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# Impacts of the 1669 eruption and the 1693 earthquakes on the Etna Region (Eastern Sicily, Italy): An example of recovery and response of a small area to extreme events

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ABSTRACT

In this paper we trace the impact of the 1669 eruption and the 1693 earthquakes in eastern Sicily, their effects on the people living in the Etna region and, more particularly, in the city of Catania and its hinterland. The former event was the largest historic eruption of Etna, having a flow field with an area of ca. 40 km$^2$ and a maximum flow length of ca. 17 km, whereas the latter – occurring only 24 years later – killed between 11,000 and 20,000 of Catania's estimated 20–27,000 inhabitants, plus many more in smaller settlements. Using a combination of field-based research, contemporary accounts and archival sources, the authors are able to draw a number of conclusions. First, the 1669 eruption, although it did not kill or injure, was economically the most devastating of historical eruptions. Although it affected a limited area, inundation by lava meant that land was effectively sterilized for centuries and, in a pre-industrial agriculturally-based economy, recovery could not occur quickly without outside assistance from the State. Indeed some of the worst affected municipalities (i.e. Comuni) were only able to support populations that were much reduced in size. Secondly, much of the damage caused to buildings by volcanic earthquakes was effectively masked, because most of the settlements affected were quickly covered by lava flows. The vulnerability to volcanic earthquakes of traditionally constructed buildings has, however, remained a serious example of un-ameliorated risk exposure through to the present day. A third conclusion is that the 1693 earthquakes, although more serious with respect to the number of people and the area they affected in terms of mortality, morbidity and their immediate economic impact, saw a rapid and sustained recovery. This was due in part to the fact that, in contrast to lava flows, an earthquake does not sterilize land, but more significant was the reduction in population numbers which served both to release and concentrate funds for investment in recovery. By the close of the eighteenth century Catania was known throughout Europe for the quality of its townscape and buildings, many of which were constructed in the then fashionable (and expensive) baroque style. Finally, the 1669 and 1693 disasters were seized on by the authorities as opportunities to plan new and re-build old settlements with improved infrastructure to facilitate economic growth. By the nineteenth century many of the lessons had been largely forgotten and there were many examples of: poor seismic design of individual buildings; and the location of new residential and commercial areas that placed more people at greater risk from future extreme events. Indeed it is only recently have new regulations been enacted to prevent the construction of buildings in the vicinity of active faults and to control development in other hazardous zones.



## 1. Introduction

There is a growing awareness that the ways in which traditional societies have used indigenous knowledge to respond to geophysical extremes, is not only important in terms of the historical record – revealing both the impacts of events of differing magnitude and their effects on the society at the time, but may also inform present-day approaches to hazard management (Kelman et al., 2012). In studying eruptions of Etna between 1789 and 1923 two of us made use of this approach (Chester et al., 2012) using a framework first devised by White (1974, pp. 5), in which he proposed a tripartite classification: *pre-industrial (or folk)*; *industrial* and *post-industrial*, to analyse the ways human responses to disasters are related to varying levels of economic development (Table 1). Whereas some *economically less developed* countries – and especially isolated regions within them – are still characteristically *pre-industrial* in their responses to a range of disasters (e.g. Gaillard, 2007), in Sicily a State-based (i.e. *industrial* – Table 1)

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**Table 1**
Responses of societies to disasters at three characteristic levels of development Modified after Chester et al., 2012 (Table 1, pp. 66) and based on information in White (1974) and additions from Chester (1998); Chester et al., 2010).

