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## Geological tourist mapping of the Mount Serrone fault Geosite (Gioia dei Marsi, Central Apennines, Italy)

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### ABSTRACT

The Geological tourist map of the Mount Serrone fault Geosite (Gioia dei Marsi, Italy) has been realized for describing, in an educational perspective, the surface expression of one of the main active faults of the Central Apennines, connected with the 1915 Fucino earthquake (magnitude 7, historically, one of the strongest in Italy). The Central Apennines are a mountain range whose landscape is deeply connected to active tectonics and seismicity, as documented by recent earthquakes. In this framework, the map is a useful tool for the dissemination of the geological knowledge of the Fucino area and faults in general and for the promotion of a geological landscape through a modern, sustainable and environmentally aware tourism. The map is double-sided with simple texts and cartoons on the front outlining general info about the geosite, faults and earthquakes, how to behave in seismic areas and historical notes. The back shows the [Main Map](#) with its visual legend featuring the main geological and tectonic elements of the Mount Serrone fault Geosite and the long term history of the landscape. Through simple keywords and concepts, tectonics, faults and earthquakes are shown to be natural features that have contributed to shape the landscape of the Apennines over geological time, as well as something to be afraid and worried of, as they are connected to natural hazard and disasters. This approach is aimed at increasing people's awareness of geological processes and hazards (i.e. seismic), which with adequate knowledge and proper land management, can be lived with.

### ARTICLE HISTORY

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Geological tourist map; landscape; fault scarp; tectonics; 1915 Fucino earthquake; seismic hazard awareness; Abruzzo; Italy

## 1. Introduction

Geotourism is a type of sustainable tourism defined and developed in the last few decades in the broad field of geoheritage enhancement, which focuses on geosites, geomorphosites, geoconservation, physical landscape management and geopark/natural park management (Reynard & Brilha, 2017). However, its roots lie in the late seventeenth and eighteenth centuries (Hose, 2016). The main focuses and goals of geotourism are (Panizza & Piacente, 1993; Reynard & Coratza, 2007; Coratza & Regolini-Bissig, 2009; Miccadei, Piacentini, & Esposito, 2011; Hose, 2016; Reynard & Brilha, 2017):

- to define geosites-geomorphosites as geological features and landforms that have acquired a scientific, cultural/historical, aesthetic and/or social/economic value (Panizza, 2001; Coratza & Panizza, 2010; Miccadei et al., 2011);
- to define integrated proposals based on tried and tested itineraries incorporating geological elements

(e.g. geosites; Piacente & Coratza, 2005; Coratza, Ghinoi, Piacentini, & Valdati, 2008; Panizza, 2010; Brandolini, Faccini, Robbiano, & Bulgarelli, 2011; Piacentini, Castaldini, Coratza, Farabollini, & Miccadei, 2011; Faccini, Roccati, & Firpo, 2012; Faccini et al., 2018; Scalise, 2017; Piacentini et al., 2018; Sacchini et al., 2018);

- to realize maps and illustrative materials (for parks, geosites, itineraries, etc.; Carton, Coratza, & Marchetti, 2005; Castaldini et al., 2005a; Castaldini, Valdati, Ilies, Chiriac, & Bertogna, 2005b; Castaldini et al., 2008; Bertacchini, Benito, & Castaldini, 2007; Bissig, 2008; Miccadei et al., 2008; Regione Emilia Romagna, 2009; Panizza, 2010; Piacentini et al., 2011; Faccini et al., 2018);
- to increase, among people of all ages, sensitivity towards the processes and hazards of the Earth within their spatial and temporal scale (Brandolini, Canepa, Faccini, Robbiano, & Terranova, 2007; Alcántara Ayala, 2009; Coratza & de Waele, 2012; Reynard & Brilha, 2017; Badiali, Ilies, & Castaldini, 2018);

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- to encourage the establishment of a new scientific tourism professional figures working particularly in disadvantaged areas (Panizza & Piacente, 2005).

The geological tourist maps are tools that may accomplish many (or even all) of these goals by establishing a visual connection between the landscape features and the geological heritage and the perception of tourists, young people, and observers in general. These maps should be produced and widely distributed (e.g. in park, reserves, geological landscapes, and geosites, as well as in schools), since they provide an understanding of natural geological processes and also an awareness of their hazards (i.e. earthquake, landslides, floods, etc) (Carton et al., 2005; Castaldini et al., 2005a, 2005b, 2008; Bertacchini et al., 2007; Bissig, 2008; Miccadei et al., 2008; Regione Emilia Romagna, 2009; Piacentini et al., 2011; Faccini et al., 2018, Sacchini et alii, in press). However, many existing maps which one can find in various sites are basically simplified versions of scientific/technical geological maps or simply tourist maps which happen to incorporate some geological features or information.

The Central Apennines area has been largely affected by strong recent seismicity (many magnitude >6 earthquakes occurred in the last century and three in the last decade; L'Aquila 2009; Central Italy 2016–2017). Its present landscape is the result of long-lasting geological evolution related to large faults from Neogene (ca. 20 million years ago) to present and particularly during the Quaternary (e.g. last 2 million years) (Cavinato, Carusi, Dall'Asta, Miccadei, & Piacentini, 2002; Galadini, Messina, Giaccio, & Sposato, 2003; Giaccio et al., 2012; Piacentini & Miccadei, 2014; Gori et al., 2017a; Gori, Falcucci, Ladina, Marzorati, & Galadini, 2017b; Piacentini, Buccolini, & Miccadei, 2017). However, people's awareness of the seismic hazard is still not at a very high level (Marincioni et al., 2012), although largely increased in recent years (Amato et al., 2013; Pignone, Nostro, Amato, & Meletti, 2016). The Gioia dei Marsi area was struck by the magnitude 7 Fucino earthquake in 1915 suffering severe damages and casualties, which deeply affected the recent history and the development of the area and whose centenary was recently acknowledged. The damage done by the earthquake, as well as the landscape modifications along the main faults are still preserved and visible along the Mount Serrone ridge and in the old ruined villages of Manaforno and Sperone.

