New paleoseismological and morphotectonic findings along the 2018 surface ruptures of the Fiandaca Fault, eastern flank of Etna volcano

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Supplementary material

1. **Historical earthquakes and surface faulting events along the Fiandaca Fault**
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1. Historical earthquakes and surface faulting events along the Fiandaca Fault

Table S1 summarizes the information about the earthquakes that are briefly described in section 3.2.

Table S1: Historical known earthquakes along the Mt. Etna E flank around the Fiandaca Fault with the corresponding fault activated, high uncertainties until the year 1831. Intensity and magnitude from CPTI (Rovida et al. 2020) and Azzaro and Castelli (2015). SR: surface ruptures evidence. SRL: surface rupture length. Slip: the slip amount is referred as heave (h), throw (t) and dextral strike-slip (ss). Faults: faults involved coded as follow: FIA: Fiandaca; FLE: Fleri; CAT: Aci Catena.

d m y	*Time (UTC)*	I_{EMS}	*Mw*	*Epicentral location*	*SR*	*SRL (km)*	*Faults*	*Slip (cm)*	*References*
28/06/1329	22:00	7-8	4.03	E and S flank	yes	-	-	-	Nicolaus Specialis, 1791
13/07/1766	-	4-5	-	Acireale but highly felt in Zafferana E.	?	-	-	-	Recupero, 1815
--/04/1809	-	HF	-	Acireale, NE and E flank	yes	-	-	-	Ferrara, 1810 and 1818
26/08/1819	03:30	4-5	-	Acireale	?	-	-	-	Maravigna, 1819
28/08/1829	-	F	-	Surroundings of Acireale	?	-	-	-	Alessi, 1829-1835
5 and 9/05/1831	-	HF	-	Acireale	?	-	-	-	Alessi, 1829-1835
07/01/1875	23:45	7	3.75	Zerbate		1.5	FIA	-	De Rossi, 1875
08/08/1894	05:16	8-9	4.6	Mazzasette-Fleri-Pennisi-Zerbate	yes	7-8	FLE, FIA, CAT	at least 8-15 (t)	Platania & Platania, 1894; Riccò, 1894; Platania, 1915
07/12/1907	21:28	7	4.0	Fiandaca	yes	2.5	FIA	at least 4 (h)	Platania, 1908
07/05/1914	17:36	6	3.2	Fiandaca	yes	2	FIA	-	Platania, 1915
07/05/1914	20:59	6	3.2	Fossa dell'Acqua	Yes	2	FIA	-	Platania, 1915
03/08/1931	21:12	6-7	3.5	Fiandaca	yes	-	FIA	-	Cavasino, 1935; Imbò, 1935
27/03/1941	05:20	6-7	3.5	Fleri	?	-	FLE	-	Ponte, 1941
17/06/1984	16:51	5-6	2.9	Santa Maria la Stella	yes	-	FIA	-	Patanè and Imposa, 1995
19/06/1984	15:19	7	3.96	Fiandaca	yes	1.6	FIA	2-3 (h) 20 (t) 1 (ss)	Benina et al., 1984; Patanè and Imposa, 1995
25/10/1984	01:11	8	4.4	Fleri	yes	1.7	FLE	-	Villari, 1984; Patanè and Imposa, 1995
11/11/1997	07:27	5-6	3.38	Santa Maria la Stella	yes	0.9	FIA	1.5 (h) 0.3 (t)	Azzaro, 1999; This study
19/04/2005		5-6	2.2	C.da Cubisia (Aci Catena)	yes	1	FIA	2-3 (h)	Azzaro et al., 2006
25/09/2014		5-6	3.3	Santa Maria la Stella	yes	1	FIA	1-2 (h)	Azzaro et al., 2020
26/12/2018		8	5.0	Fleri-Pennisi-Fiandaca	yes	8	FLE, FIA, CAT	120 (h) 45 (t) 30 (ss)	Azzaro et al., 2022; Civico et al., 2019; Tringali et al., 2023

The earthquakes that occurred before 1875, except for the 1329 event, were felt in Acireale and its surroundings, therefore the actual epicenter location is uncertain. In some cases, also date and time is uncertain. These earthquakes are described by Azzaro and Castelli (2015).

The seismic events in 1875 (De Rossi, 1875), 1907 (Platania, 1908), 7 May 1914 (Sabatini, 1913-14; Platania, 1915), 1931 (Cavasino, 1935, Imbò, 1935), 17 and 19 June 1984 (Benina et al., 1984; Villari, 1984; Patanè & Imposa, 1995), 1997 (Azzaro, 1999) and 2014 (Azzaro et al., 2020), all occurred along FIA, between Pennisi and Santa Maria La Stella. These earthquakes were characterized by surface ruptures represented by extensional cracks with a minor dextral component and throws up to 20 cm. Several historic earthquakes have as epicentral location Zerbate which is a locality between Santa Maria la Stella and Fiandaca. Zerbate was a populated small village that has not been rebuilt after the 1907 earthquake.