| Level of Development | | |
|---|---|---|
| Pre-Industrial (Folk) Responses | Industrial Responses | Post-industrial (Comprehensive) Responses |
| A wide range of adjustments<br>Action by individuals or small groups.<br>Emphasis on harmonization with, rather than technological control over, nature.<br>Low capital requirements. | A restricted range of adjustment.<br>Action requires co-ordination by the authorities.<br>Emphasis is placed on technological control over nature, rather than harmonization with nature.<br>High capital requirements. | A *post-industrial response* ideally includes the best elements of the *pre-industrial* and *industrial* and represents a future planning goal. There is innovation, not only of technical responses and planning policies, but are also sensitive to indigenous methods of coping which are characteristic of a particular society and its history. |
| Responses vary over short distances.<br>Responses are flexible and are easily abandoned if unsuccessful. | Responses mostly uniform.<br>Responses are inflexible and difficult to change. | Such an approach is in agreement with current international policies, such as those proposed by the United Nations' *International Strategy for Disaster* |
| Losses are perceived as inevitable. The 'mindset' of many inhabitants is strongly influenced by notions of supernatural punishment, vengeance and the need to appease divine wrath. | Losses may be reduced by government action, technology, economic development and science. | *Reduction (IDNDR)* and which are spelt out in the *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disaster* and the recently articulated *Sendai Framework for Disaster Reduction 2015–2030.* |
| Responses continue over time scales ranging from hundreds to thousands of years. There is learning from experience. | *Industrial responses* were not commonly observed until the mid-nineteenth century and not widespread until the mid-twentieth. It is only from the mid-nineteenth century and starting in *economically more developed countries*, that there have been alternatives to bearing losses on an individual, family and local community basis. | *Comprehensive responses* have not been fully innovated anywhere in the world, though Iceland, the USA and Japan come closest to them (Chester, 1993, pp. 237). |

approach to disaster management may by dated to 1908 in the case of the Messina earthquakes (Dickie, 2000; Naldi et al., 2008); and to the 1928 eruption of Etna, when the regime under Benito Mussolini took charge of responses which included rebuilding the village of Mascali in a grandiose Fascist style (Duncan et al., 1996; Chester et al., 1999, 2008). Elements of the *pre-industrial*, such as a wrathful God being invoked to explain losses, still featured in 1928 and many later eruptions (Chester et al., 2008, 2012), whereas limited State involvement in reaction to earlier earthquakes and eruptions may be discerned from the classical period onwards (Rodwell, 1878; Chester et al., 2010).

In the second half of the seventeenth century, when the region was impacted by the 1669 eruption and the 1693 earthquakes, Sicily was under Spanish colonial administration. From the collapse of Roman rule in CE[1] 827 to 1861 when it became part of unified Italy, Sicily had been ruled by a succession of foreign powers: Arabs, both Berbers and Spanish Muslims (827–1091); Normans (1091–1194); Swabians (1194–1268); Angevins (1268–1282); Spanish (1282–1713); Austrians (1720–1734) and Bourbons (1734–1861). There was even a short interval of British rule between 1806 and 1815 (Finley et al., 1986; Chester et al., 2010, pp. 238–9). The early years of Spanish administration in the fourteenth century coincided with pan-European economic difficulties that were related in part to the Black Death (1347–50), and this was followed by a breakdown in central authority in Sicily, warfare, the end of the island's quasi-independence and its incorporation in 1412 into the Kingdom of Aragon. Hereafter the Spanish ruled through Viceroys based in Palermo, of whom there were seventy-eight between 1412 and 1734, the Viceroys at the time of the 1669 eruption and 1693 earthquakes being, respectively: Francisco Fernández de la Cueva – Duque de Albuquerque, who served from 1667–70 (Scarth, 1999) and Juan Francisco Pacheco y Téllez-Girón – Duque de Uzeda, who was in office between 1689 and 1696 (Rodriguez de la Torre, 1995). Concessions were made to the Sicilian aristocracy who were allowed to run their estates with little government interference in exchange for passivity and the relinquishment of political power. Viceroys had to deliver a fixed cash sum to Madrid each year, a burden that fell ultimately on the impoverished peasantry who were taxed *inter alia* on their production of wheat and other commodities. The negative impact of absentee landlords was an important issue and the barons delegated management of their estates to *Gabelloti.*[2] There was a disconnection between the colonial authorities and the administration of rural communities. As one commentator has noted, by the eighteenth century the administration of the island was notable for its 'inefficiency, corruption and incompetence (with Sicily having) one of the worst governments in the world' (Anon, 2004, pp. 17), but this statement only applies to the latter stages of Spanish rule which ended in 1713, with Sicily falling under Austrian and Bourbon rule for the rest of that century. The more moderate judgement of King (1973, pp. 47), that 'Spanish rule on the whole did not benefit Sicily, which sank into obscurity and decay' is nearer the mark, and during the centuries up to 1713 the long-established contrast between the highly productive coastal margins of the island – including the Etna region – and the degraded interior lands became much clearer[3] (Chester et al., 2010, pp. 237–240 and Fig, 15.2 pp. 237). To meet the demands of funding Spanish involvement in the Thirty Years War (1618–1648), the burden of taxation in Sicily was increased to the point when the Viceroy reported that no more tax revenues could be raised. In 1647 famine led to a revolt in Palermo against Spanish rule and this was followed in 1674 by a rebellion in Messina against the increasing centralisation of colonial rule (Finley et al., 1986). Notwithstanding the increasing civil unrest in Sicily during the last century of Spanish administration, 'no man-made events had quite the impact of the eruption of Mount Etna in 1669 and the terrible earthquake of 1693' (Finley et al., 1986, pp. 111).