With the support of the Gioia dei Marsi Municipality and of the Mount Serrone Association, a process of enhancement and promotion of the landscape has been developed, consisting of: (i) defining the Mount Serrone fault Geosite, (ii) realizing the geological tourist map (presented in this work) and (iii) organizing events and field trips in the geosite. With the broad intention of promoting geotourism in the inner

Apennines areas, this process aims also at raising awareness of environmentally related hazards, particularly the seismic ones, and hopes to reach all readers whoever they are young people, adults, tourists, local citizens, through simple keywords and concepts (Coratza & de Waele, 2012; Reynard & Coratza, 2016). This is particularly significant more than 100 years since the Fucino earthquake and after the more recent L'Aquila 2009 and Central Italy 2016–2017 earthquakes.

The geological tourist map presented in this work is specifically designed to describe the Mount Serrone Fault Geosite (Gioia dei Marsi, Italy) in an educational and geological tourist perspective. The geosite is strictly connected to natural hazards being the surface expression of one of the main active faults of the Central Apennines connected with strong recent-historical seismicity. The geological tourist map is designed to (i) specifically describe an active fault, (ii) observe its surface expression and (iii) tell the history of its landscape deeply connected to tectonics and seismic hazard. It is realized integrating previous data from geological mapping and detailed geostructural investigations (Vittori, Cavinato, Miccadei, Rughi, & Serva, 1991; ISPRA, 2014; Miccadei, D'Alessandro, Parotto, Piacentini, & Praturlon, 2014). New geological and geomorphological observations were focused on the selection of the best exposure of rocks and landforms from a touristical and educational perspective.

## 2. The Mount Serrone area (Gioia dei Marsi, Fucino Plain, Central Italy)

The Serrone ridge (in the Gioia dei Marsi municipality, AQ, Abruzzo, Figure 1), mostly known in the area as Mount Serrone, is located in the heart of the central Apennines. It is in the Marsica region, in the SE part of the Fucino intermontane basin and in the NW



**Figure 1.** Location map of the Mount Serrone fault Geosite (Gioia dei Marsi, AQ, Fucino Plain, Abruzzo, Central Italy).

edge of the Abruzzo, Lazio and Molise National Park. The Serrone (1305 m a.s.l.) ridge is NW-SE elongated and surrounded by parallel ridges, from 1300 to 2000 m a.s.l. in height. In the western side, a steep slope drops down to the Fucino plain, the largest intermontane tectonic basin in Central Italy, once occupied by a large lake and reclaimed in 1876 for agricultural purposes.

The central Apennines chain features several different landscapes shaped by a complex geological and geomorphological history. It is the result of the Neogene–Quaternary evolution of an east-verging chain-fore-deep-foreland orogenic system forming large NW-SE thrust sheets, affected by uplift and extensional tectonics during the Quaternary (Patacca & Scandone, 2007; Cosentino, Cipollari, Marsili, & Scrocca, 2010; Piacentini & Miccadei, 2014; Santo et al., 2014; Piacentini et al., 2017). The chain is affected by strong recent seismicity along the main NW-SE trending faults dissecting the thrust sheets (Figure 2; Vannoli, Burrato, Fracassi, & Valensise, 2012; Bonini, Di Bucci, Toscani, Seno, & Valensise, 2014; Gori et al., 2017a, 2017b). The competing endogenic (i.e. tectonic) and exogenic processes connected to Quaternary climate fluctuations (i.e. slope, karst, fluvial, weathering), led to the development of different types of landforms carved in a variety of rock types through time (D’Alessandro, Miccadei, & Piacentini, 2003; Piacentini & Miccadei, 2014).

Several million years ago (from Jurassic to Lower Cretaceous) an ancient shallow water sea occupied the whole area. On its seafloor, calcareous, fossil-rich, rocks were formed. Thereafter (Miocene-Pliocene), the rocks were lifted above the sea level by compressional tectonic pushes. Their deformation and stacking one above the other led to the emersion from the sea and to the creation of the first landscape, consisting of a moderate hilly relief (Colacicchi, 1967; Miccadei et al., 2014 and references therein). Over the last 2 million years (Pleistocene - Holocene), the whole area was affected by regional uplift and by several large scale NW-SE trending normal faults with strong connected seismicity. The combination of uplift and extensional tectonics and surface processes (e.g. slope, fluvial, karst, glacial) shaped the present landscape composed of steep, high elevation (>2500 m a.s.l.) faulted ridges and large intermontane tectonic basins, such as the Fucino plain (Ciccacci, D’Alessandro, Dramis, & Miccadei, 1999; Cavinato et al., 2002; Galadini et al., 2003; Ascione, Cinque, Miccadei, Villani, & Berti, 2008; Santo et al., 2014; Piacentini & Miccadei, 2014).