The earthquakes occurred in 1875 occurred between Fiandaca and the locality Fossa dell'acqua, where the village Zerbate was located (De Rossi, 1875). The 1875 earthquake was characterized by a surface rupture length of 1,5 km and offset of few centimetres along ruptures with evident relative subsidence of one of the two sides (De Rossi, 1875).

The 8 August 1894 earthquake with its epicentre in Mazzasette, between Fleri and Fiandaca, was associated with 4-5 km of surface rupture length with extensional and oblique dextral ground cracks (Azzaro, 1999; Baratta, 1894; Platania & Platania, 1894; Riccò, 1894). Nevertheless, the information provided by Platania (1908; 1915) and a 1894 newspaper (La Tribuna, 1894) allows to extend the rupture at least to 7-8 km. The surface faulting length and the macroseismic data confirms that the 1894 and 2018 earthquakes are very similar each other.

On May 7, 1914, a sequence of two earthquakes shook the area of Fiandaca, Piano D'Api and Fossa dell'acqua. The earthquakes were associated by Platania (1915) to the central and southern termination of FIA because of the well evident surface ruptures for at least 2 km in Fiandaca and Fossa dell'acqua. These earthquakes were part of a seismic swarm which was involving the TFS, preceding the main shock which occurred along the Linera Fault (LIN in Fig. 1a) the day after (Platania, 1915). The 8 May 1914 Linera earthquake caused relevant damages with a maximum EMS intensity of 9-10 (Azzaro, 1999; Rovida et al., 2021), and extensive surface faulting (Platania, 1915; Azzaro, 1999 and references therein). The Linera earthquake may have attracted so much attention that smaller events were overlooked.

The earthquakes occurred on 17 and 19 June 1984, were associated with surface ruptures for a total length of 1,6 km and throw up to 20 cm in the southern sector of FIA.

On November 11, 1997, two earthquakes occurred during the day along southern termination of FIA where very well evident creep phenomena are present. The earthquakes produced the reactivation of pre-existing creep ruptures that accumulated a maximum heave of 1.5 cm and 0.3 cm of throw (Fig. S1). The accurate measures were recorded by two fissurometers installed in 1995 and positioned along the southern sector of FIA on damaged walls delimiting a road (Fig. S1e and f). In the following days some creep phenomena remobilised the ground ruptures with new

opening observed in November 11 (Fig. S1a). After the creep the fessurimeter accumulated 2.2 cm of heave, 0.6 cm of throw and 1 cm of right lateral displacement, until they broke down on November 15.

The 2014 earthquake occurred along the same sector of 1997. The 1997 and 2014 earthquakes were characterized by ~1 km of surface faulting (Azzaro, 1999; Azzaro et al., 2020) with offset of few centimetres (Azzaro, 2020).

Finally, the earthquake occurred in 2005 interested the southernmost sector of FIA producing centimetric offset along pre-existing creep surface ruptures (Azzaro et al., 2006).

