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Review of historical earthquakes and survey of active faults in the San Leonardello Graben area, Mt. Etna (Sicily)

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Abstract: Mount Etna is the largest active volcano in Europe, grown by accumulation of lavas and pyroclastics erupted by numerous vents during the last 180 kyr. It is located along the Ionian coast of Sicily, on the margin of two main structural domains: the Apennine-Maghrebian Chain to the north and the Hyblaean Foreland to the south. While eastern Sicily is characterized by a general uplift, the sector bounded by the North-East Rift and the Pernicana Fault northward, and by the Montagnola-Aci Castello Fault System toward SW is lowering; three more fault systems are active in the eastern sector of Etna: i) the Giardini-Mascali Fault System (NE–SW and NNE–SSW trends); ii) the Ripa della Naca-Piedimonte Fault System (NE–SW trend); iii) the Timpe Fault System (NNW–SSE trend). In historical times, the Giardini-Mascali Fault System was active only in 1847, while the Ripa della Naca-Piedimonte Fault System was active before and during the 1865, 1928 and 1971 eruptions.

Several earthquakes have occurred along the Timpe Fault System from 1805 to present. The analysis of seismological data and volcanic activity shows that the Timpe Fault System is the most active of the eastern flank of Etna. The most important faults of this system are the Moscarello, San Leonardello and Macchia-Stazzo Faults forming the San Leonardello Graben. Shallow earthquakes occur along these faults, frequently causing surface fractures. In this paper we analyze historical records of earthquakes stronger than VII degree EMS-98. Macroseismic data are available since 1805. The epicenters are located along the northernmost segment of the faults. Along these faults offsets are mainly vertical with the maximum value of 80 cm recorded along the Moscarello Fault after the 1911 Fondo Macchia Earthquake.

Key words: Mount Etna volcano eastern slope, S. Leonardello Graben, historical seismicity, active faults, geomorphology

1. Introduction

In this paper we examine historical records of earthquakes with intensity larger than VII degree of the EMS-98 scale; our aim is a review of the seismic hazard of a tectonically active area located on the lower eastern slope of Mount Etna (Fig. 1). This area is bounded by the Moscarello Fault (Fig. 2 – mf) to the west and by the Macchia-Stazzo Fault (Fig. 2 – msf) to the east.

Historical earthquakes have been reported in this area since 1805. The aim of the present work is to provide a detailed macroseismic analysis for a seismic hazard evaluation in a highly populated area.

2. The structural framework of Mt. Etna volcano

Mt. Etna is the largest active volcano in Europe; it is formed by the accumulation of products of several eruptive vents that were active in different

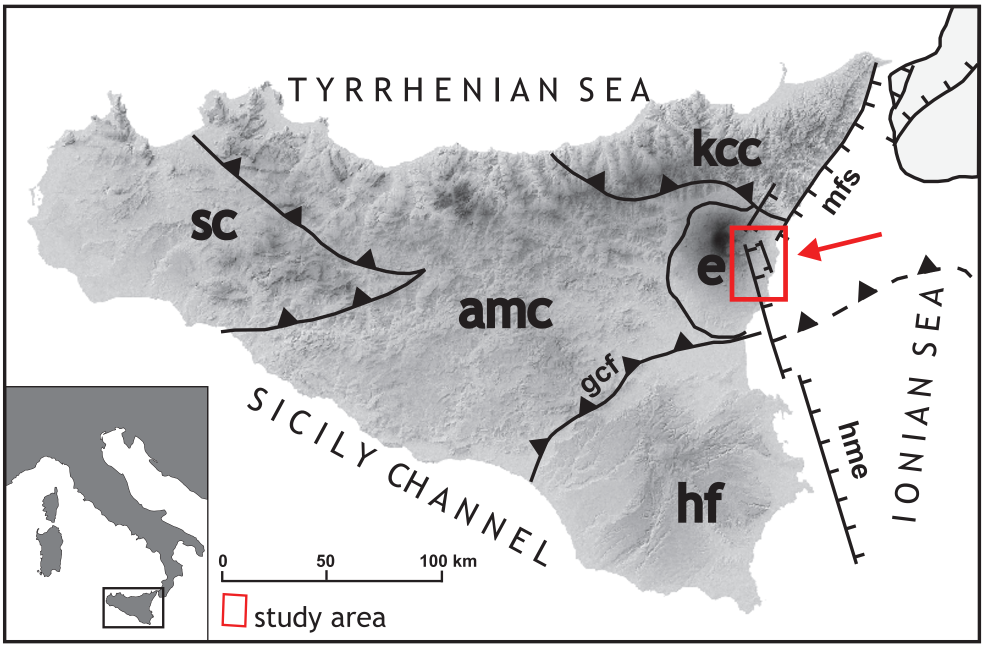

Fig. 1. Location of the studied area in the structural frame of Sicily. **kcc**) Kabilo-Calabrian Chain; **amc**) Apennine-Maghrebian Chain; **sc**) Sicanian Chain; **hf**) Hyblaean Foreland; **e**) Mt Etna volcano; **hme**) Hyblaean-Malta Escarpment; **mfs**) Messina-Fiumefreddo System; **gcf**) Gela-Catania Foredeep.