Located in the south-eastern side of the Fucino plain, the Serrone fault is part of the NW-SE oriented, SW dipping Serrone–Parasano fault system. This system has had a long-term and complex tectonic history being one of the main faults responsible for the creation and shaping of the basin, once occupied by the greatest lake on the Italian peninsula (Galadini &

Messina, 1994; Galadini, Galli, & Giraudi, 1997; Cavinato et al., 2002; ISPRA, 2014; Miccadei et al., 2014).

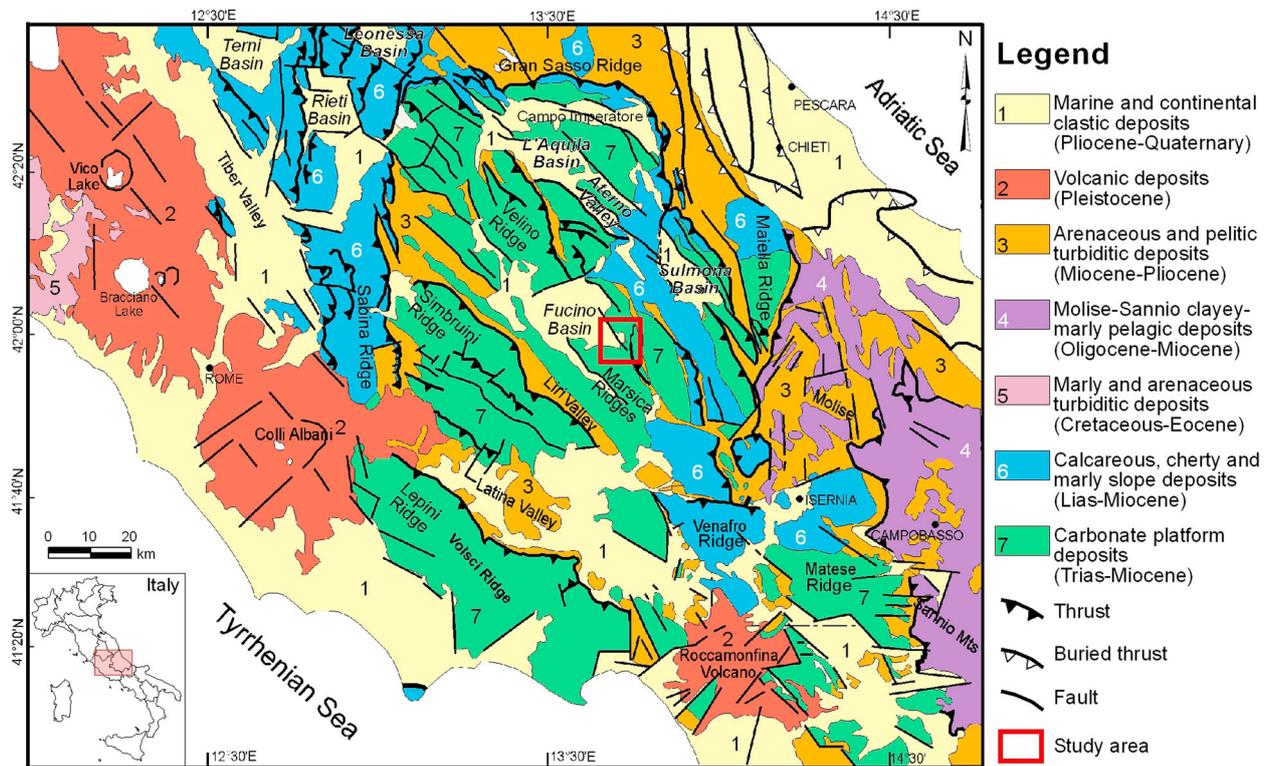
On the 13 January 1915, a magnitude 7 earthquake (one of the strongest ever in Italy, Amoroso, Crescentini, & Scarpa, 1998; Rovida, Locati, Camassi, Lolli, & Gasperini, 2016) struck the area devastating the entire Marsica region and in particular the Fucino area (the damage reached Rome and the Adriatic coast). The Serrone fault - and its prosecution toward the Fucino plain - has been recognized as one of the normal faults ‘activated’ during the earthquake generating a 0.5–1 m high fault scarp. The surface evidence of this fault was observed right after the earthquake (Alfani, 1915; Oddone, 1915), and in several paleoseismological studies done in the last few decades on the SW slope of the Serrone (Serva, Blumetti, & Michetti, 1988; Galadini et al., 1997; Castenetto & Galadini, 1999; Amoroso et al., 2015; Gori et al., 2017a, 2017b). The appearance of the fault scarp is not only results of tectonic processes but also of different geomorphological processes and it is also debated in terms of tectonic vs. other surface processes origin (e.g. soil erosion, landslides, sediment compaction; Kastelic, Burrato, Carafa, & Basili, 2017). The area was also affected by large deep-seated gravitational slope deformations (Moro et al., 2012; Kastelic et al., 2017). However, these features resulting from detailed scientific studies and debate (see Moro et al., 2012; Kastelic et al., 2017 and references therein) are not considered in the map, which is mainly focused on the tectonic features and earthquakes that affected the Serrone area.

Here, the former Gioia dei Marsi village (once called Manaforto) and the nearby Sperone village were completely ruined by the earthquake. Moreover, this fault system retrieves signs of recent tectonics and surface faulting referable to some of the strongest earthquakes, which occurred in central Italy in the last few centuries (Castenetto & Galadini, 1999; Gori et al., 2017a).