Although reactions to the 1669 eruption and the 1693 earthquakes were predominantly *pre-industrial*, strong State involvement under the Spanish colonial authorities and their Viceroy was very much in evidence (see Sections 4, 5 and 6) and was far more efficient and effective than has been assumed in earlier studies (Condorelli, 2006, 2012; Scalisi, 2013). Re-building and reconstruction occurred using predominantly local resources, though within a framework of law and administration controlled by the State. This differs from the situation today. It

[1] For reasons of inclusiveness, the abbreviation CE (i.e. Common Era), rather than AD (i.e. *Anno Domini* – of the Christian era) is used in this paper.

[2] Particularly in Central Sicily the *gabelloto* (or agent) was a key figure who leased land from large landowners and rented out small areas to peasant farmers. 'Economically (*gabelloti*) … were parasitic, but wielded enormous power…. In the face of increasing population pressure and land hunger (they were able) to continually bid up rents' (King, 1973, pp. 127).

[3] Italian geographers often refer to Sicily as an 'ugly picture in a frame of gold: the dry poverty-stricken core of the island contrasting vividly with the intensively-cultivated, irrigated coastal periphery' (Milone, 1960; King, 1973, pp. 112).

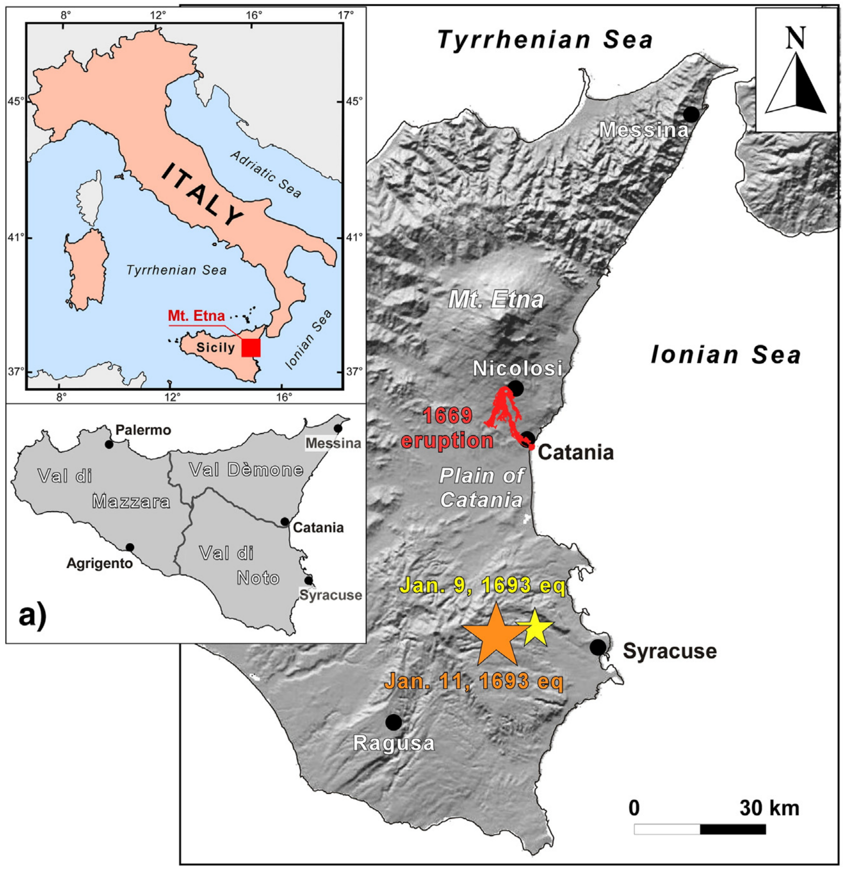


**Fig. 1.** Location of the 1669 Etna eruption and the 1693 Val di Noto earthquakes in Eastern Sicily. Inset map (a) illustrates the three historic subdivisions of Sicily, which were recognised from the 11th century and after the time of the Moors.

involved no major inflow of funds or non-material resources from central government and was still essentially a localised response, although a wider area was affected than was the case with lower magnitude events which occurred frequently during the *pre-industrial* era. For instance, from 1792 to 1923 and despite damaging earthquakes in 1818 and 1848 (Azzaro et al., 1999) and major eruptions in 1792/93, 1809, 1832, 1843, 1852/53, 1865, 1879, 1886, 1892, 1910, 1911 and 1923 (Chester et al., 2012), the resilience of the region was never overwhelmed by its vulnerability. Even the 1908 Messina earthquake did not have a major impact on the Etna region. Using largely indigenous methods of coping, the region recovered and indeed prospered. One measure of this is that, despite having to cope with frequent disasters, the population of the region not only increased in absolute terms, but also as a proportion of that of Sicily as a whole.