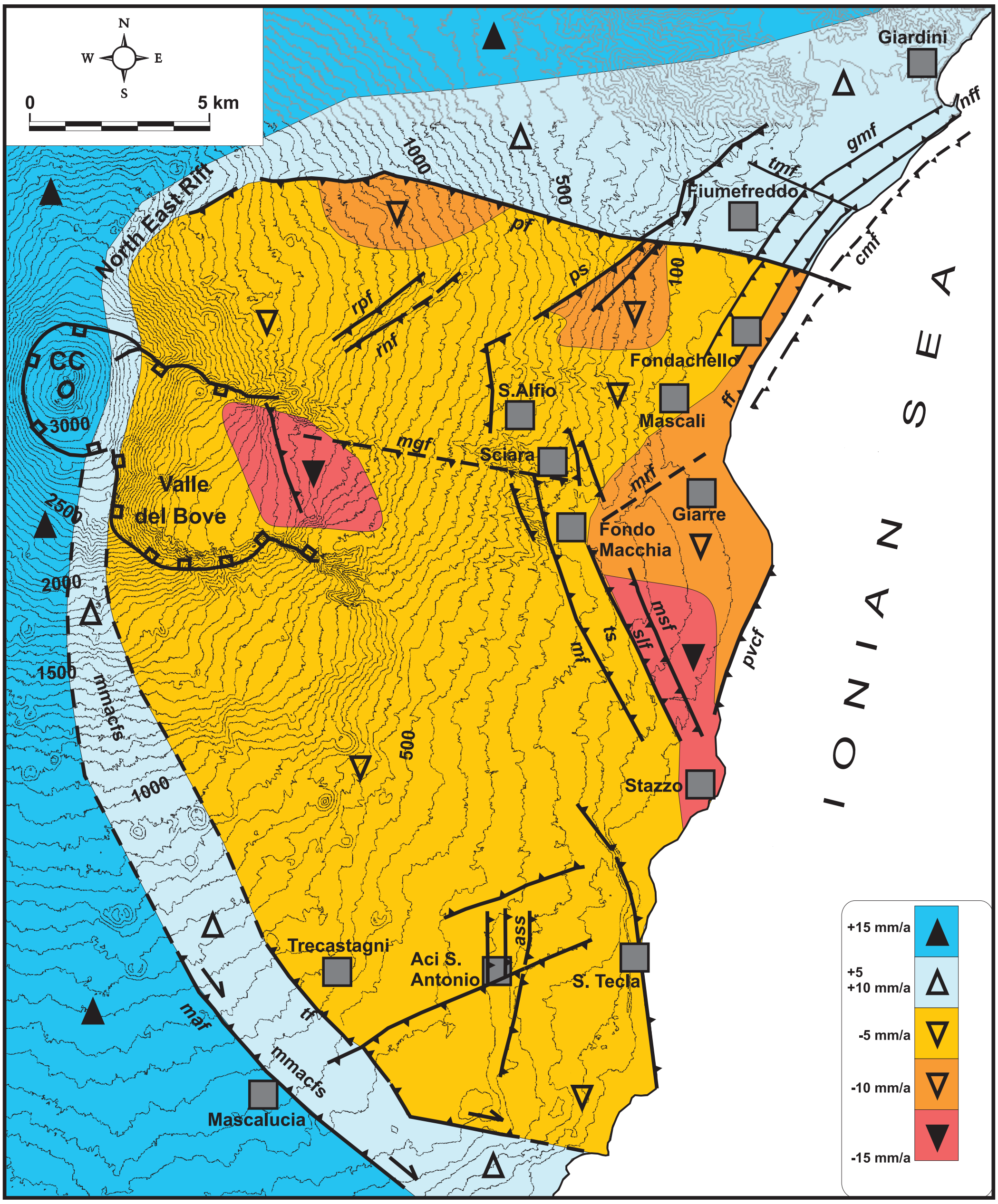

Fig. 2. Main faults on the eastern slope of Mt. Etna (CC: central craters); **ass**) Aci S. Antonio System; **ff**) Fondachello Fault; **gmf**) Giardini-Mascali Fault; **mf**) Moscarello Fault; **maf**) Mascalucia Fault; **cmf**) Capo Schisò-Macchia stream Mouth Fault; **mgf**) Milo-Giarre Fault; **mmacfs**) Montagnola-Mascalucia-Aci Castello system; **mrf**) Macchia-Riposto Fault; **ts**) Timpe system; **tmf**) Torrente Macchia Fault; **msf**) Macchia-Stazzo Fault; **nff**) Naxos-Fondachello Fault; **pf**) Pernicana Fault; **pvcf**) Praiola-Villa Calanna Fault; **rpf**) Ripa di Piscio Fault; **rnf**) Ripa della Naca Fault; **slf**) San Leonardello Fault; **tf**) Trecastagni Fault; **ps**) Piedimonte System. Triangles indicate uplift and lowering zones up to ±15 mm/y (after *Gironi et al., 2003*; *Carveni et al., 2005a, 2005b*).

periods during the last 180 kyr (e.g. *Gillot et al., 1994*). Mt. Etna is located in eastern Sicily. It is bounded northward and westward by the Apennine-Maghrebian Chain, southward by the Hyblaean Foreland, and eastward by the Ionian Block (Fig. 1). The Apennine-Maghrebian Chain consists of several structural units over-thrusted from Eocene to Pleistocene *(Lentini, 1982)*. The Hyblaean Foreland belongs to the northern African Plate margin *(Barberi et al., 1974)*; it is characterized by carbonatic units deposited from Triassic to Pleistocene, with intercalations of basaltic rocks *(Cristofolini, 1966; Di Grande, 1967; 1969; Patacca et al., 1979; Carbone et al., 1982; Lentini et al., 1986; Carbone et al., 1987; Carveni et al., 1991a; 1991b; 1993; Carveni and Sturiale, 1999)*.

The Ionian block is a remnant of the Mesozoic Neotethys *(Aubouin et al., 1986; Underhill, 1989)*. The transition from the Ionian Sea to inland Sicily occurs through a NNW–SSE system of normal faults forming the Hyblaean-Maltese Escarpment (Fig. 1 – **hme**) the northernmost tip of which crosses the eastern flank of Etna *(Lo Giudice et al., 1982)*. From the structural point of view, Mt. Etna is located at the intersection between several tectonic trends *(Ogniben et al., 1975)*, and much of its seismic activity is not directly associated with volcanic activity.

Marchesini et al. (1964) made the first analytic study of the structural pattern of Mt. Etna identifying four tectonic trends: N–S, ENE–WSW, NE–SW and NW–SE. In following studies, *Romano (1970)* and *Rittmann et al. (1973)* confirmed the importance of the N–S and ENE–WSW trends, whilst *Frazzetta and Romano (1978)* identified two main trends of preferential paths for dikes emplacement in areas with a high probability of flank eruptions: NE–SW to ENE–WSW, NNW–SSE.

The eastern flank of the volcano is characterized by four tectonic trends: ENE–WSW, NNW–SSE, WNW–ESE and E–W; N 60° E and N 20° W correspond to the structural trends of the Hyblaean mountains and the Patti area, belonging to the domain of the Apennine-Maghrebian Chain *(Lo Giudice et al., 1982)*. Moreover, the N 20° W trend is common to many direct faults located along the lower eastern flank of Mt. Etna, corresponding to the northernmost segment of the Hyblaean-Maltese Escarpment *(Lo Giudice et al., 1982)*. *Ferrucci et al. (1992)* provided evidence that major magma pulses from mantle sources are strongly controlled by this fault system. Other authors *(Borgia et al., 1992; Lo Giudice and Rasà, 1992;*

Carveni and Bella, 1994; McGuire et al., 1996) suggested that the volcano eastern flank is affected by a SE-ward sliding of the mobile substratum of Pleistocene clay. In such a context, the structural alignments which form the removal zone of the hypothetical mega-slide would have a left-lateral strike-slip component northward: *the North-East Rift* (Fig. 2) and *Pernicana Fault* (Fig. 2 – **pf**); and a right-lateral one to the southeast: *the Montagnola-Mascalucia-Aci Castello Fault System* (Fig. 2 – **mmacfs**; see *Carveni et al., 2007*).