The main surface features of the fault (e.g. fault scarps, fault planes, contact between different rocks, heavy jointed and cataclastic rocks), as well as the remains of the Manaforto and Sperone villages, are still clearly visible along the Serrone SW slope. Moreover, the area is easily accessible by car (Gioia dei Marsi is 15 min from the A25 Parks’ Highway) and an easy mountain trail runs along the slope of Mount Serrone (from Gioia to Sperone) and was recently restored by the Municipality.

### 3. The Mount Serrone fault Geosite

The identification of the fault scarp and the slope of Mount Serrone as a Geosite was based on the ISPRA (2002) guidelines. The geosite was defined after the 1915 Fucino earthquake centenary for the high geological, geomorphological and historical values, in terms of landforms, tectonics, seismicity and earthquake



**Figure 2.** Geological scheme of central Italy (modified from Cosentino et al., 2010; Piacentini & Miccadei, 2014).

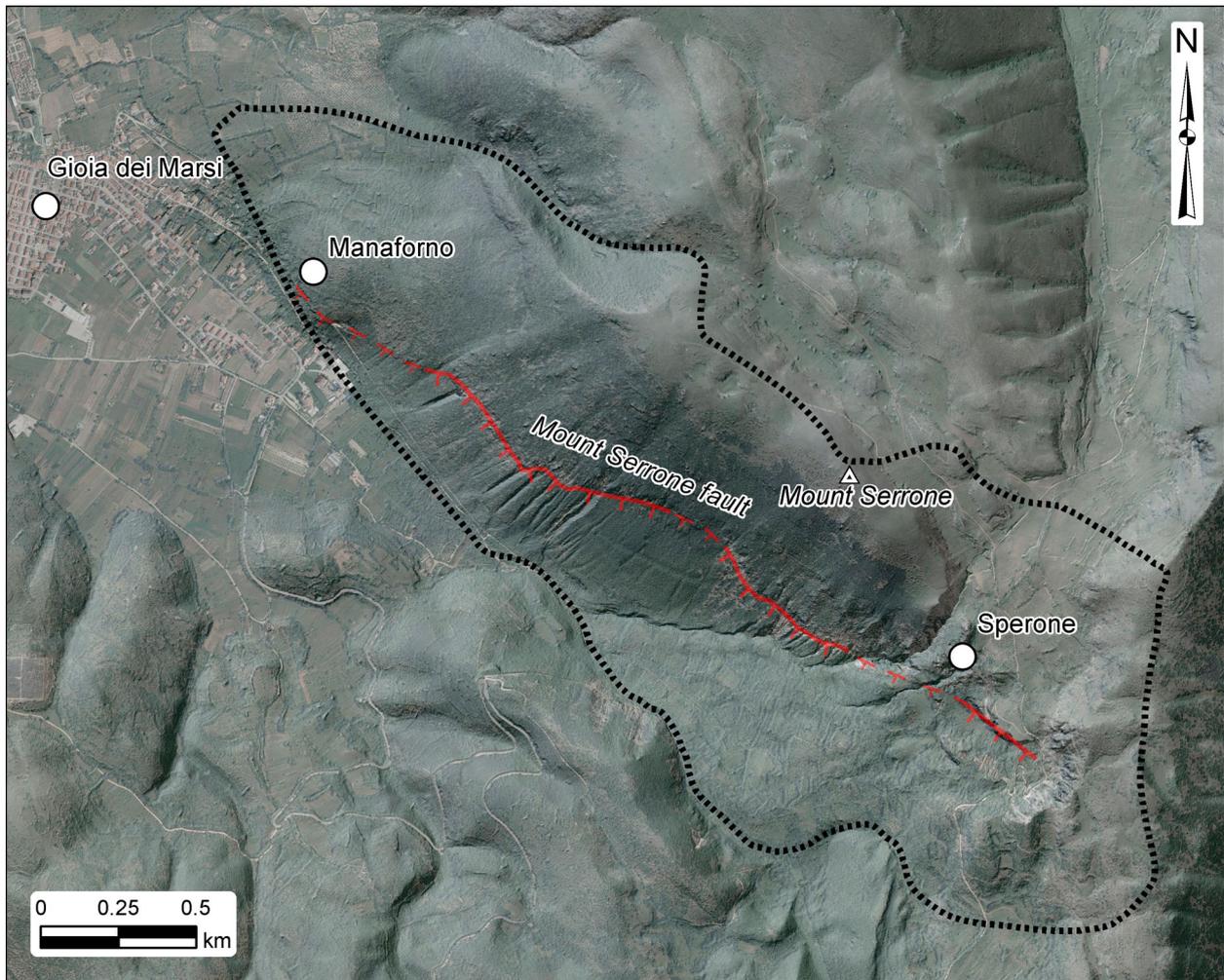
damaging. It is of primary geotourist interest and then of educational and landscape interest. Moreover, it is aimed at becoming a useful tool for the dissemination of the geological knowledge of the Abruzzi region and the Marsica territory in schools, for landscape-seismic hazard awareness and for the enhancement of local tourism in an area located right at the entrance of one of the most ancient national parks in Italy.

The Mount Serrone fault Geosite landscape is characterized by steep mountainous NW-SE ridges with a gently rolling top area, which drops down toward the Fucino basin along a steep slope. The top of the ridge is almost bare, while a heavy tree canopy covers the slope and particularly the lower part (Figure 3).