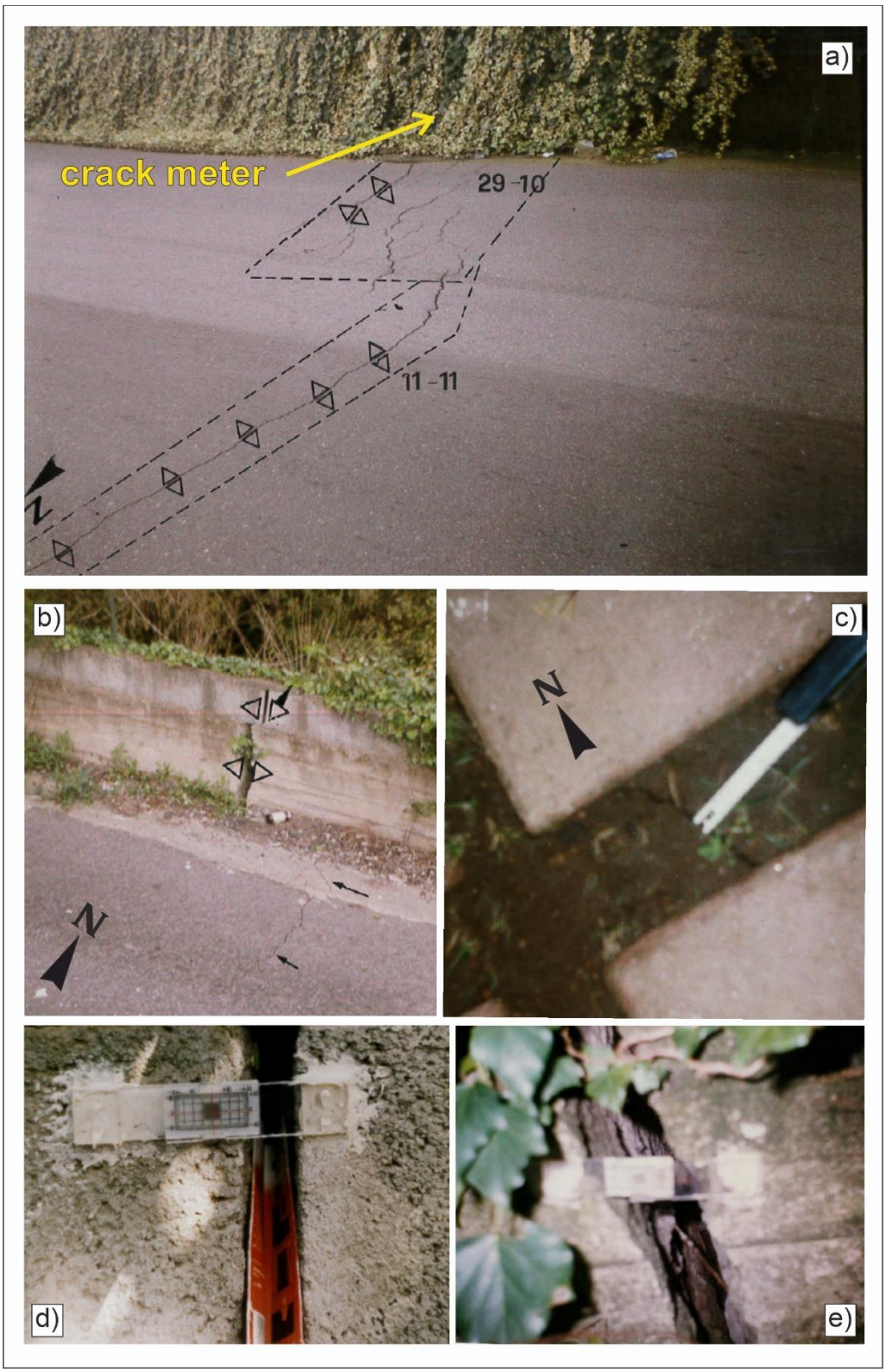

Figure S1: Field photos taken after the earthquake occurred in 1997: a) coseismic surface ruptures of October 29 and aseismic creep ruptures observed on November 11; b) coseismic ruptures along a road taken just few metres to the N of the (a) photo; c) coseismic rupture on soil in private courtyard taken just few metres to the N of the (b) photo; d) fissurometers installed few metres to the N of (b) photo; e) fissorometer indicated in (a) photo.

2. Methods: sediment elemental composition

Sediment samples, named WFIA and EFIA, were collected from the East and West walls of the FIA1 trench in U2 using polyethylene bags, keeping them away from the light and temperature changes. Elemental chemistry composition was determined via highly sensitive analytical Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) technique. Samples were previously dried at 40°C for 12 h and homogenized and pulverized in an agate mill. Subsequently, 250 mg of sample underwent microwave-assisted digestion (ETHOS One, Milestone MLS, USA) using aqua regia (EPA, Method 3051) and HF to dissolve the silica recalcitrant fraction (Pinna et al., 2022). Ultrapure nitric and hydrochloric acid solutions were obtained by sub-boiling distillation of Carlo Erba (Italy) reagents 65% volume solution, using Milestone (USA) duoPUR. The digested solutions were then diluted with ultrapure water (18.2 MΩcm resistivity) and analysed using Rh as internal standard. The results are reported in Table S3 as mg of the extracted element by a unit of volume (kg) of dry sediment.

Table S3: Sediment chemical composition from samples collected in U2.

	mg/kg																							
	Li	**Be**	**Na**	**Mg**	**Al**	**K**	**Ca**	**Ti**	**Cr**	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Rb**	**Sr**	**Zr**	**Ag**	**Cd**	**Sn**	**Ba**	**Pb**
WFIA	0,506	0,053	182,041	467,145	2240,924	81,698	560,991	181,538	0,559	35,589	2138,525	0,739	7,114	3,769	0,177	0,097	0,707	20,244	3,780	0,002	0,006	0,020	11,948	0,612
EFIA	0,497	0,053	185,503	442,501	2245,885	79,494	574,049	164,653	0,539	31,078	2118,228	0,543	8,604	3,041	0,151	0,097	0,654	20,747	4,238	0,002	0,004	0,021	12,314	0,513

The highlighted chemical composition shows similar values allowing to confirm that the collected samples are from the same horizon identified in the U2.

3. Geological cross sections along the Fiandaca Fault

The location of the 12 geological cross sections is showed in Fig. S2. The geological cross sections are showed in Figs. S3-S5.