The main faults affecting the lower eastern flank of the volcano are characterized by lengths of several kilometers and by vertical offsets ranging from several meters (*Macchia-Stazzo Fault*, Fig. 2 – **msf**) to several hundred meters (*Moscarello Fault*, Fig. 2 – **mf**) *(Cristofolini et al., 1979; Lo Giudice et al., 1982; Adorni and Carveni, 1993a; 1993b; Carveni and Bella, 1994; Gresta et al., 1997; Carveni et al., 2005a; 2005b; 2007).*

A network of fault escarpments isolating blocks tilted westward *(Platania, 1904; 1922; Kieffer, 1985; Carveni and Bella, 1994)* sharply dislocates to the east the gently inclined coastal flank producing a step-fault system that culminates with the small *"San Leonardello Graben"* that is the object of this research. The earthquake activity of the Etna eastern flank is very shallow ($h < 2$ km) with energy release up to $Mmax = 5.0$ (*Gresta and Patanè, 1987*). Several studies underline the different seismic behavior between the western and the eastern Etna flanks: minor earthquakes with deeper foci ($h > 5$ km) occur in the western flank, while more frequent and larger earthquakes with shallower foci ($h < 5$ km) occur in the eastern flank *(Glot et al., 1984; Gresta et al., 1990; Ferrucci and Patanè, 1993).*

3. The San Leonardello Graben

The studied area is located on the lower eastern flank of Mt. Etna between the villages of S. Alfio, Stazzo and Giarre and the Moscarello Mount (Fig. 2). Morphological evidence of several faults characterizes this area.

They have been identified and mapped through stereo photos and field surveys (see also *Adorni and Carveni, 1993a; 1993b; Carveni and Bella, 1994*). Direction and length of the faults and their morphological evidence are listed in Table 1.

Table 1. Faults direction, length and morphological evidence

Fault	Direction	Length	Morphological evidence
Moscarello	N 20° W	10.0 km	Scarp up to 200 m high
San Leonardello	N 20° W	5.5 km	Scarp up to 40 m high
Macchia – Stazzo	N 20° W	8.0 km	Scarp up to 10 m high, many fluvial captures

4. Local seismicity

The lower eastern slope of Mt. Etna is a high seismic hazard zone characterized by shallow hypocenters *(Patanè, 1975; Benina et al., 1984; Lo Giudice, 1985; Bottari et al., 1989; Azzaro et al., 1989a; 1989b; Lo Giudice and Rasà, 1992)*. The information available from the literature about the earthquakes occurred in this area during the last two centuries are summarized in Table 2. Some of these earthquakes caused serious damages, sometimes causing the complete destruction of villages and significant loss of life, notwithstanding their low magnitude, probably due to the very shallow hypocenters.

Tectonic movements caused also important landscape variations, like waterfalls and river diversions, and co-seismic opening of fractures were reported by many authors *(Grassi, 1865; Silvestri, 1865; 1866; 1867; 1883; Platania and Platania, 1894; Platania, 1908; 1920; Riccò, 1911; 1912; Sabatini, 1914; Castorina, 1920; Cumin, 1954; Riuscetti and Distefano, 1971; Azzaro et al., 1989a)*.

4.1. Earthquakes linked to the Moscarello Fault

The Moscarello Fault is an active lineament, as testified by the following earthquakes with epicenters located at Fondo Macchia, in the Sciara area and Guardia (Fig. 2). It is oriented N 20° W and about 10 km long, dissecting lava flows, pyroclastic rocks and recent alluvial sediments. The fault scarp reaches a maximum height of about 200 m near the village of Fondo Macchia.

Table 2. Parameters of earthquakes and related faults: I_0: intensity of the mesoseismic area; O: offset; T: sense of strike-slip movement; Rif: bibliography. 1) *Grassi, 1865*; 2) *Riccò, 1911; 1912*; 3) *Silvestri, 1865*; 4) *Riuscetti and Distefano, 1971*; 5) *Patanè, 1975*; 6) *Castorina, 1920*; 7) *Platania, 1920*; 8) *Cumin, 1954*; 9) *Postpischl, 1985*; 10) *Azzaro et al., 1989a*; 11) *Baratta, 1900*

Date	Epicentre	Fault	I_0 (EMS-98)	Depth (km)	O (m)	T	Rif
1805, 11th July	Fondo Macchia	Moscarello	VIII-IX (?)				1, 2
1855, 26th Jan.	Fondo Macchia	Moscarello	VIII			dx	1
1865, 19th July	Fondo Macchia	Moscarello	XI	1.6±16% (9)	0.6	dx	1, 3
1881, 12th Febr.	San Matteo	Macchia – Stazzo	VIII				8, 11
1911, 15th Oct.	Fondo Macchia	Moscarello	X	1.0	0.9	dx	2
1920, 26th Sept.	Codavolpe	San Leonardello	X	0.5±3.4% (9)	0.6		6, 7
1950, 08th Apr.	Codavolpe	San Leonardello	IX	0.7±13.6% (9)			8, 9
1971, 21st Apr.	Sciara	Moscarello	X				4
1973, 19th Aug.	Mangano	Moscarello	VII				5
1989, 29th Jan.	Codavolpe	San Leonardello	VIII	0.5±7.7% (9)		dx	10

4.1.1. 1805, July 11th

Grassi (1865) and *Riccò (1911, 1912)* gave a brief report of an earthquake occurred at Fondo Macchia. Following these authors, the event is similar to that occurred on 1865, July 19th, thus we assign to it an intensity of VIII-IX degree (EMS-98).

4.1.2. 1855, January 26th

Information about this earthquake are from *Grassi (1865)*. All buildings in Macchia and Fondo Macchia were strongly damaged and aftershocks went on for eight days. In the nearby village of San Giovanni the shocks were of small intensity, with little damage (V degree EMS-98); Giarre and Milo were reported to have felt a III degree. Not enough data are available to reconstruct the macroseismic field of this earthquake *(Lo Giudice et al., 1990)*, however an epicentral intensity of VIII degree EMS-98 is hypothesized on the basis of the damages reported at the village of Macchia.

