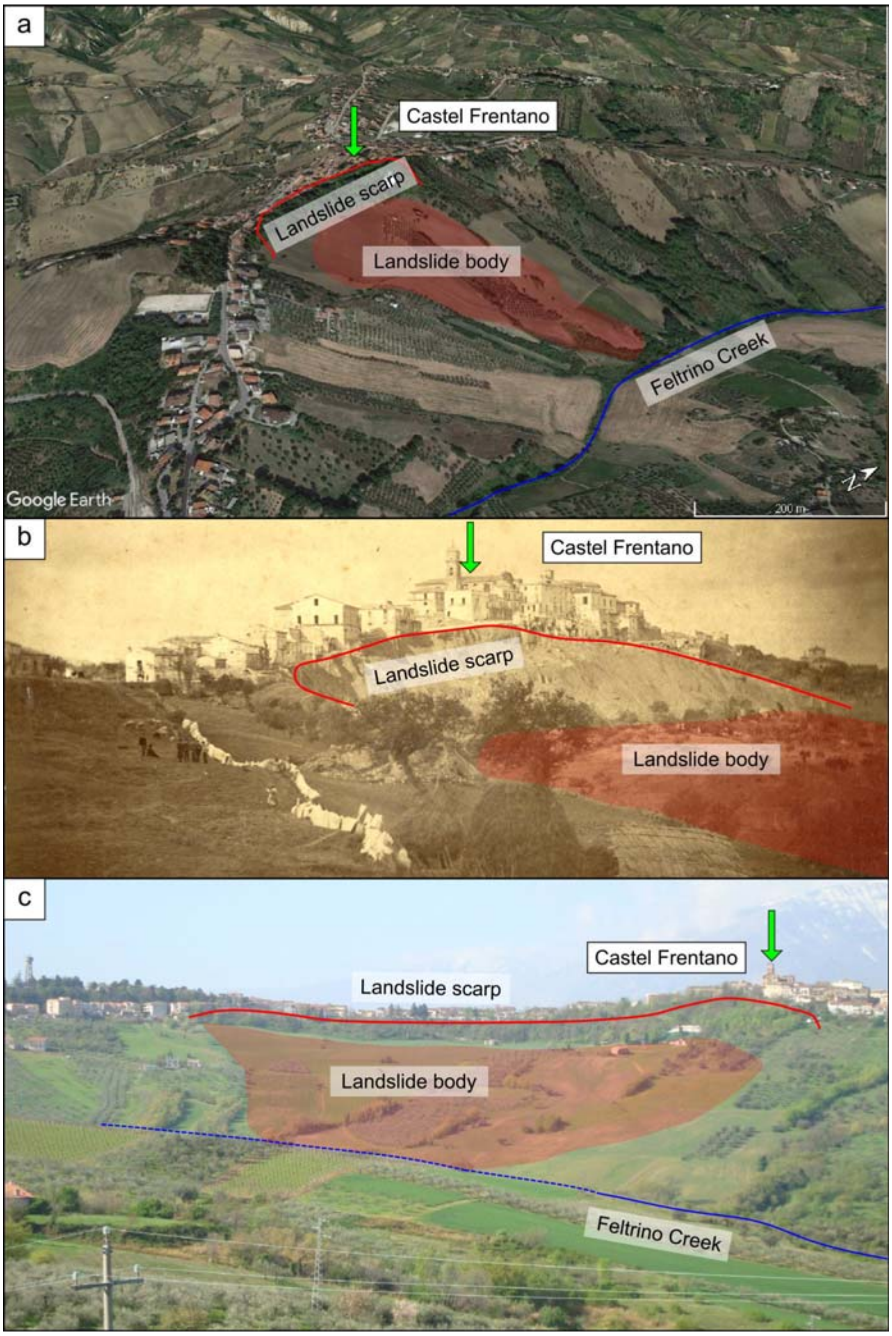

Fig. 5 - (a) GoogleEarth™ view of the Castel Frentano landslide (CFL); (b) historical photograph of the landslide taken in 1881 (from the Historical Archive of the Castel Frentano Municipality); (c) the CFL today. The green arrow indicates the Santo Stefano Protomartire Church. The dashed blue line in (c) indicates the portion of the Feltrino Creek below the hillslopes.