[4] In last third of the seventeenth century the situation was quite different because within a period of twenty four years, the Etna region had to deal with the effects of two tremendous natural catastrophes, the largest historic eruption in 1669 (Branca et al., 2013) and in 1693 one of Italy's most devastating earthquakes which impacted Eastern Sicily severely. In Catania, Etna's principal city (Fig. 1), between 11,000 (more probable) and 20,000 of its estimated 20–27,000 inhabitants were killed by the earthquake; together with many more in smaller settlements (Azzaro et al., 1999; Condorelli, 2006).

In this paper we trace the impact of these two extreme events on the people of the Etna region, their responses and recovery in the decades that followed. In Sections 3, 4 and 5 the characteristics and consequences of, and the initial recovery from, these two late seventeenth century disasters are reviewed. This is followed in Section 6 by an assessment of the ways in which the region recovered over the longer term and, indeed, surpassed its pre-disaster wealth and status.

Although there have been many published accounts of the characteristics and physical impact of the 1669 eruption and the 1693 earthquakes some of them being penned by the present authors (e.g. Chester et al., 1985; Azzaro et al., 1999), this is the first time the detailed impact of these two events on society and its recovery has been charted. This has involved integration and use of data not only collected in the field on, for example, the extent of volcanic products, but also across a far wider range of contemporary and near contemporary multilingual source materials than has been conventional in the earth sciences. Particularly important for the study of the effects of and recovery from the 1669 eruptions are accounts by: 'some inquisitive English merchants' (Anon, 1669); Winchilsea (1669) and Borelli (1670), while for the 1693 earthquake, Bonajutus (1694) have proved to be vital sources. These accounts provide both information on the behaviour of the local population and insights into the natural phenomena, but sources all require careful analysis and interpretation because they were written before the era of modern scientific understanding. Residents and visitors' accounts of the area in the eighteenth and nineteenth centuries provide invaluable information on recovery, with studies by Brydone (1773), Recupero (1815) and Rodwell (1878) being particularly noteworthy.