4.1.3. 1865, July 19th

The most destructive effects in the San Leonardello Graben area were caused by the 1865, July 19th earthquake (Fig. 3). Fondo Macchia was razed with most of the buildings fell toward the west, and only people that were outdoors during the earthquake survived *(Silvestri, 1865)*. The eastern block of the fault slided down of about 30 ÷ 60 cm, while fractures 100 ÷ 150 cm wide

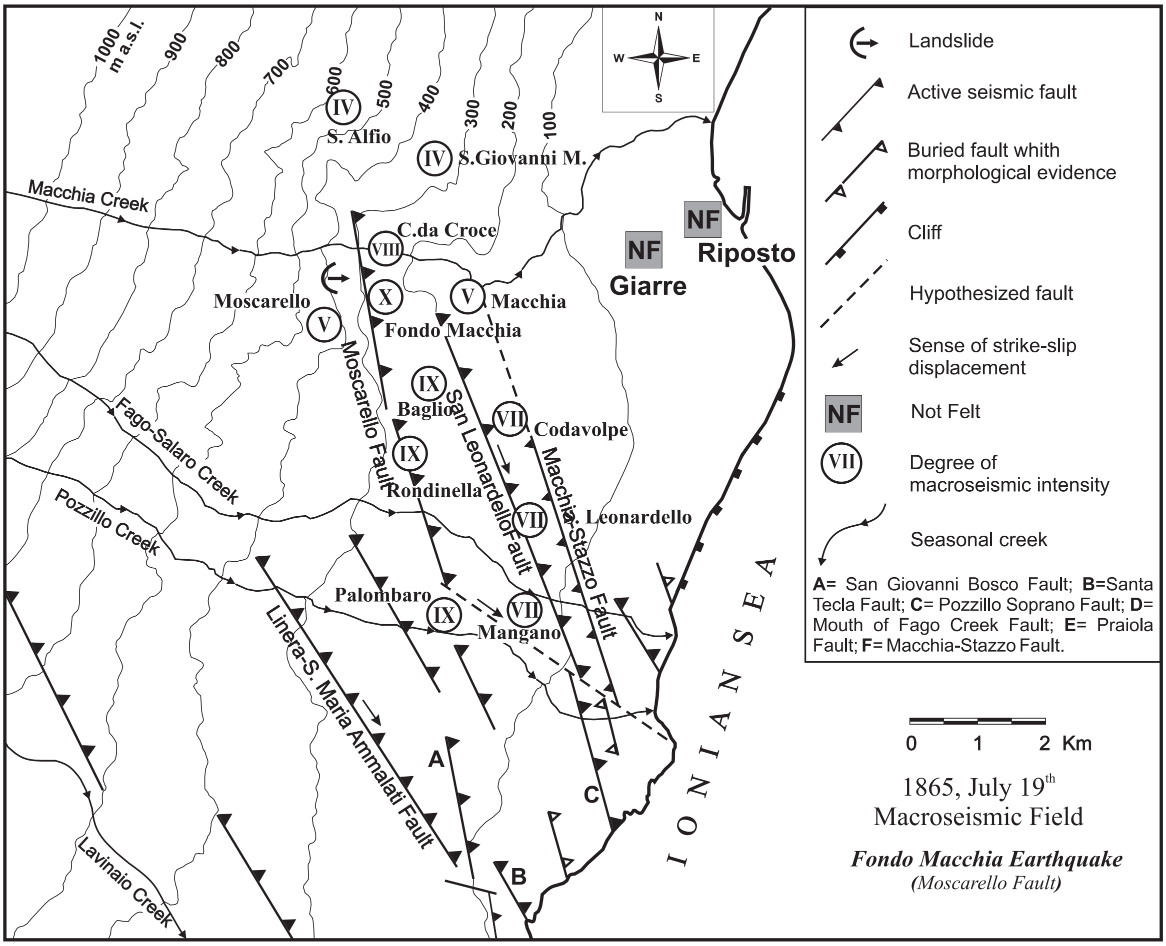

Fig. 3. Macroseismic field of the Fondo Macchia, July 19th, 1865 earthquake.

formed, parallel to the fault strike; some landslides occurred at Moscarello Timpa *(Silvestri, 1865; Grassi, 1865)*. Aftershocks went on for about one month *(Silvestri, 1865)*.

Postpischl (1985) calculated a focus depth of about 1.6 km. Based on the available data we hypothesize that:

(i) the maximum intensity of XI degree EMS-98 was felt at Fondo Macchia, that was completely destroyed;
(ii) seismic waves propagation was maximum toward the SSE, while the maximum attenuation was toward the WSW;
(iii) the strong attenuation of seismic energy toward the north could be due to a hypothetic E–W fault running along the Torrente Macchia valley *(Carveni et al., 2005b)*.

4.1.4. 1911, October 15th

This earthquake had destructive effects on the same villages affected by the 1865, July 19th event. Foreshocks were reported to have occurred *(Riccò, 1911; 1912)*. The epicenter was located at Fondo Macchia that was almost completely destroyed. The estimated focus depth is 1 km and the intensity of the mesoseismic area is X degree EMS-98 *(Bottari et al., 1989)*.

4.1.5. 1971, April 21st

This earthquake is related to the northern segment of the Moscarello Fault. This event affected the village of Sciara *(Riuscetti and Distefano, 1971)* where all buildings were destroyed. We thus assign to this event an epicentral intensity of X degree EMS-98.

4.1.6. 1973, August 19th

Patanè (1975) assigned an intensity of VII degree EMS-98 to this event. It is probably linked to the southern segment of the Moscarello Fault.

4.2. Earthquakes linked to San Leonardello Fault

The San Leonardello Fault (Fig. 2 – **slf**) is an active structure trending N 20° W and 5.5 km long, extending from Fondo Macchia toward the coast between Stazzo and Santa Tecla. Earthquakes originated along the northern sector of San Leonardello Fault, while its southern part is only affected by small movements of about 1.2 cm/year measured from fractures formed in buildings located close to the fault, at San Leonardello, and about 0.4 cm/year at Stazzo.

4.2.1. 1920, September 26th

This earthquake was recorded by *Castorina (1920)* and *Platania (1920)*. The macroseismic field is shown in Fig. 4. Several buildings collapsed at Codavolpe, others were strongly damaged; heavy furniture moved to the NW due to the inertial movement linked to the right-hand sense of displace-