4.2. Description and chronology of the CFL event

Two main landslide episodes occurred in 1881, strongly modifying the eastern hillslope of Castel Frentano and causing heavy damages to the old village (Fig. 5a). As already mentioned, the main event occurred on the 31st of July, 1881; then, on the 10th of September, 1881, an earthquake reactivated the landslide (Savarese et al., 2011).

Historical information helped reconstructing the evolution of the gravitational processes and the chronology of events that occurred before the main landslide event. This event was first described by Enrico Niccoli (Niccoli, 1882), an engineer who was delegated by the Italian Royal Geological Committee to compile a report on it. Therein, information on the CFL is presented critically and methodically.

"During the afternoon of the 31st of July a widespread groundfall began to occur on the eastern hillslope and slide northeastwards, towards the bottom of the Feltrino Creek. The movement continued until night, leading to a very large landslide, which was about 1-km long and 500-m wide. The displaced mass is estimated to be about 9 million m^3 […]. The ground surface

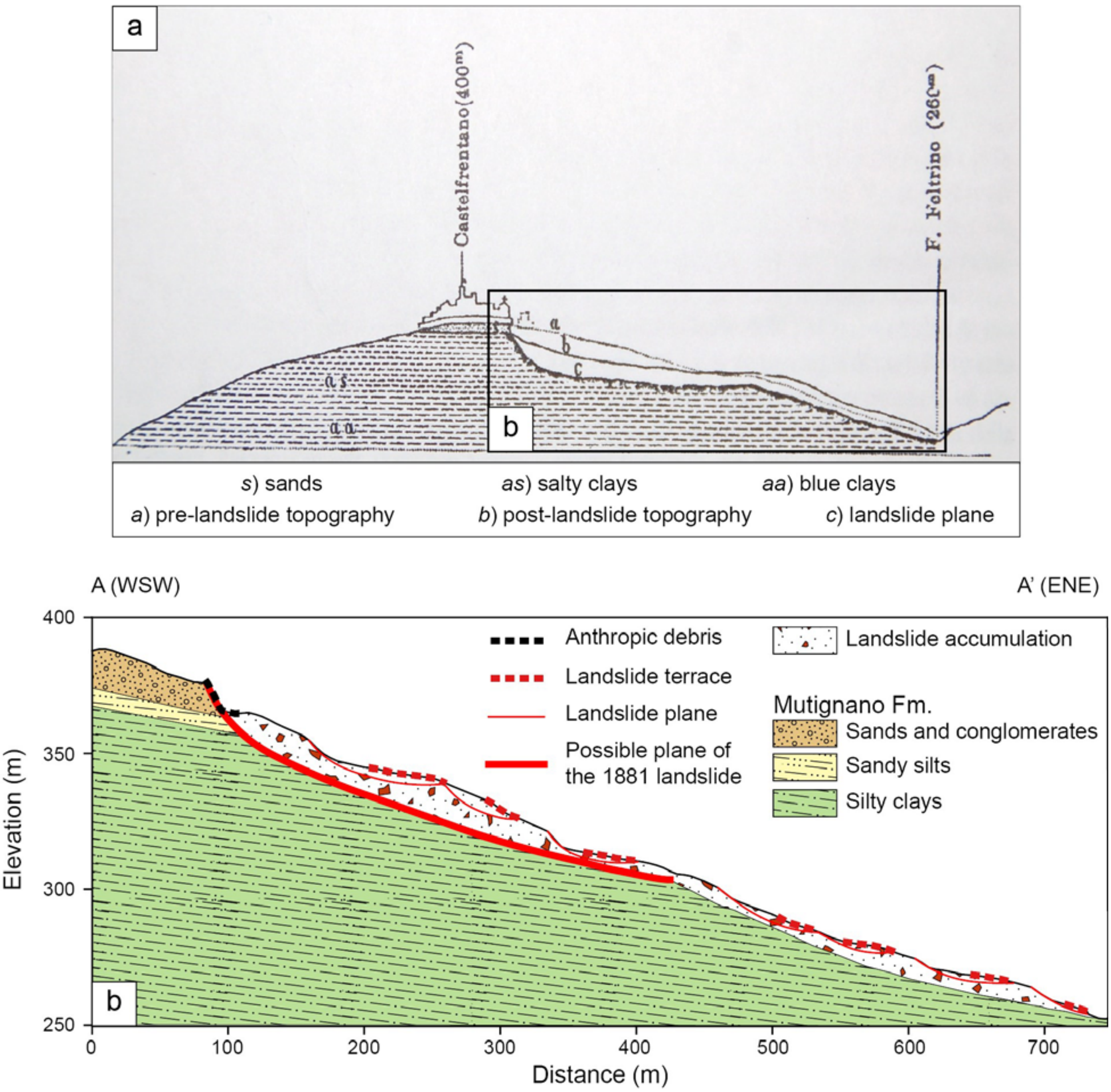

Fig. 6 - (a) Landslide profile by Niccoli (1882) and section of Fig. 6b; (b) landslide profile interpreted from the geological-geomorphological map (Fig. 4a).

collapsed at about 30 m close to the village, while it swelled in the lower part of the valley; the landslide […], due to the presence of widespread and deep transverse cracks, was similar in shape to a glacier or even to a lava flow […]." (translated from Niccoli, 1882).