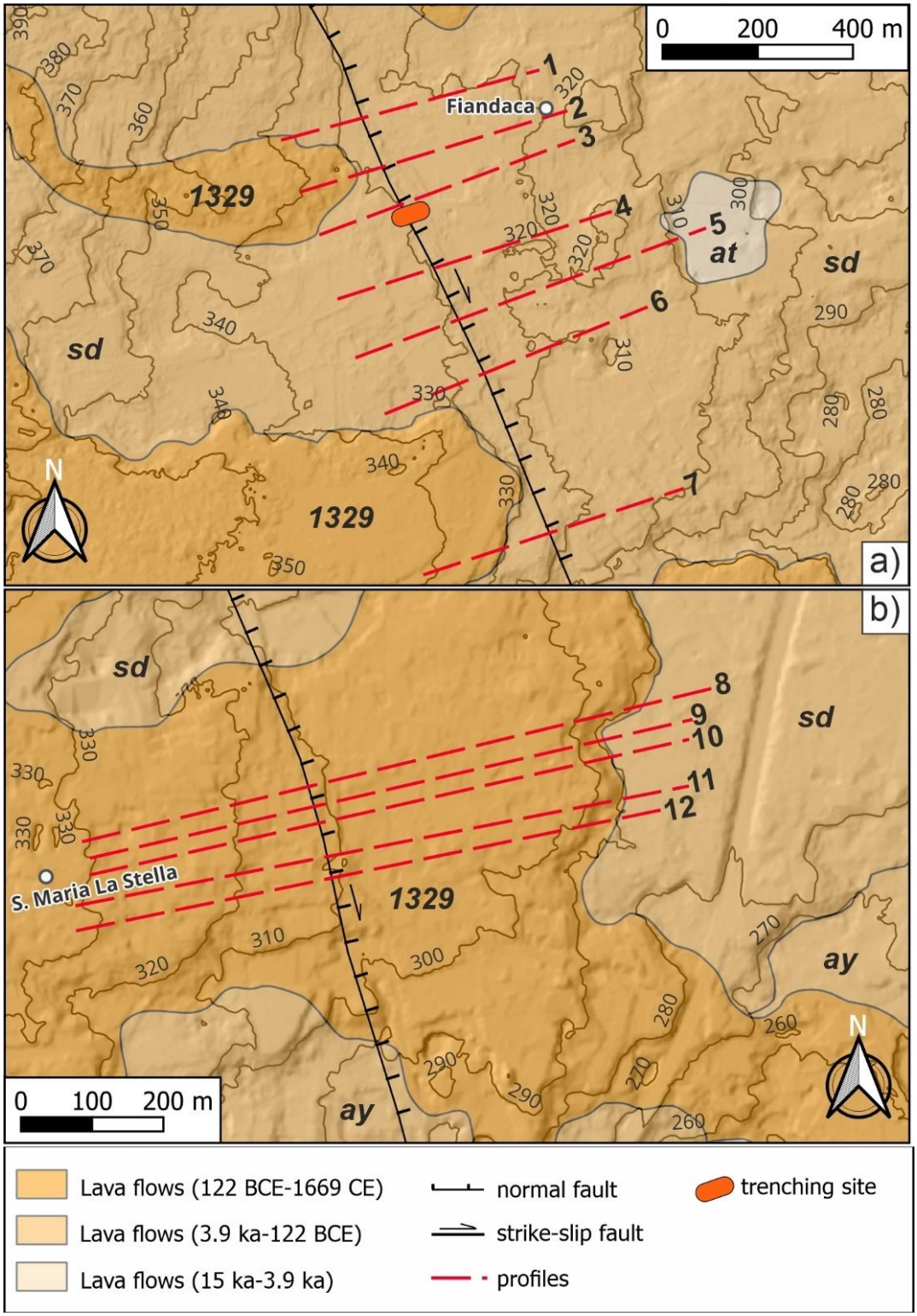

Figure S2: Geological maps with capable faults (modified after Branca et al., 2011; Azzaro et al., 2012; Barreca et al., 2013; ITHACA Working group, 2019) showing profiles along the Fiandaca Fault. Lava flows chronologically labelled: *sd:* Mt. Salto del Cane (150±200 BCE; *ay:* Piano d'Api; *at*: Aci Platani.