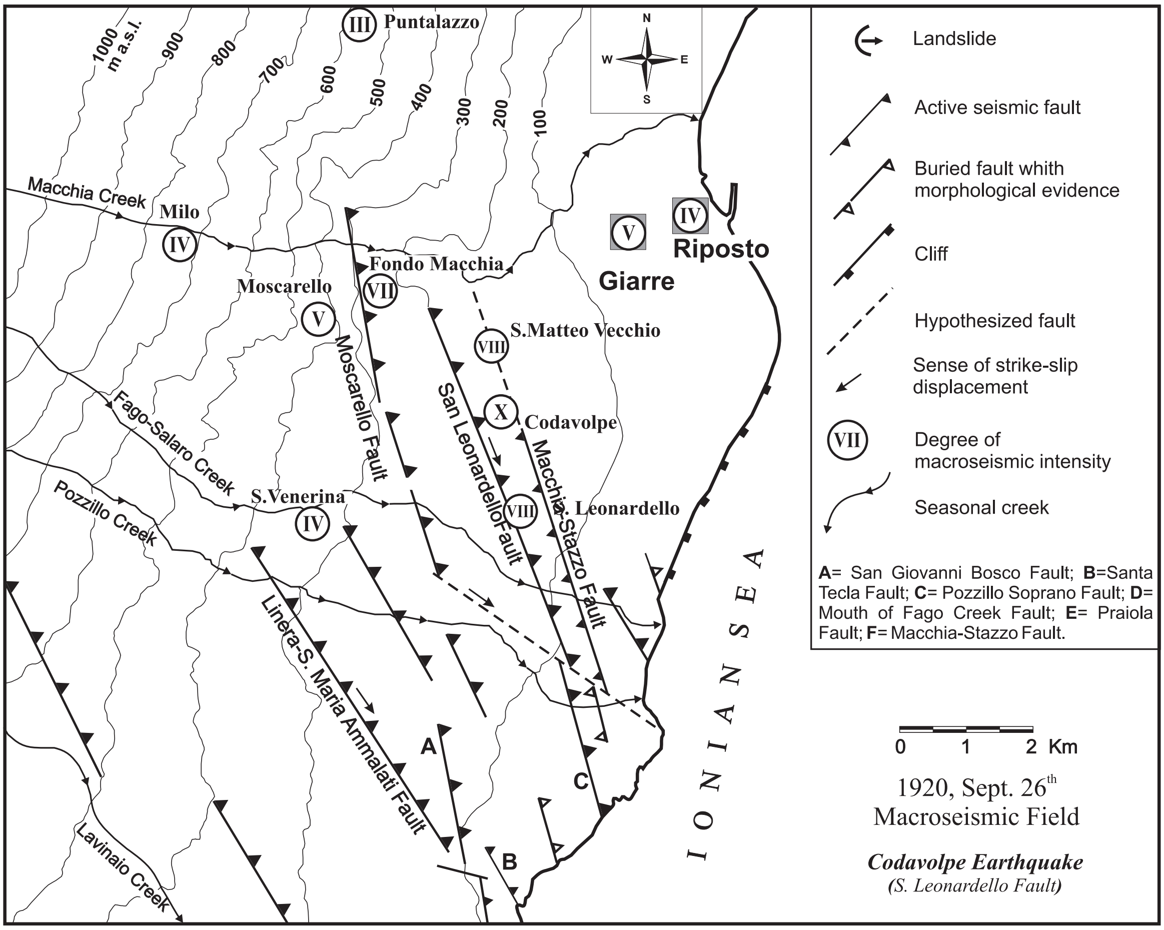

Fig. 4. Macroseismic field of the Codavolpe, September 26th, 1920 earthquake.

ment. At San Leonardello many buildings were strongly damaged *(Castorina, 1920)*. The vertical offset was of about $30 \div 60$ cm.

A hypocenter depth of 0.5 km and an epicenter intensity of VIII degree EMS-98 were estimated for this earthquake *(Postpischl, 1985)*, while we assign the X degree EMS-98 based on the report of *Castorina (1920)*.

4.2.2. 1950 April 8th

Another earthquake affected the Codavolpe area destroying most buildings. Fractures reactivated the previous ones formed during the 1920 earthquake and new fractures opened *(Cumin, 1954)*. Focus depth is 0.7 km and intensity is IX degree EMS-98.

4.2.3. 1989, January 29th

The epicenter of this earthquake fell in the Codavolpe area. Intensity is VIII degree EMS-98; the horizontal slip along the fault was of 3 cm, while the vertical one was of 30 cm; two fractures opened in the N–S and NNW–SSE directions. Focus depth is 0.5 km *(Azzaro et al., 1989a)*.

4.3. Earthquakes linked to Macchia-Stazzo Fault

The Macchia-Stazzo Fault (Fig. 2 – **msf**) trends N 20° W, is 8 km long and borders to the east the San Leonardello Graben. It is anthitetic to the faults discussed above. There is no clear morphological evidence, however, this structure originated some stream diversions *(Adorni and Carveni, 1993a; 1993b; Carveni and Bella, 1994; Bella et al., 1996; Carveni et al., 1997)*.

4.3.1. 1881, February 12th

We know of only one earthquake that is probably linked to the Macchia-Stazzo Fault; this earthquake damaged the village of San Matteo according to *Baratta (1900)* and *Cumin (1954)*, and some fractures opened at the base of the fault scarp *(Cumin, 1954)*. We assign an epicenter intensity of VIII degree EMS-98, while *Gresta et al. (1997)* estimated an intensity of VI-VII degree EMS-98. The mesoseismic field is shown in Fig. 5.