This morphological description of the event reflects the characteristics of a rotational landslide, which are confirmed by a photo shot after the event and by the present-day morphology of the hillslope (Fig. 5b,c). Niccoli (1882) also compiled a geological description of the hill and drew a scheme of the landslide section, which is similar to that obtained based on our geomorphological map: the landslide cuts and exposes the bedrock at the hilltop (Fig. 6a,b). Niccoli (1882) reported that the hill was composed of "*Tertiary-Pliocene units*" with sub-horizontal strata, mainly composed of grey-yellow marly clays, often interbedded with sands. The sands locally showed a "marly-calcareous" cement, but were generally consolidated "*and formed an 8-m thick bank at the top of the hill, in correspondence of the urban centre of Castel Frentano*".

A detailed description of the catastrophic events can be found in the historical documents of Castel Frentano's City Council. One of them, produced on the 9th of September, 1881 (i.e. the day preceding the earthquake), reports some instability phenomena that had already affected the village before the main event of the 31st of July, 1881: *"[…] last June, major clues of instability (depressions in the Orientale Street and in its proximity, and cracks in the surrounding fields) alerted us and we asked for assistance to an engineer*." [translated from City Council historical documents, folder B9, file F168, 1861-1881].

A document produced on the 5th of August, 1881 (City Council historical document, folder B9, file F168, 1861-1881) declares instead that 469 citizens suffered the consequences of the landslide damages (including the complete destruction of their houses), which mainly affected residential buildings (Fig. 7). After the main event, no further significant landslide movements were recorded until the earthquake of the 10th of September, 1881. In his report, Niccoli (1882) wrote: "*[…] The movements did not stop after the first one, because the earthquake induced the falling of other slices of soil and continued to damage the area […]*". (translated from Niccoli, 1882).