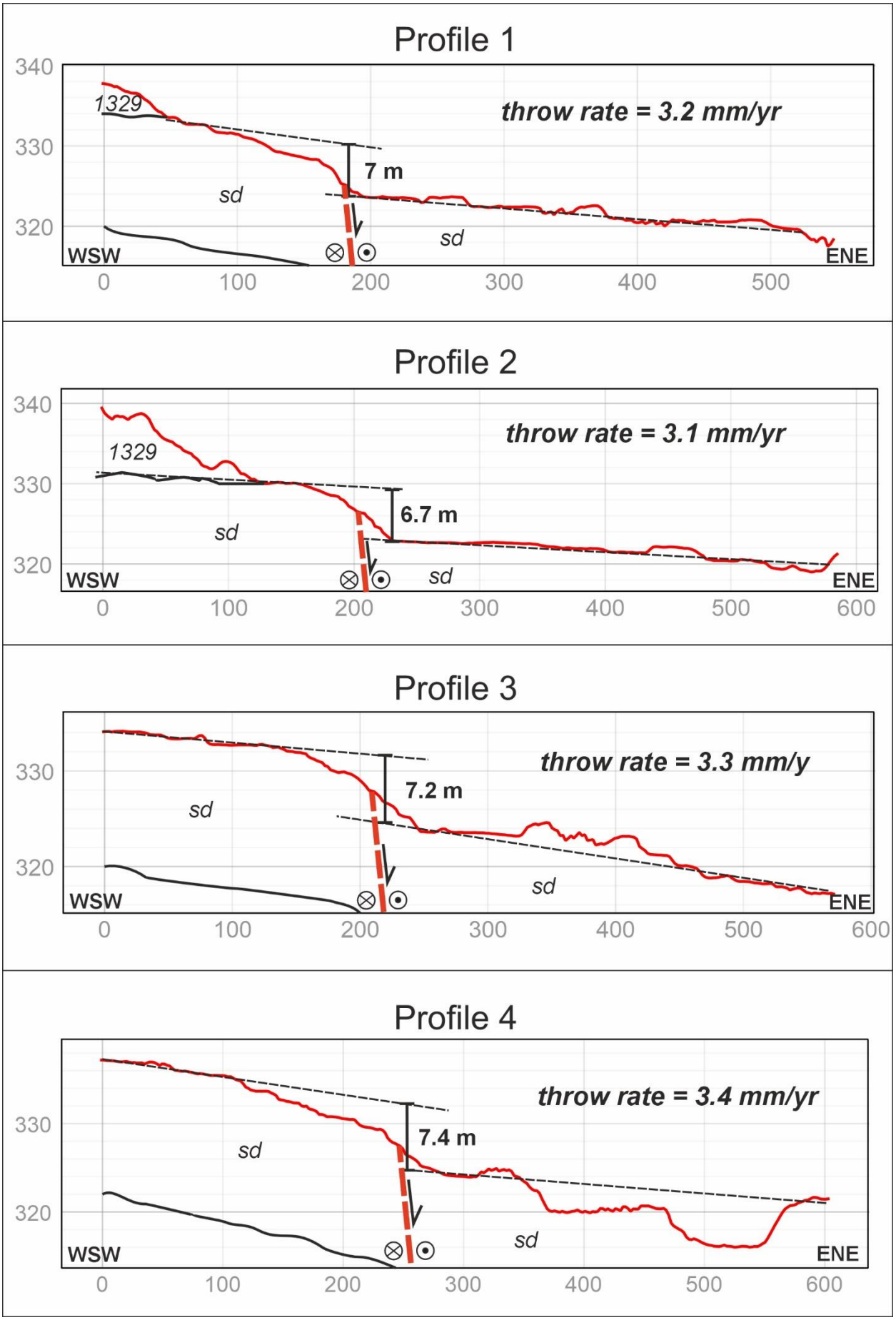

Figure S3: Geological profiles 1-4 along the Fiandaca Fault (FIA). *sd*: Mt. Salto del Cane lava flow (150±200 BCE).