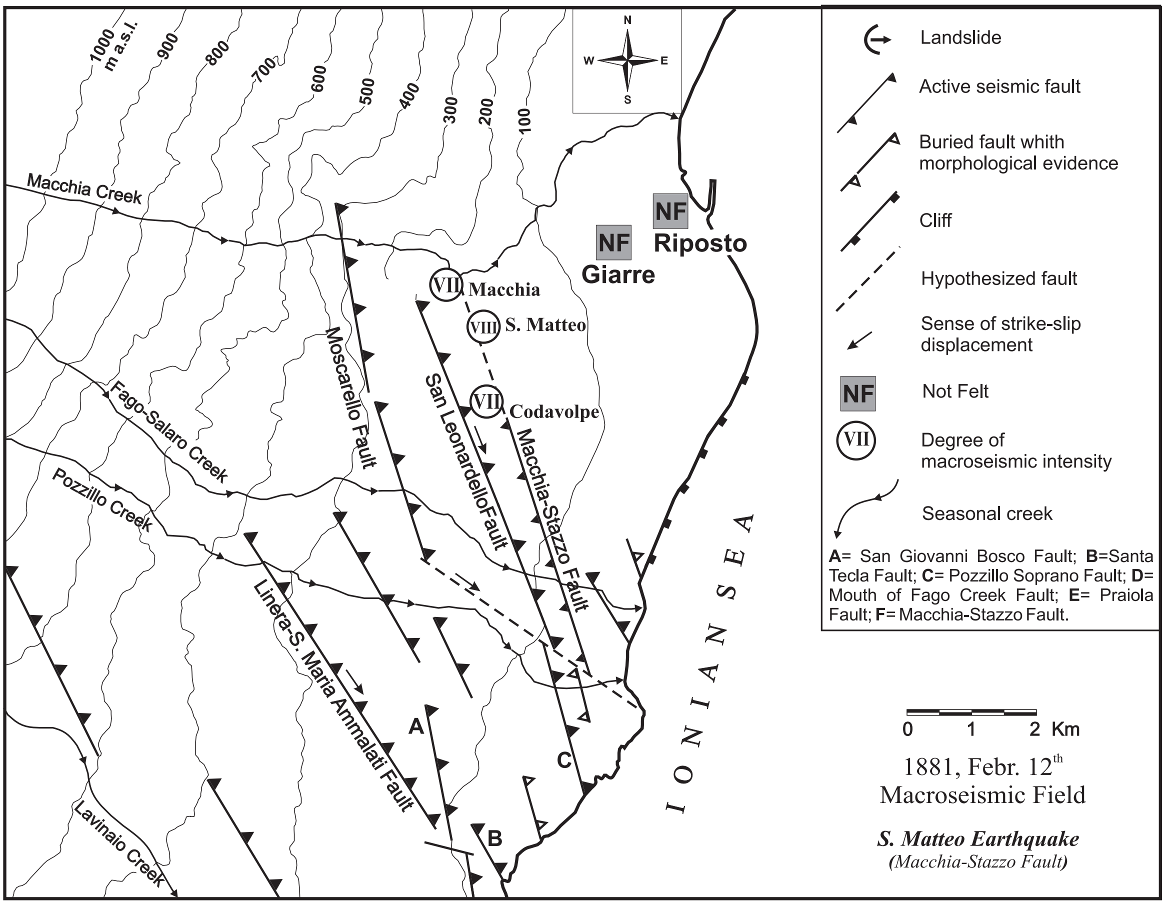

Fig. 5. Macroseismic field of the S. Matteo, February 12th, 1881 earthquake.

5. Discussion and concluding remarks

The analysis of damages and ground coseismic effects due to earthquakes occurred during the last two centuries on the eastern flank of Mt. Etna shows a correlation with the San Leonardello Graben faults. The San Leonardello Graben is located in a sector of the eastern flank of Mt. Etna that is bounded to the north by the Pernicana Fault and to the SW by the Montagnola-Mascalucia-Aci Castello Fault System.

The Etna eastern flank is affected by deep gravitational phenomena; this is particularly evident in the port of Stazzo, where the previous dock, that was 1 m high in 1949, today is by the sea level (Fig. 6).

We have mapped the macroseismic fields of the studied earthquakes on

Fig. 6. Old and new docks in the Stazzo port during ebb tide.

the basis of historical data and new geological and geomorphological field surveys. The shape of the macroseismic fields shows an anomalous attenuation of seismic waves toward north; on this basis we hypothesize the presence of an E–W fault along the Torrente Macchia Valley, which limits to the north the San Leonardello Graben, as in *Carveni et al. (2005b)*.

In conclusion, from the analysis of historical records we point out that the presence of many villages, rural buildings and factories on the lower eastern slope of Mt. Etna poses an issue of environmental risk that has been probably underestimated so far. In this context, the results of this study might contribute to a better definition of risk scenarios.

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References

Adorni G., Carveni P., 1993a: Geomorphology and seismotectonic elements in the Giarre area, Sicily. Earth surface processes and landforms, **18**, 275–283.

Adorni G., Carveni P., 1993b: Anomalies of hydrographical pattern caused by seismotectonic events. (Anomalie del reticolo idrografico causate da eventi sismotettonici sul basso versante orientale del vulcano Etna). Boll. Acc. Gioenia Sc. Nat. Catania, **26**, 342, 196–206.

Aubouin L., Le Pichon X., Monin A. S. (Eds.), 1986: Evolution of Tethys. Tectonophysics, 123, 315 p.

Azzaro R., Carveni P., Lo Giudice E., Rasà R., 1989a: 1989, January 29th Codavolpe earthquake, on lower eastern Etna flank: macroseismic field and cosismic fractures. (Il terremoto di Codavolpe (basso versante orientale etneo) del 29 gennaio 1989: campo macrosismico e fratturazione cosismica). Bollettino del Gruppo Nazionale di Vulcanologia, **1**, 1–12.

Azzaro R., Lo Giudice E., Rasà R., 1989b: Catalog of macroseismic effects and of creep phenomenology in Etna area, between 1980 August and 1989 December. (Catalogo degli effetti macrosismici e delle fenomenologie da creep nell'area etnea dall'agosto 1980 al dicembre 1989). Bollettino del Gruppo Nazionale di Vulcanologia, **1**, 13–46.

Baratta M., 1900: Earthquakes in Italy. Historical, geographical and bibliographical assay. (I terremoti d'Italia. Saggio di Storia, Geografia e Bibliografia sismica italiana). Arnaldo Forni Editore, Torino, 950 p.

Barberi F., Civetta L., Gasparini P., Innocenzi F., Scandone R., Villari L., 1974: Evolution of a section of the Africa-Europa plate boundary: paleomagnetic and volcanological evidence from Sicily. Earth Planet. Sci. Letters, 22, 123–132.

Bella D., Carveni P., Musumeci C., Gresta S., 1996: Geomorpholocical aspects due to local seismic activity on lower eastern Etna volcano flank. (Aspetti geomorfologici conseguenti all'attività sismica locale sul basso versante orientale del vulcano Etna). Il Quaternario, **9**, 1, 365–368.

Benina A., Imposa S., Gresta S., Patanè G., 1984: Macroseismic and instrumental study of two tectonic earthquakes happened on southern flank of Mt. Etna. (Studio macrosismico e strumentale di due terremoti tettonici avvenuti sul versante meridionale dell'Etna). Atti del 3° Convegno del Gruppo Nazionale Geofisica della Terra Solida, **2**, 931–940.

Borgia A., Ferrari L., Pasquarè G., 1982: Importance of gravitational spreading in the tectonic and volcanic evolution of Mt. Etna. Nature, **357**, 231–235.

Bottari A., Carveni P., Lo Giudice E., Pietrafesa M., Birritta G., Stillitani E., 1989: Criteria for the employement and graphic representation of macroseismic data to draw a seismotectonic map. (Criteri di utilizzo e rappresentazione grafica del dato macrosismico nella redazione di una carta sismo tettonica). Att. 8° Conv. Ann. Gr. Naz. Geof. Terra Solida, 191–202.

Carbone S., Grasso M., Lentini F., 1982: Elements for an evaluation of Cretaceous to Quaternary tectonic-sedimentary events in S. E. Sicily. (Elementi per una valutazione degli eventi tettonico-sedimentari dal Cretaceo al Quaternario nella Sicilia

Sud-Orientale). In: Catalano R., Dargenio B. (Eds.), Guida alla geologia della Sicilia occidentale, Soc. Geol. It., Palermo, 103–109.

Carbone S., Grasso M., Lentini F., 1987: Geological outlines of Hyblaean Plateau [S. E. Sicily] Presentation of S. E. Sicily geological maps. (Lineamenti geologici del Plateau Ibleo [Sicilia S. E.]. Presentazione delle carte geologiche della Sicilia sud-orientale). Mem. Soc. Geol. It., **38**, 127–135.

Carveni P., Grasso M. F., Romano R., Tricomi S., 1991a: Volcanism along the Hyblaean Mountains northern margin. (Vulcanismo del margine settentrionale ibleo). Mem. Soc. Geol. It., **47**, 417–429.