Several damages affected the portion of village closest to the landslide scarp after the earthquake event, as reported by Bucci (1990) in his *Memoriae* (provided by the personal communication of Ferrante and Paione families). He stated that, after the earthquake, the pre-existing landslide damaged the most picturesque part of the village, but there were no casualties. Other documents found in the Italian State Archive of Chieti - Section Lanciano and in that of Pescara, as well as information collected from newspapers found at the Chieti Library, reveal that also buildings far from the landslide suffered damages induced by the earthquake: "*Numerous houses that were not in the landslide area were strongly damaged and a lot of people were injured, although there were no victims*" (telegram to the Prefect of Chieti, available in the State Archive of Chieti-section Lanciano, Sottoprefettura, folder 20, file 115, 9th of October, 1881); "*In Castel Frentano, a lot of houses outside of the landslide zone were damaged […]*" (La Gazzettina di Chieti, 15th of October, 1881).

4.3. Landslide genesis

Although massive slope movements are usually related to rainfalls and/or earthquakes, there is no evidence that such triggering phenomena can be attributed to the 1881 landslide. The first evidence of instability was observed in June, while the collapse of the hillslope and of the eastern part of Castel Frentano occurred at the end of July. No detailed climatic records were found for the period of interest (even after consulting the AVI catalogue); moreover, no strong rainfalls, nor unusually wet summers or wet preceding months are mentioned in the available historical documents for 1881 and previous years. This absence of information is of great significance. In fact, the landslide events that occurred in 1881 had a large resonance, as highlighted by the numerous "media reports" of that time and descriptions of the event that have supported hypotheses on its origin (see next paragraphs of this section). Overall, the lack of reference in all documents to anomalously frequent and abundant summer rainfalls (which would have provided an easy explanation for the catastrophe) suggests that the slide processes were likely not triggered by excessive rainfall.

Apart from extreme events, the available data (Fig. 8) were searched for irregular trends in the cumulative rainfalls related to specific climatic periods. For the investigated area (the territory of Lanciano) two climatic series can be discussed: they refer to the periods 1834-1843 and 1886-1902, and include the number of rainy days per month. The number of rainy days per year ranged approximately between 60-100. Figure 8 shows a plot based on data collected between 1834-1842: the average number of rainy days per year varied generally between 95-100; however, a low number of rainy days (only 62) was registered in 1843. No data are available for the period 1842-1885. Between 1886-1895, the average number of rainy days per year was about 70; then, between 1895-1902, this value increased to 95-100. Daily rainfall data were also obtained for the period 1886 -1902: the cumulative number of rainy days during the summer (i.e. the season during which the CFL occurred) of those years was plotted (Fig. 8). The resulting diagram shows a regular contribution of summer months to the total yearly rainy days. Additional data from the Fucino Basin (Giraudi, 1990), an intermontane depression in the Abruzzo Apennines (about 70 km west of Castel Frentano), indicate a decrease in rainfall between 1855-1862, when slope instability significantly increased in the area (see next paragraphs of this section). Notably, the average annual rainfall in Central Italy was quite regular between 1850-1905 (Maugeri et al., 2004). Overall, no climate anomalies causing periods of heavy rain can be inferred for the Abruzzo Region and Central Italy in general during the decades of interest. Some historical documents indicate that the source of instability might have been of completely different nature. Niccoli (1882) wrote: "*[…] concerning the description of the phenomenon, […] it was mainly due to the nature of the terrain that constitutes the hillslope, which led to a slow but continuous slope movement […]*" (translated from Niccoli, 1882).

In summary, this author related the origin of the landslide to the characteristics of the soil and shallow subsoil. He also provided some critical details about land use while inferring the causes of the landslide: "*[…] before 1815, the collapsed hillslope was covered by trees. Later, however, the expansion of agricultural activities here and elsewhere encouraged ploughing […] and, soon, [it triggered] some ground movements, mostly on the higher portion of the hillslope. Nevertheless, the ploughing continued, and increasingly larger and numerous movements occurred from 1831 onwards, causing the fall of several houses. Deforestation occurred mostly after 1860 and the landslide area continued to increase […] until, in June 1881, the maximum level of hazard was reached […]*" (translated from Niccoli, 1882).