From the geological point of view, the geosite is featured with marine Mesozoic and Cenozoic sedimentary calcareous and clay rocks, fault rocks and superficial deposits developed in subaerial environments due to gravity, fluvial-alluvial fan processes and karst weathering. Looking at the Mount Serrone slope from SW, a wide greyish band with no vegetation can be observed, located in the middle upper portion of the slope with an arched shape (Figures 3 and 4). It is composed of several vertical and southwest dipping rock scarps and walls, which correspond to smooth fault planes (also called fault mirrors) as surface expression of different segments of the Serrone fault (Figures 4 and 5). The main fault is a normal fault (Figure 5(a)) composed of several fault planes with N45W-N60W strike orientation and 65°–40° SW dipping (Figure 4(b,c,d)). Along the fault, a wide cataclastic band is composed of

heavily jointed and ‘crushed’ calcareous rocks deformed and resulting in a massive limestone breccia and sand (Figure 4(e)). In the lower part of the slope, talus slope deposits are onlapping onto the carbonate rocks along the fault plane (Figure 4(c,d)). The geomorphological features outline a fault scarp at mid-elevation along the slope, which could be defined as fault generated mountain front as a whole (Vittori et al., 1991; Agosta, Prasad, & Aydin, 2007; Miccadei et al., 2014). The fault scarp was affected by surface faulting during the 1915 earthquake as documented right after the earthquake by Alfani (Figure 4(b)) and in paleoseismological studies, and thereafter by surface processes that locally exhumed the fault plains.

Due to its peculiar features, the Mount Serrone fault Geosite is meaningful for different types of activities: (i) geological and environmental education for school students, (ii) activities leading to greater awareness of natural hazards (i.e. seismic hazard) and (iii) tourism activities in general that focus on a sustainable approach to the exploitation of the landscape in a highly sensitive area. Here, several activities (e.g. workshops, conferences and seminars, field trips, school Earth science education projects) have been already realized (Figure 6) and others are planned, in collaboration with primary and high schools from the Abruzzo area and with the support of the Gioia dei Marsi Municipality and of the Mount Serrone Association. These activities, through the use of the geological tourist map, are focused on the present features of the geosite and of its landscape, which incorporate and are connected to long-term (geological) and



**Figure 3.** Mount Serrone fault Geosite (Gioia dei Marsi, AQ). Orthophoto and hillshade image of the Geosite area (black dotted line). The fault scarp is evident all along the Mount Serrone slope (red line). Orthophoto is provided by Regione Abruzzo cartographic office; DEM is provided by Ministry of Environment (National Cartographic Portal).

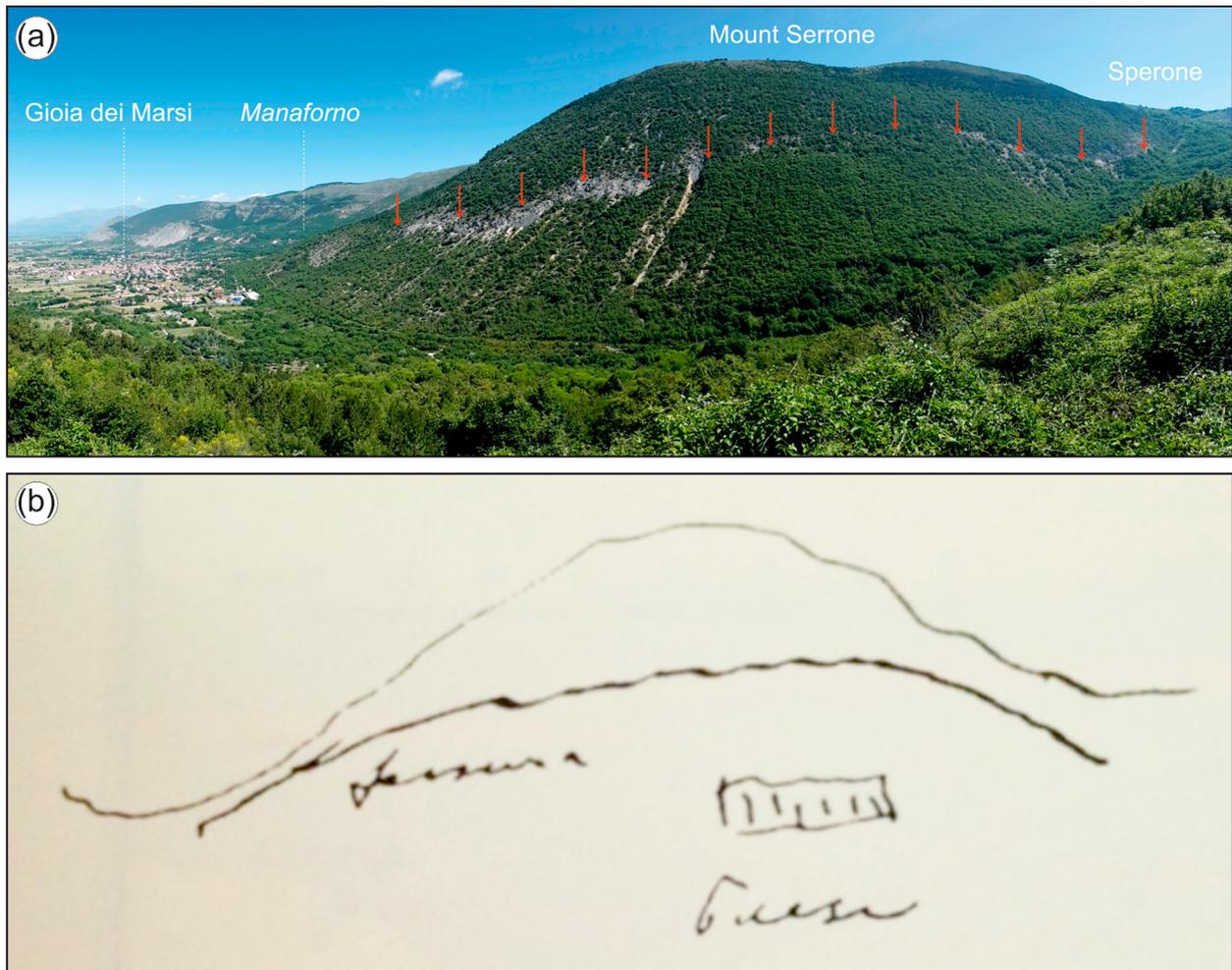
short term (historical) memories of the landscape shaping and of the present geological hazards.