Carveni P., Romano R., Capodicasa A., Tricomi S., 1991b: Geology of Capo Passero volcanic area [S. E. Sicily]. (Geologia dell'area vulcanica di Capo Passero [Sicilia sud-orientale]). Mem. Soc. Geol. It., **47**, 431–447.

Carveni P., Leonardi A., Romeo M., 1993: Connection between submarine volcanic rocks and Plio-Pleistocene sediments outcropping in Palagonia surrondings [Hyblaean Foreland, Sicily]. (Rapporti tra vulcaniti submarine e depositi plio-pleistocenici dei dintorni di Palagonia [Avampaese Ibleo, Sicilia]). Boll. Acc. Gioenia Sc. Nat., **26**, 342, 207–237.

Carveni P., Bella D., 1994: Geomorphological features connected to seismic activity on active Volcanoes: low south Etna flank as study model. (Aspetti geomorfologici legati all'attività sismica su vulcani attivi: il basso versante meridionale dell'Etna come modello di studio). Boll. Acc. Gioenia Sc. Nat. Catania, **27**, 346, 253–285.

Carveni P., Filetti G., Bella D., 1997: Geomorphological and seismic aspects connected to gravitational tectonic phenomena on the low eastern slope of Mt. Etna [Italy]. (Aspetti geomorfologici e sismologici connessi a fenomeni di tettonica gravitativa nel basso versante orientale dell'Etna). Geogr. Fis. Dinam. Quat., **20**, 41–49.

Carveni P., Sturiale G., 1999: Tectonic phases, volcanic phenomena and geomorphology in the Monte Casale di San Basilio zone, along the Hyblaean Mountains north margin [Eastern Sicily]. (Fasi tettoniche, fenomeni vulcanici e geomorfologia della Zona di Monte Casale di San Basilio, lungo il margine settentrionale dei Monti Iblei [Sicilia orientale]). Il Quaternario, **12**, 1, 85–98.

Carveni P., Benfatto S., Maniscalco R., Salleo Puntillo M., Sturiale G., 2005a: Tectonic control on the morphology of the northeastern lower slope of Mount Etna Volcano (Sicily). (Controllo tettonico sulla morfologia del basso versante nord-orientale dell'Etna [Sicilia]). Il Quaternario, **18**, 2, 57–68.

Carveni P., Bella D., Benfatto S., Maniscalco R., Salleo Puntillo M., Sturiale G., 2005b: Regional uplift and consequent gravitational phenomena: the example of eastern slope of Mt. Etna volcano. (Sollevamenti a grande scala e conseguenti fenomeni gravitativi: l'esempio del versante orientale dell'Etna [Sicilia]), Il Quaternario, **18**, 2, 157–171.

Carveni P., Benfatto S., Salleo Puntillo M., 2007: Eastern Sicily uplift and some seismic and volcanic implications. (Il sollevamento della Sicilia orientale e salcune implicazioni sismiche e vulcaniche). Il Quaternario, **20**, 1, 57–66.

Castorina G., 1920: Codavolpe earthquake [1920, September 26th]. (Sul terremoto di Codavolpe [26 settembre 1920]). Tipografia "Dante Alighieri", Riposto, 16 p.

Cristofolini R., 1966: Basic eruptive manifestations of Upper Trias in Ragusa underground. (Le manifestazioni eruttive basiche del Trias superiore nel sottosuolo di Ragusa). Per. Min., **35**, 1–38.

Cristofolini R., Lentini F., Patanè G., Rasà R., 1979: Geological, geophysical and petrographic data integration, for drawin up a crustal section along Mount Etna. (Integrazione di dati geologici, geofisici e petrologici per la stesura di un profilo crostale in corrispondenza dell'Etna). Boll. Soc. Geol. It., **98**, 239–247.

Cumin G., 1954: 1950, 8th April, Codavolpe earthquake, on eastern Etna slope. (Il terremoto di Codavolpe (versante orientale dell'Etna) dell'8 aprile 1950.) Boll. Sed. Acc. Gioenia Sc. Nat. Catania, IV, **2**, 473–483.

Di Grande A., 1967: Pleistocene sediments along the Hyblaean Plateau north margin. (I sedimenti pleistocenici del margine settentrionale dell'Altipiano Ibleo). Att. Acc. Gioenia Sc. Nat., Catania, Serie VI, **18** (Suppl. Sc. Geol.), 247–263.

Di Grande A., 1969: Neogene-Quaternary volcanic and sedimentary rocks alternation along the Hyblaean Plateau NW margin. (L'alternanza neogenico-quaternaria di vulcaniti e sedimenti al margine nord-occidentale dell'Altipiano Ibleo). Att. Acc. Gioenia Sc. Nat., Catania, **4**, 36 p.

Ferrucci F., Rasà R., Gaudiosi G., Azzaro R., Imposa S., 1992: Mt. Etna: a model for 1989 eruption. J. Volc. Geoth. Res., **56**, 35–56.

Ferrucci F., Patanè D., 1993: Seismicity accompanying the out break of the 1991–1993 eruption of Mt. Etna (Italy). J. Volcanol. Geotherm. Res., **56**, 1319–1329.

Frazzetta G., Romano R., 1978: First study for drawing up a volcanic risk map (Mt. Etna – Sicily). (Approccio di studio per la stesura di una carta del rischio vulcanico [Etna-Sicilia]). Mem. Soc. Geol. It., **19**, 691–697.

Gillot P. Y., Kieffer G., Romano R., 1994: The evolution of Mount Etna in the light of potassium-argon dating. Acta Vulcanol., **5**, 81–87.

Gironi F., 2003: What is in the underground. (Cosa c'è sotto). Quark, **23**, 50–57.

Glot J. P., Gresta S., Patanè G., Poupinet G., 1984: Earthquake activity during the 1983 Etna eruption. Bull. Volcan., **47**, 953–963.

Grassi M., 1865: Historical report and observations about 1865 Etna eruption and about "burning" earthquakes which happened after this eruption. (Relazione storica ed osservazioni sull'eruzione etnea del 1865 e su' tremoti flegrei che la seguirono). Stabilimento Tipografico di Crescenzio Galatola, Catania, 92 p.

Gresta S., Patanè G., 1987: Review of seismological studies at Mount Etna. Pure Appl. Geophys., **125**, 951–970.

Gresta S., Longo V., Viavattene A., 1990: Geodynamic behaviour of eastern and western sides of Mt. Etna. Tectonophysics, 179, 81–92.

Gresta S., Bella D., Musumeci C., Carveni P., 1997: Some efforts on active faulting processes (earthquakes and aseismic creep) acting on the eastern flank of Mt. Etna (Sicily). Acta Vulcanologica, **9**, (1-2), 101–108.

Kieffer G., 1985: Dèplacement progressif vers l'est des voies d'alimentation magmatiques de l'Etna (Sicile). Bull. Soc. Géol. Fr., **25**, 3, 369–378.