The first reference to a landslide along the eastern hillslope of Castel Frentano has been found in a City Council document dated 1861. This document highlighted the evacuation of the population from Contrada Ripitelli (Fig. 7a), which was on the eastern slope of Castel Frentano's hill before being destroyed by the landslide in 1881 (City Council documents, folder B9, file F168, 1861-1881, 17th of February, 1861). After 1861,

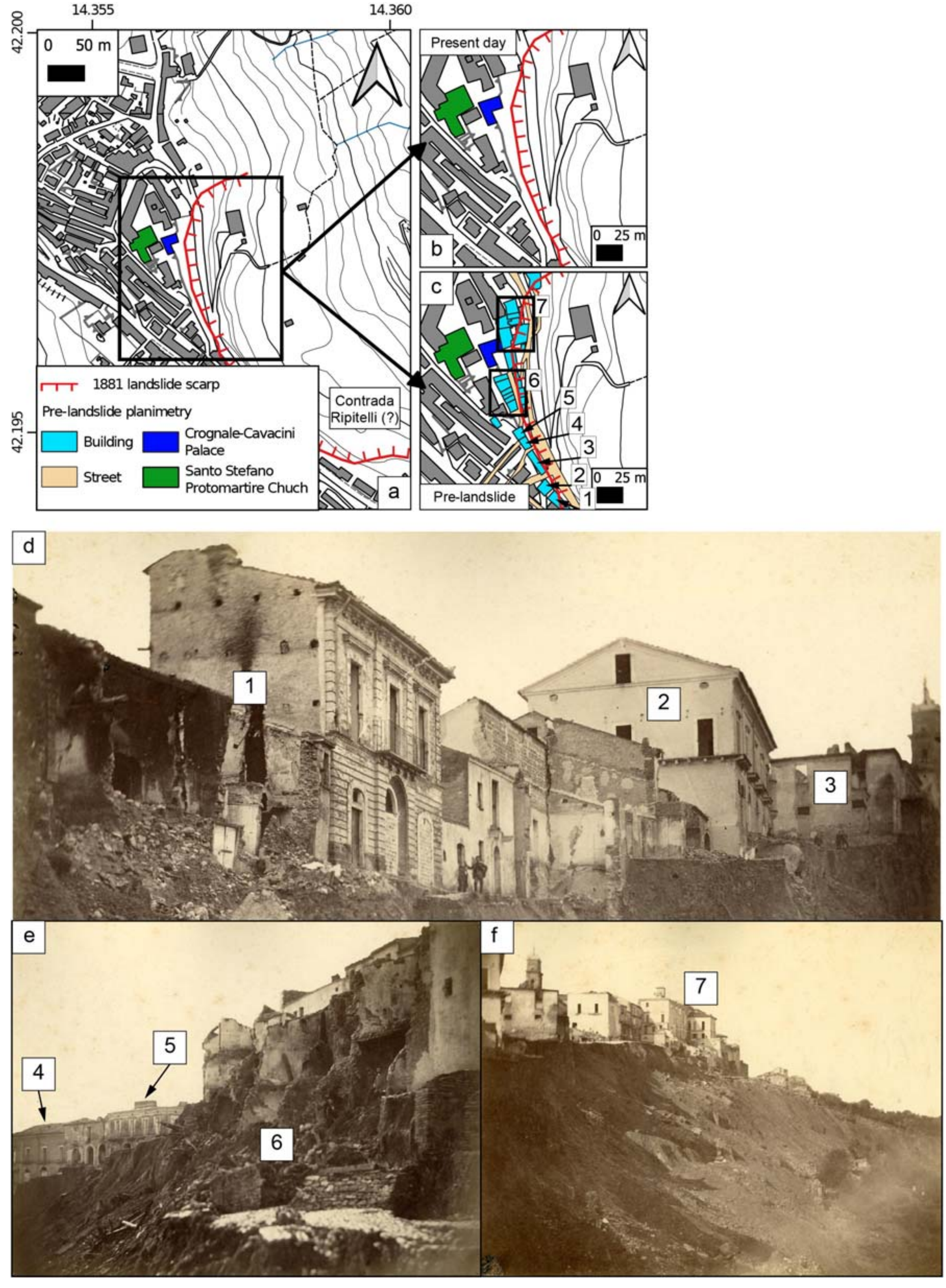

Fig. 7 - (a) Planimetry of the centre of Castel Frentano, possible location of Contrada Ripitelli and comparison between the (b) present-day and (c) pre-landslide urban fabrics; (d), (e), (f) historical photos, in which the numbers indicate the damaged buildings (as reported in the map (c)).