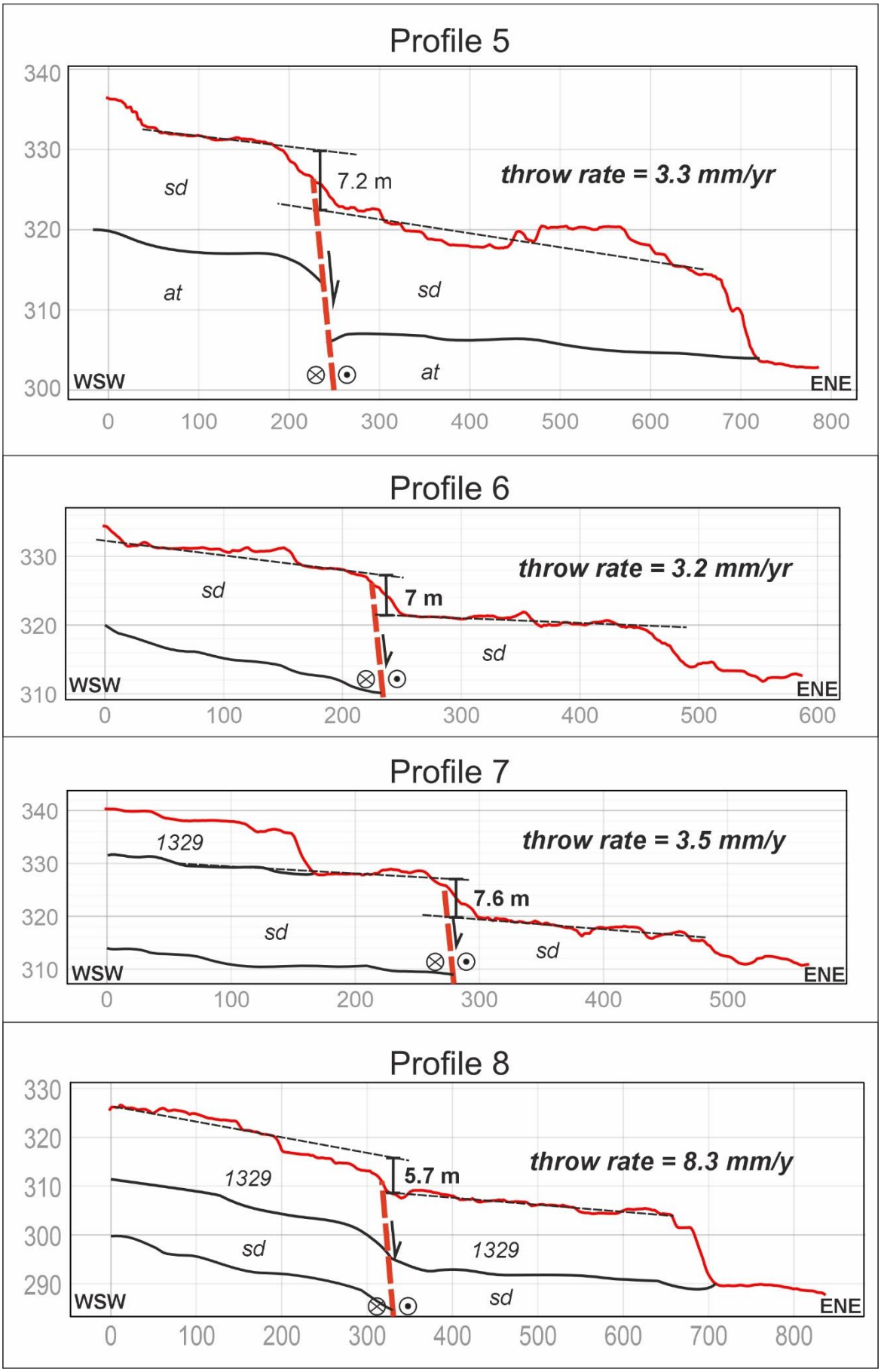

Figure S4: Geological profiles 5-8 along the Fiandaca Fault (FIA). *1329*: 1329 lava flow; *sd*: Mt. Salto del Cane lava flow (150±200 BCE); *at*: Aci Platani lava flow.