#### 4. Methods and realization of the map

The geological tourist map is designed to establish an easy, guided visual connection between the landscape features and the geological heritage of the geosite and the observers or geotourists. To help simplify this connection – particularly for children –, the reading and understanding of the map is supported by a little girl named ‘Gioia’, which is both the name of the village and the Italian word for ‘joy’. She accompanies the readers, as a geological guide, in an observation, comprehension and knowledge process of the geological and tectonic features visible in the geosite’s landscape and along the trail helping the observer in the comprehension of the technical and scientific tasks. She helps to outline, with a smile, the faults as an element of Nature, but also to focus on the hazards and risks connected to faults and earthquakes that heavily affected the Gioia dei Marsi and the Fusino area.

The map incorporates previous data from geological mapping for defining the base map (ISPRA, 2014; Miccadei et al., 2014) and detailed geostructural investigations (Vittori et al., 1991). New investigations (field geological-geomorphological survey and aerial photo interpretation) were focused on defining the geosite’s features and values and the best sites for the geosite observation along the trails (in terms of geological exposures, their connection to the geological history of the landscape and their accessibility).

The map is double-sided and eight times foldable for a final A5 folded size. The front is explanatory, the back is illustrative. On the front, complex features and processes, such as the long-lasting geological history and the earthquakes, are explained in an easy-to-understand language supported by charts and cartoons. The back shows the **Main Map**, a simple visual legend, a geological time scale and a cartoon of the Gioia dei Marsi-Sperone trail. The visual legend describes, with a color, an image and text, the different rock types that can be found in the Geosite area. The descriptions are headed by simple paraphrases outlining how, where, and when the rocks were formed, as well as



**Figure 4.** (a) Panoramic view of the Mount Serrone slope and of the entire geosite area; the fault scarp is outlined by the arch-shape grey band (red arrows) in the middle of the slope. (b) Sketch of the Mount Serrone slope, from the original manuscript of Padre Alfani (1915), while traveling in the Fucino area in the area affected by the earthquake. The upper line is the Mount Serrone profile, the mid line is the fault scarp, which Alfani observed on the slope, and the lower line marks the approximate location of the ancient village of Manaforno (thanks to the Ximenian Observatory, Florence).

the main tectonic features (fault planes and fault rocks).

More specifically the front of the map is arranged in seven sections:

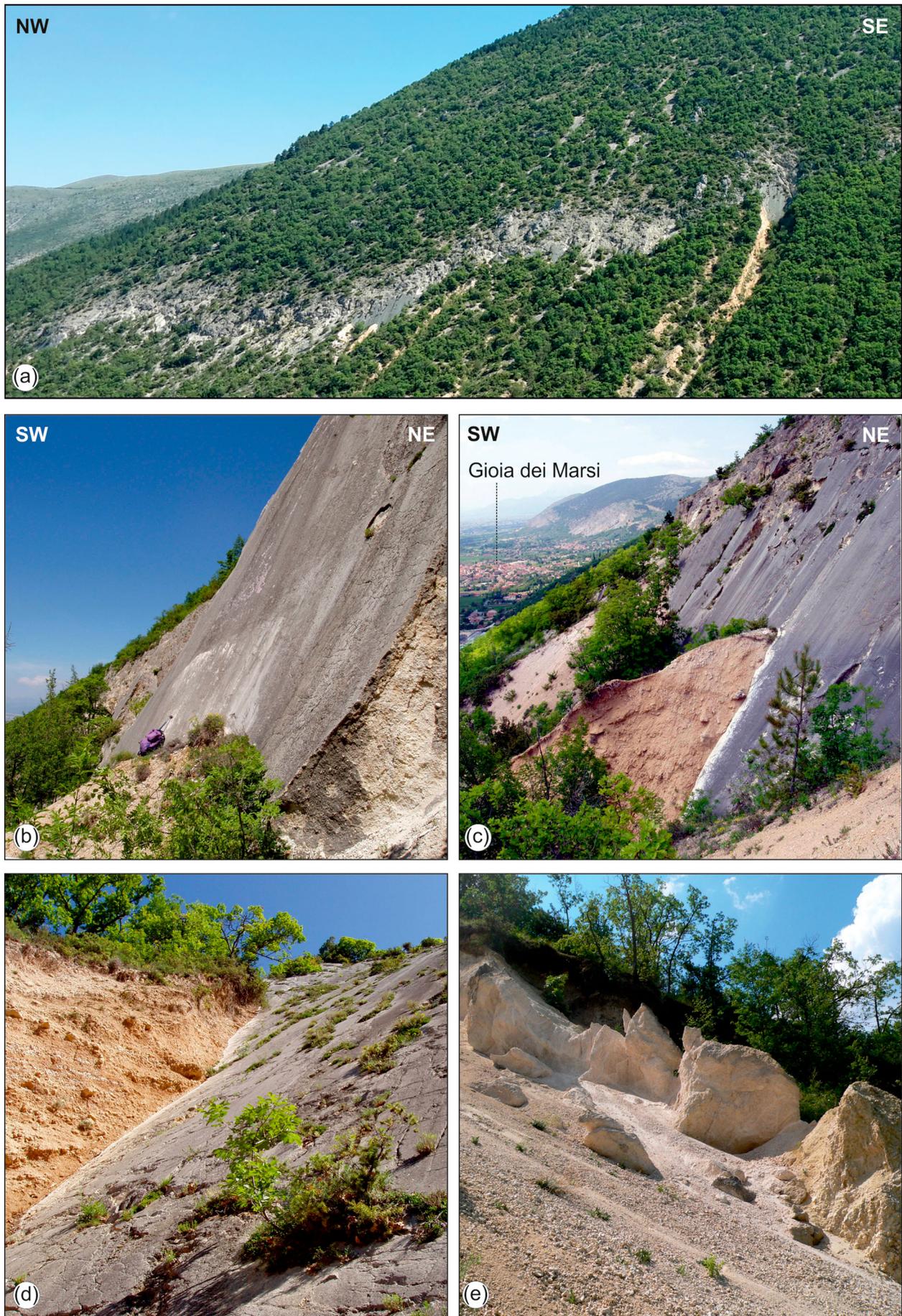
- (1) an introductory part on the main features and relevance of the Mount Serrone fault Geosite;
- (2) definition of a fault;
- (3) description and classification of the different types of faults (i.e. thrust, strike-slip, and normal faults) and their state of activity ('good' or 'bad' faults);
- (4) description of an earthquake;
- (5) historical notes about the great 1915 Fucino earthquake, which changed the recent history of the Fucino area, focusing on the Gioia dei Marsi town and on the Manaforno and Sperone villages (Sinibaldi & Granato, 2015) (Figure 4);
- (6) health and safety guidelines in seismic areas, to be followed before, during and after an earthquake, according to the guidelines provided by the Italian Civil Protection Agency ([www.protezionecivile.gov.it](http://www.protezionecivile.gov.it));

- (7) further readings provided for those interested in more scientific and technical details.

The back of the map is composed of:

- (1) the **Main Map** (Figure 7), with a location map;
- (2) the visual legend;
- (3) a cartoon of the Gioia dei Marsi-Sperone trail;
- (4) a geological time scale outlining the main rocks and the main steps of the >100-million-year geological history of the geosite.

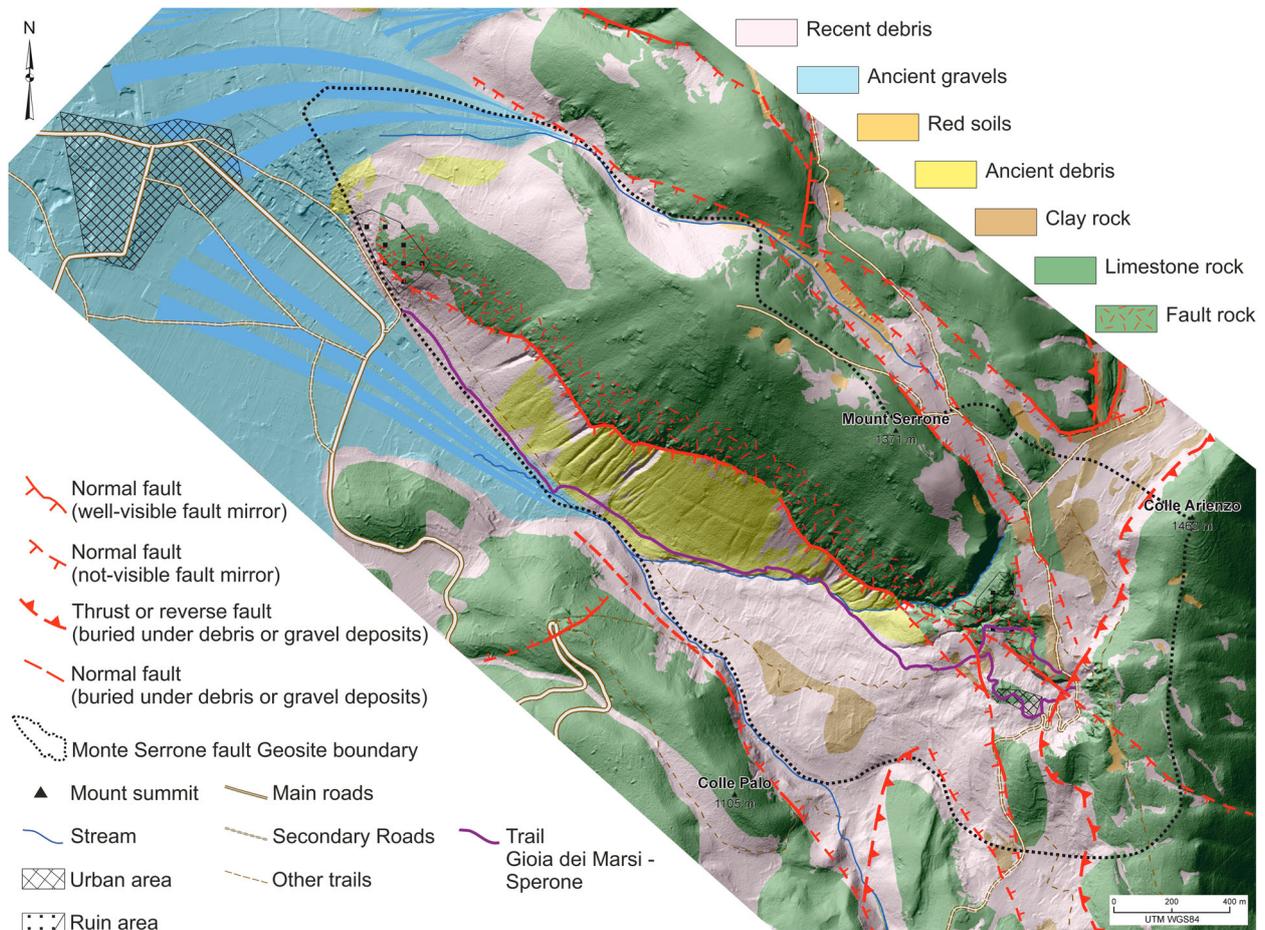
The map and the visual legend show that the backbone of the Mount Serrone ridge is composed of limestone carbonate platform rocks formed in a shallow sea before the formation of the Apennines (Jurassic-Cretaceous and Miocene, ca. from 100 million to 10 million years ago). Small patches of clay and sandstone rocks formed in a deep sea during the formation of the Apennines are also present (Late Miocene, ca. from 10 million to 5 million years ago; Colacicchi, 1967; Praturlon, 1968; Cavinato et al., 2002; ISPRA, 2014; Miccadei et al., 2014).