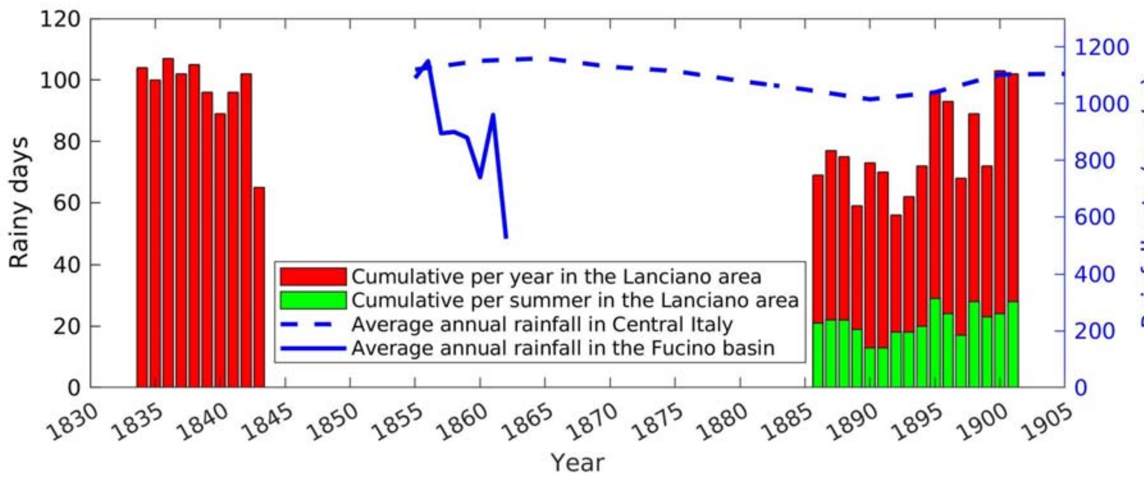

Fig. 8 - Rainy days per year between 1834-1901 (from "Annali Civili del Regno di Napoli", State Archive of Chieti-Lanciano) and rainfall rates in Central Italy (Maugeri et al., 2004) and in the Fucino area (Giraudi, 1990).

the area of slope instability on the eastern flank of the relief was known as "*the landslide*". These conditions led to the destruction of about 100 buildings by 1868. In the documents of the City Council, building crumbling and collapse were attributed to the erosional action of the Feltrino Creek, flowing along the lower portion of the hill. This process "*sank and destroyed many valuable houses located in the village*" (City Council documents, folder B9, file F168, 1861-1881, 8th of November, 1868). These notes report also the erosional activity of the Feltrino Creek at the base of the hillslope as an additional factor contributing to the evolution of the landslide.

Regarding the phenomenon of water seepage in the subsoil, a document of the City Council mentions undetailed problems in the drinking water supply to the village. Drinkable water was lacking, creating inconveniences to the population. This issue was linked to a malfunctioning of the shallow aqueduct, which would have been penetrated by roots and filled with waste. Apparently, water was spilling from the aqueduct and, hence, could not reach the buildings in the village (City Council documents, folder B9, file F168, 1861-1881, 5th of August, 1863). No further information is available about this issue and we could not find any map of the aqueduct, nor any reference to its position. The potential role of water seepage and land use activities in the activation of the landslide are discussed in Section 5.