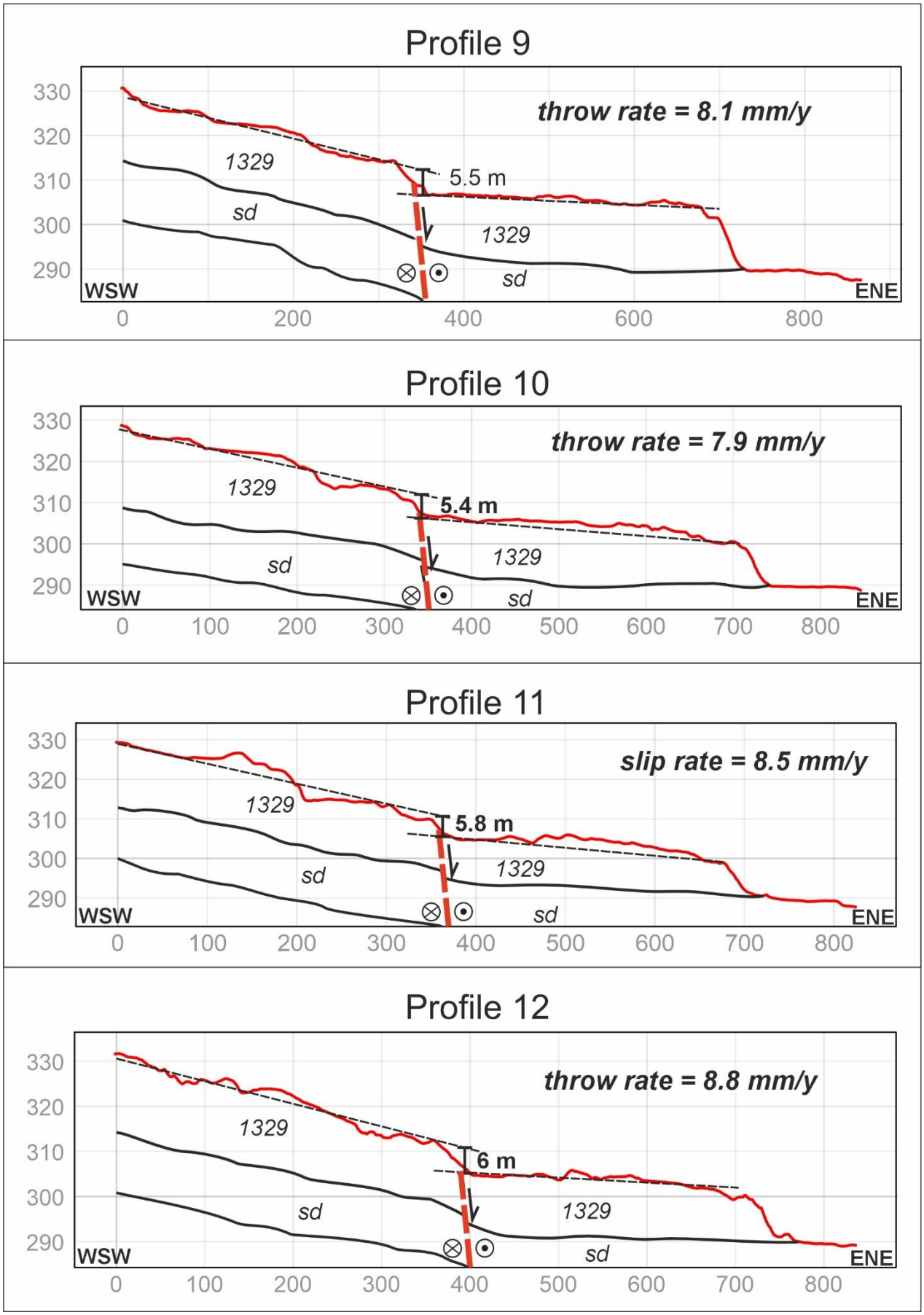

Figure S5: Geological profiles 9-12 along the Fiandaca Fault (FIA). *1329*: 1329 lava flow; *sd*: Mt. Salto del Cane lava flow (150±200 BCE).

References

Alessi, G., (1829-1835). Storia critica delle eruzioni dell'Etna. *Atti Accademia Gioenia di Scienze Naturali di Catania, ser. 1, vol. 3, pp. 17-75; vol. 4, pp. 23-75; vol. 5, pp. 43-72; vol. 6, pp. 85-116; vol. 7, pp. 21-66; vol. 8, pp. 99-149; vol. 9, pp. 121-206, Catania*.

Azzaro, R., (1999). Earthquake surface faulting at Mount Etna volcano (Sicily) and implications for active tectonics. *Journal of Geodynamics 28, 193–213*. https://doi.org/10.1016/S0264-3707(98)00037-4

Azzaro, R., and Castelli, V. (2015). Materiali per un catalogo di terremoti etnei dal 1600 al 1831. Quaderni di Geofisica, 123, 284 pp., https://doi.org/10.13127/qdg/123

Azzaro, R., D'Amico, S., Mostaccio, A., Scarfì, L., Tuvè, T., (2006). Terremoti con effetti macrosismici in Sicilia orientale nel periodo Gennaio 2002 – Dicembre 2005. *Quaderni di geofisica, 41, 41-42.*

Azzaro, R., D'Amico, S., Tuvè, T., Mostaccio, A., & Scarfì, L., (2020). Terremoti con effetti macrosismici in Sicilia nel periodo gennaio 2014 dicembre 2018. *Quad. Geofis., 160: 1-62*. https://doi.org/10.13127/qdg/160

Azzaro, R., Pucci, S., Villani, F., Civico, R., Branca, S., Cantarero, M., et al. (2022). Surface faulting of the 26 December 2018, Mw5 earthquake at Mt. Etna volcano (Italy): Geological source model and implications for the seismic potential of the Fiandaca fault. *Tectonics, 41, e2021TC007182*. https://doi.org/10.1029/2021TC007182

Barreca, G., Bonforte, A., & Neri, M. (2013). A pilot GIS database of active faults of Mt. Etna (Sicily): A tool for integrated hazard evaluation. Journal of Volcanology and Geothermal Research, 251, 170-186. https://doi.org/10.1016/j.jvolgeores.2012.08.013

Benina, A., Imposa, S., Gresta, S. & Patanè, G., (1984). Studio macrosismico e strumentale di due terremoti tettonici avvenuti sul versante meridionale dell'Etna. *Proc. 3th Conv. GNGTS, CNR, Rome (1984), 3, 934-940.*

Branca, S., Coltelli, M., Groppelli, G., & Lentini, F. (2011). Geological map of Etna volcano, 1: 50,000 scale. *Italian Journal of Geosciences, 130(3), 265-291*. https://doi.org/10.3301/IJG.2011.15

Cavasino, A., (1935). I terremoti d'Italia nel trentacinquennio 1899-1933. *Mem. R, Uff. C. Meteor. E Geof. 6 (III), 266*.