Lentini F., 1982: The geology of the Mt. Etna basement. Mem. Soc. Geol. It., **23**, 7–25.

Lentini F., Carbone S., Cugno C., Grasso M., Scamarda G., Sciuto F., 1986: Geological map of NE Hyblaean sector, SE Sicily. (Carta geologica del settore nord-orientale ibleo [Sicilia S. E.] Scala 1:50.000) S. El. Ca., Firenze.

Lentini F., Grasso M., Carbone S., 1987: Introduction to Sicily geology and trip guide book. Introduzione alla geologia della Sicilia e guida all'escursione. Conf. Soc. Geol. It.: "Sistemi avanfossa-avampaese lungo la Catena Appenninico-Maghrebide", Naxos-Pergusa, 1987, April 22nd-25th, 60 p.

Lo Giudice E., Patanè G., Rasà R., Romano R., 1982: The structural framework of Mt. Etna. Mem. Soc. Geol. It., **23**, 125–158.

Lo Giudice E., 1985: Peculiar points of view about seismic risk on Etna area. (Particolari aspetti del rischio sismico nell'area etnea). Atti del Convegno Internazionale dell'Associazione dei Geografi Italiani: "L'organizzazione territoriale delle aree sismiche e vulcaniche", 59–85.

Lo Giudice E., Birritta G., Bottari A., Carveni P., Stillitani E., 1990: Methodological considerations and operative proposal for a macroseismic fields classification. (Considerazioni metodologiche e proposta operativa sulla caratterizzazione e la classificazione dei campi macrosismici). Atti del Convegno del Gruppo Nazionale per la Difesa dai Terremoti 1990, **2**, 297–313.

Lo Giudice E., Rasà R., 1992: Very shallow earthquakes and brittle deformation in active volcanic areas: the Etnean region as an example. Tectonophysics, **202**, 257–268.

McGuire W. J., Stewart I. S., Saunders S. J., 1996: Intra-volcanic rifting at Mount Etna in the context of regional tectonics. Acta Vulcanologica, **9**, 147–156.

Marchesini E., Conedera C., Morabito G., Macii L., 1964: Etna photogeological study. (Studio fotogeologico dell'Etna). Rivista Mineraria Siciliana, **85-87**, 83–95.

Ogniben L., Parotto M., Praturlon A., 1975: Structural model of Italy. C. N. R., Quaderni de "La Ricerca Scientifica", **90**, 502 p.

Patacca E., Scandone P., Giunta C., Liguori V., 1979: Mesozoic paleotectonic evolution of the Ragusa zone (SE Sicily). Geol. Romana, **18**, 331–369.

Patanè G., 1975: 1973 August S. M. Ammalati and Guardia earthquakes. (I terremoti di S. M. Ammalati e di Guardia dell'agosto 1973). Rivista Mineraria Siciliana, **154-156**, 199–206.

Platania G., 1904: On the differencial motion of the eastern Etna beaches. (Su un moto differenziale della spiaggia orientale dell'Etna). Att. 5° Congr. Geogr. It., **2**, Sez. I, Scientifica, 214–219.

Platania G., 1908: 1907, December 7th earthquake. (Il terremoto del 7 dicembre 1907). Rendiconti e Memorie della Regia Accademia degli Zelanti di Acireale, **6**, 3, 13–20.

Platania G., 1920: 1920 September Codavolpe earthquake, Etna. (Terremoto di Codavolpe [Etna] del settembre 1920) Boll. R. Osserv. Geodin. Catania, 8 p.

Platania G., 1922: Origin of the etnean terraces. (Origine dei terrazzi dell'Etna). Pubbl. Ist. Geogr. Fis. R. Univ. Catania, 19, 11 p.

Platania G., Platania G., 1894: Notes about Etna earthquakes. (Note sui terremoti etnei). Rendiconti dell'Accademia di Scienze, Lettere e Arti degli Zelanti di Acireale, **6**, 5 p.

Postpischl D., (Ed.), 1985: 1000 to 1980 year Italian earthquakes catalog. (Catalogo dei terremoti italiani dall'anno 1000 al 1980). Progetto Finalizzato Geodinamica - CNR, Quaderni de la Ricerca Scientifica, 114-2A, Bologna.

Riccò A., 1911: 1911, September 15th Fondo Macchia earthquake. (Terremoto di Fondo Macchia del 15 ottobre 1911). Boll. Sed. Acc. Gioenia Sc. Nat. Catania, n.s., 19, 6–23.

Riccò A., 1912: Geodynamic phenomena after 1911 September Etna eruption. (Fenomeni geodinamici consecutivi all'eruzione etnea del settembre 1911). Boll. Soc. Sismol. It., **16**, 11–32.

Rittmann A., Romano R., Sturiale C., 1973: Some considerations on the 1971 Etna eruption and on the tectonophysics of the Mediterranean area. Geol. Rund., **62**, 2, 418–430.

Riuscetti M., Distefano R., 1971: Macchia earthquake, Catania district. (Il terremoto di Macchia [Catania]). Boll. Geof. Teor. Appl., **13**, 51, 150–164.

Romano R., 1970: Tectonic control on magmatic differentiation: an example. Bull. Volc., **34**, 4, 823–832.

Sabatini V., 1914: Notes about 1914, May 8th Linera earthquake. (Note sul terremoto di Linera dell'8 maggio 1914). Boll. R. Comit. Geol. It., **44**, 245–293.

Silvestri O., 1865: Report about Etna earthquakes. (Relazione sopra i terremoti dell'Etna). Stabilimento Tipografico "La Fenice", Catania, 12 p.

Silvestri O., 1866: About 1865 Etna eruption. (Sull'eruzione dell'Etna del 1865. Studi geologici e chimici, "Nuovo Cimento"). Geological and chemicals studies, 21-22, 20 p.

Silvestri O., 1867: Volcanic phenomena on Etna volcano during 1863-64-65-66 years connected with 1865 big eruption. (I fenomeni vulcanici presentati dall'Etna nel 1863-64-65-66 considerati in rapporto alla grande eruzione del 1865). Mem. Acc. Gioenia Sc. Nat., Catania, **3**, 1, 53–319.

Silvestri O., 1883: About 1883, March 22nd, Etna explosion, related to volcanic phenomena (geodynamic and eruptive) presented by Etna during 1880 January – 1883 December period. Observations and studies. (Sulla esplosione etnea del 22 marzo 1883 in relazione ai fenomeni vulcanici [geodinamici ed eruttivi] presentati dell'Etna durante il quadriennio compreso dal gennaio 1880 al dicembre 1883. Osservazioni e studi). Att. Acc. Gioenia Sc. Nat., **3**, 18, 237–421.

Underhill L. R., 1989: Late Cenozoic deformation of the Hellenide foreland, western Greece. Bull. Geol. Soc. Am., **101**, 613–634.