5. DISCUSSION

Overall, the available information shows that the CFL was a peculiar event: no major natural triggering factors can be invoked for the widespread slope mass movement that struck Castel Frentano. In Italy, catastrophic landslides are usually associated to heavy rainfalls, as in the case of Valtellina in 1987 (Alexander, 1988) and Sarno in 1998 (Cascini et al., 2011), or to seismic crises, as in the case of Irpinia in 1980 (Del Gaudio & Wasowski, 2004) and Molise in 2002 (which triggered the Salcito landslide; Bozzano et al., 2008).

Rainfalls and climatic conditions are generally considered potential triggers of landslide events; however, no evidence of a significant role of these factors in the evolution of the CFL raised from the available information. The period in which the catastrophe occurred was not anomalous in terms of rainfall amount, and local historical sources do not mention the occurrence of heavy rainfalls before the slope collapse. Mancini et al. (2001) investigated the response of Periadriatic hillslopes to seismic loads, concluding that significant slope movements would tend to involve mainly colluvial deposits saturated by a water table (situated at least 4 m above the colluvium/clays contact surface). However, these authors erroneously considered the CFL to have been seismically induced: the available historical documents have revealed instead that, on the 10th of September, 1881, the earthquake led simply to the reactivation of an already displaced mass. Regarding the seismicity characterizing the period of interest, the shock that occurred on the 14th of August, 1871 (i.e. the only earthquake reported in the catalogue preceding the paroxysmal gravitational event; Fig. 3a) should not be considered as a potential cause of the landslide. In fact, (1) it occurred ten years after the beginning of slope instability and ten years before the main landslide event; (2) shaking was insignificant, due to the low magnitude of the seismic event (moment magnitude = 3.8; Rovida et al., 2022) and as testified by the lack of associated damage in the territory struck by the shock: the effects in the zone of Castel Frentano were well below the damage threshold (the MCS intensity was 4 in the nearby town of Lanciano; Locati et al., 2022).

Beyond these considerations, it is well known that changes in land use practices, whether conditioned by natural events or human choices, can influence local and regional slope stability (Sidle et al., 1985; Wasowski, 1998; Glade, 2003; Sidle & Ochiai, 2006; Wasowski et al., 2010). An illuminating case of a landslide outside of Italy that did not depend on climatic factors is that of the Thompson River Valley (British Columbia, US). There, large instability phenomena occurred atop or within silt-clay units, triggered by the irrigation of benchlands above the river (Clague & Evans, 2003). The CFL case has some points in common with that of the Thompson River Valley. Our data revealed that the geological characteristics (i.e. the occurrence of clays, sands and colluvium) of Castel Frentano's hill and the geomorphological processes (i.e. the narrow incisions created by stream channels) affecting it predispose the area to landslide phenomena. The available information also suggests that Niccoli (1882) was probably right in invoking anthropogenic activity as one of the key factors that triggered the catastrophic event. Indeed, the growing need for agricultural fields in Italy is known to have caused massive deforestations in all parts of the Italian Peninsula from the second half of the 18th century (Vecchio, 1974). This has resulted in a widespread growth of slope instability phenomena (Bevilacqua, 1996). Historical sources have revealed that movements along the eastern Castel Frentano hillslopes started to occur with the initiation of deforestation along the slope, which was linked to the expansion of agricultural activities. Deforestation, combined with the agricultural usage of the hillslope, the geology of the area and the erosion activity of the Feltrino Creek, should have led to a progressive loss of hillslope stability, ultimately inducing landsliding.

Additional aspects that may have led to landsliding include water leaking from the aqueduct (described by the City Council in 1863). In fact, although the location of the aqueduct could not be reconstructed and no clear evidence was collected on the role of water seepage in the landslide paroxysmal evolution, a potential contribution of this phenomenon cannot be excluded. In any case, water leaking would have had a secondary role compared to the intensive agricultural land exploitation that was affecting the area around 1881.