Civico, R., Pucci, S., Nappi, R., Azzaro, R., Villani, F., Pantosti, D. et al. (2019). Surface ruptures following the 26 December 2018, Mw 4.9, Mt. Etna earthquake, Sicily (Italy). EMERGEO Working Group (Etna 2018). *Journal of Maps, 15(2), 831-837*. https://doi.org/10.1080/17445647.2019.1683476

De Rossi M.S., (1875). Terremoti presso l'Etna e conati eruttivi del medesimo vulcano, dal 7 al 20 Gennaio. *Bull. Vulc. It., 19-21*.

Ferrara, F., (1810). I Campi Flegrei della Sicilia e delle isole che le sono intorno o descrizione fisica e mineralogica di queste isole. *Messina, 424 pp.*

Ferrara, F., (1818). Descrizione dell'Etna, con la storia delle eruzioni e il catalogo dei prodotti. *Palermo, L. Dato, 256 pp*.

Imbò, G., (1935). I terremoti Etnei. *Pubblicazione della Commissione Italiana per lo Studio delle Grandi Calamità, Regia Accademia Nazionale dei Lincei, Roma, 5, parte 1*.

ITHACA Working Group: ITHACA (ITaly HAzard from CApable faulting), A database of active capable faults of the Italian territory, Version December 2019; ISPRA Geological Survey of Italy. Web Portal http://sgi2.isprambiente.it/ithacaweb/Mappatura.aspx, 2019.

Maravigna, C., (1819). Istoria dell'incendio dell'Etna del mese di maggio 1819. *Catania, 102 pp*.

Nicolaus Specialis (1791). Historia Sicula ab anno 1282 ad annum 1337, jam antea edita, nunc vero supplementis aucta et castigatissima prodit e Siculis manuscriptis codicibus. *In "Bibliotheca scriptorum qui res in Sicilia gestas sub Aragonum imperio retulere", ed. R.Gregorio, tomo 1, pp.283-508, Palermo*.

Patanè, G. & Imposa, S., (1995). Atlante delle isosiste dei terremoti etnei dal 1971 al 1991. *CNR-GNGTS, Ist. Geologia e Geofisica Università di Catania 81*.

Pinna, M., Signorelli, A., Binda, G., Dossi, C., Rampazzi, L., Spanu, D., & Recchia, S. (2022). How to Clean and Safely Remove HF from Acid Digestion Solutions for Ultra-Trace Analysis: A Microwave-Assisted Vessel-Inside-Vessel Protocol. *Methods and Protocols*, 5(2), 30. https://doi.org/10.3390/mps5020030

Platania, G. (1908). Il terremoto del 7 Dicembre 1907. *Mem. Cl. Sci. R. Acc. Zelanti 5 (3), 13-20*.

Platania, G., (1915). Sul periodo sismico del Maggio 1914 nella regione orientale dell'Etna. *Mem. Cl. Sci. R. Acc. Zelanti 7 (3°), pp. 48.*

Platania, G., & Platania, G., (1894). Note sui terremoti etnei dell'agosto 1894. *Estr.dai Rend. dell'Acc. di Sc., Let. e Arti Zelanti di Acireale, nuova serie Vol.VI 1894*.

Ponte, G. (1941): Bollettino vulcanologico e meteorologico dell'Etna Boll. Acc. Gioenia. Sci. Nat., s. III, 18, aprile-giugno, 35-37.

Recupero G., (1815). Storia naturale e generale dell'Etna. *Regia Università degli Studi, Catania, 2 vol., 244 + 235 pp*. [ristampa anastatica Dafni Ed., Catania, 1983].

Riccò, A. (1894). Breve relazione sui terremoti del 7 ed 8 agosto 1894 avvenuti nelle contrade etnee. *Boll. Mens. Oss. Centr.*

Rovida A., Locati M., Camassi R., Lolli B., Gasperini P.: The Italian earthquake catalogue CPTI15. Bulletin of Earthquake Engineering, 18(7), 2953-2984. https://doi.org/10.1007/s10518-020-00818-y, (2020).

Tringali, G., Bella, D., Livio, F.A., Ferrario, M.F., Groppelli, G., Blumetti, A.M., Di Manna, P., Vittori, E., Guerrieri, L., Porfido, S., Boso, D., Pettinato, R., Paradiso, G., & Michetti, A.M. (2023a). Fault rupture and aseismic creep accompanying the December 26, 2018, Mw 4.9 Fleri earthquake (Mt. Etna, Italy): Factors affecting the surface faulting in a volcano-tectonic environment. *Quaternary International, 651, 25-41*. https://doi.org/10.1016/j.quaint.2021.12.019

USEPA, "EPA Method 3051: Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils," 3rd Edition, Test Methods for Evaluating Solid Waste, Washington, DC., 1995a.

Villari, L. (1984). Piano di recupero della frazione di Fleri, Relazione Geologica, RIF. 24287/LV.