**Figure 5.** The Serrone fault. a) Main fault scarp partly eroded by gully incision; b) main fault plane and rock scarp; c) fault scarp in the middle part of the fault, with ancient talus slope deposits onlapping onto and cut by the fault; d) close up of the talus slope deposits laying on one of the main fault planes; e) fault rock composed of crushed highly jointed limestones along the main fault.



**Figure 6.** Field trip along the Mount Serrone fault Geosite for an educational project carried out by a high school from the Abruzzo area.



**Figure 7.** Geological tourist map draped on a hillshade image. The fault scarp is evident all along the Mount Serrone slope. DEM for the hillshade image is provided by Ministry of Environment (National Cartographic Portal).

Along the Mount Serrone fault, limestone rocks are covered by superficial deposits formed during the Quaternary period in a subaerial landscape (e.g. debris 'rolling' along the slopes, alluvial gravel 'transported' by stream water, red soils due to karst weathering of the limestone rock; age ranging Upper Pleistocene to Holocene, from 125,000 years ago to the present). The Mount Serrone fault scarps ('mirrors') and fault rocks are also described.

This visual legend, together with a simplified geological time scale, helps the observer to outline the place and role of the different types of rocks and faults in the geological history. The little girl 'Gioia', along the Mount Serrone trail, travels an imaginary journey in geological time through the main geological steps that have led to the shaping of the present landscape. It begins from a Jurassic-Cretaceous shallow sea, moves to a Miocene deep sea, goes through the Miocene compressional tectonics and leads to the Quaternary extensional tectonics and recent fault activity (with connected earthquakes, like the 1915 Fucino one), in competition with Pleistocene to Holocene fluvial, slope and weathering surface processes. This contributes to raising the awareness of the general public about the meaning and duration of 'geological time' and of the long-term geological history of the landscape.

## 5. Concluding remarks

The Geological tourist map of the Mount Serrone fault Geosite is a key tool in promoting the landscape as a resource for tourism and for geological hazard awareness. The Gioia dei Marsi and Mount Serrone area, at the entrance of the National Park of Abruzzo, Lazio, and Molise, is poorly known in terms of tourism, but rich in resources in terms of geological history and recent history of the Fucino and Marsica area (inner Central Apennines). The geosite is defined along one of the main faults connected to the 1915 Fucino earthquake, historically, one of the strongest in Italy.

In the map, tectonics, faults and earthquakes are shown as a hazard but also as elements of Nature that have contributed to creating the landscape of the Apennines over geological time. The map establishes an easy and guided visual connection between the observers/geotourists and the landscape and geological heritage of the geosite. It incorporates long-term (geological) and short term (historical) memories of the landscape shaping and of the present geological hazards. The exploitation of these connections provides a useful tool (i) to understand how the landscape was formed through geological time, (ii) to establish the historical memories of the 1915 Fucino earthquake and of recent earthquakes, (iii) to be aware of the current hazards due to natural processes, especially seismic ones, and finally (iv) to contribute to an aware and responsible community. The history of the landscape becomes something to be understood and

increases people's awareness of geological processes. Through this awareness and proper land management, people learn to live with natural geological hazards.

Ultimately, through this type of map, the symbiosis between the activity of geotourism and the territory becomes an opportunity for tourism, cultural and cooperation activities, as well as being a powerful tool in education.

## Software

The **Main Map** presented in this work was created using Esri ArcGIS® 10.1 and overall layout of front and back side of the map, as well as the final editing work, was carried out with Corel draw X8®.

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