Overall, the analysed historical documents allowed to reconstruct a sequence of landslides that, after 1860 (i.e. when the deforestation process was completed), started to slowly move towards the hilltop. This movement would have produced the first important damage to buildings in Castel Frentano in 1868, and would have led to the complete destruction of part of the village in 1881.

Nowadays, the eastern slope of Castel Frentano's hill has still a poor tree coverage and is exploited for agricultural activities (Fig. 5a,c); moreover, it is still affected by landsliding (as revealed by our geomorphological survey). Although landsliding presently occurs on the eastern hillslope, it is predominantly of the rotational type and is much smaller in size compared to the paroxysmal event that took place in 1881. In fact, present landslides predominantly affect the colluvium and CFL accumulation, and none of them have been capable of cutting and exposing the bedrock on the eastern or western slopes of the hill.

Castel Frentano's case is not the only one in the Abruzzo Region in which landslides have had a probable anthropogenic origin. According to historical reports, the instability of Gessopalena's hill (about 17 km SW of Castel Frentano; Fig. 1) can be also attributed to the combined action of deforestation and water seepage (Galadini, 2016). In this case, however, the geological setting is completely different: the old village of Gessopalena (now abandoned) was settled on a small gypsum relief, while the adjacent valleys are characterized by highly erodible clays. Notably, 19th century documents (Galadini, 2016) report that: (1) numerous wells in the houses of Gessopalena were leaking water into the gaps of the subsoil and (2) the underlying valleys were experiencing continuous deforestation. These factors would have triggered the collapse of gypseous boulders from Gessopalena's hill and mass flows in the underlying clayey valleys (i.e. gravitational phenomena different from those of Castel Frentano). The resulting instability became a threat for the old village of Gessopalena during the 19th century, although interventions were carried out to limit the damages: hydraulic works were done to optimize the water regime and valleys previously denuded were reforested (Galadini, 2016).

6. CONCLUSIONS

The CFL is an example of a natural catastrophe mainly driven by human activity that caused the loss of cultural heritage. Although Castel Frentano's hill was already predisposed to slope mass movements due to its geological and geomorphological conditions (i.e. weak lithologies and stream linear incisions), deforestation activities and the consequent agricultural use of the eastern hillslope (possibly combined with water seepage from the aqueduct) may have been the primary causes of the CFL genesis. The collected documents suggest that landslide movement may have begun in the lower part of the hillslope following deforestation and may have been driven by the incision activity of the Feltrino Creek. Then, the landslide may have progressively migrated upwards along the landslide scarp until the paroxysmal event that involved the village on the 31st of July, 1881, leading to the collapse of historical buildings. Based on coeval documents and information on rainfall events, the following hypotheses can be considered remote: (1) the main landslide event may have been preceded by a period of heavy atmospheric precipitations and (2) a period of anomalous climate may have occurred during the decades of landslide trigger and evolution. Despite the large volume of documents mentioning the main landslide event and evaluating its origin, none of them mentions the occurrence of exceptional rainfalls during or before 1881, although this would have represented the simplest explanation. This suggests that climatic factors and weather conditions likely did not play a major role in triggering the main landslide event. In addition, historical evidence of the paroxysmal landslide evolution preceding the 1881 earthquake and the absence of any reference in historical documentation to seismic events in the area of Castel Frentano shortly before the main landslide event indicate that earthquakes unlikely caused it. Rather, a 5.4-magnitude seismic event, which occurred about 40 days after the main landslide event, should have worsened the already critical situation of Castel Frentano. Historical sources clearly described the reactivation of the landslide after this earthquake.

In conclusion, the CFL case exemplifies what the Italian landscape has experienced since the second half of the 18th century: an increase of landslide occurrence following the expansion of agricultural land exploitation. Past studies stressed the relationship between widespread anthropogenic changes of the landscape during this period and an increase in landslide and flood fatalities (Guzzetti et al., 2005). We infer that the case of Castel Frentano may be suitably included in datasets aimed at explaining the above relationship.

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