[4] Most of the Etna region is contained administratively within the Province of Catania. The population of Sicily in 1806 was estimated at 1.6 million with 14% living in Catania Province. By 1861 this had risen, respectively, to 2.4 million and 15%. The proportion living in Catania rose to 17% in 1901 and 19% in the 1921 census. The ability of this productive region to support a large population is particularly notable because until the 1940s the Plain of Catania supported a very small population as a result of it being malarial, whereas today it is a most productive agricultural area. In addition, in the late nineteenth and early twentieth centuries, out migration to the USA was an established feature of Sicilian demography which peaked at 148,000 in 1913, yet the population of the Etna region continued to increase (Pecora, 1968; Chester et al., 1985, 2012; Ligresti, 2002).

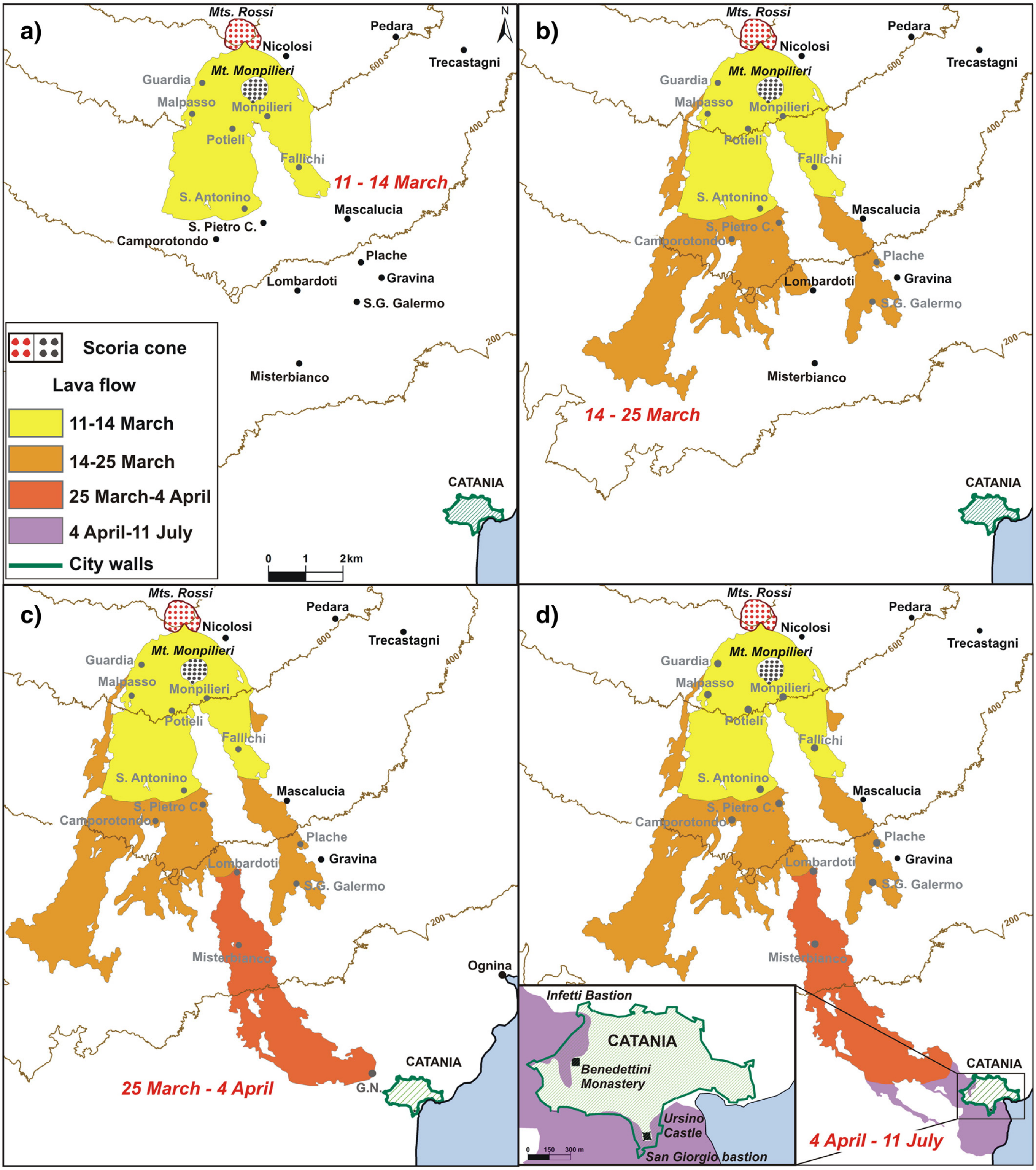


**Fig. 2.** Maps showing the evolution of the 1669 lava flow field (a) 11–14 March, (b) 14–25 March, (c) 25 March-4 April, (d) 4 April-11 July (modified from Branca et al., 2013) and the locations of the principal towns and villages at the time of the eruption. The towns, villages and other settlements that were totally destroyed by the lava flow are shown in grey. G.N. = Gurna di Nicito.

## 2. Eruptions and earthquakes at Etna: a short historical overview

The eruptive activity of Etna is characterised by almost persistent summit activity and less frequent flank eruptions which is caused by the opening of long fissures. During the past five centuries, the most frequently occurring eruptive style of flank eruptions has been almost purely effusive, being associated with weak strombolian activity (Class A eruptions of Branca and Del Carlo, 2005). Events have occasionally occurred whose effusive activity is accompanied by intense long-lasting explosive activity which produces eruptive plumes and copious tephra fallout (Class B of Branca and Del Carlo, 2005). On the whole, flank eruptions of the past 500 years are described by the following mean parametres: flow length, 6.9 km; area covered, 4.8 $km^2$ and lava volumes of $29.5 \times 10^6$ $m^3$ (Behncke et al., 2005). Eruptive fissures during this time-span are mainly located along the NE and S rift zones of the volcano, at altitudes ranging from 1600 to 2800 m a.s.l. (Azzaro et al., 2012). In particular, the S rift zone has developed in the most densely populated zone of Etna, that includes the city of Catania, and where a long eruptive fissure opened in 1669, which was the lowest in altitude of any of the past 500 years (Branca et al., 2013).

With regards to seismicity, Mt. Etna is exposed to the destructive effects of both regional earthquakes and local volcano-tectonic events (Azzaro, 2004). The former are large crustal events ($6.4 \leq MW \leq 7.4$) that occur, either in southeastern Sicily or in the Messina Straits, such as the 1693 and 1908 earthquakes (Rovida et al., 2011). In contrast, volcano-tectonic earthquakes produce damage of more limited extent because of both the shallowness of their foci ($H < 5$ km; see Alparone et al., in press) and their low magnitudes ($M \leq 5.1$). Typically the strongest events are also accompanied by extensive surface faulting, and there is clear evidence of intense seismotectonic activity on the southern and eastern flanks of the volcano because they are crossed by a dense network of active faults (Azzaro, 1999). It is, however, the high frequency of occurrence of damaging earthquakes that presents the most serious source of hazard for the densely urbanized slopes of Etna, where local communities experience constant unease, periodic economic losses and occasionally high death tolls. Over the last 180 years, the historical earthquake catalogue (CMTE Working Group, 2014) shows that there have been 167 shocks which exceed the damage threshold, with some 15 producing heavy damage and/or destruction.

## 3. The 1669 Etna eruption

The 1669 eruption was the largest event to have occurred on Etna during the past 400 years (Tanguy et al., 2007). It was characterised by the emission of a large volume of lava (i.e. $607 \pm 105 \times 10^6$ $m^3$ ) between March 11th and July 11th, at a high average effusion rate of $58 \pm 10$ $m^3s^{-1}$ (Branca et al., 2013). The 1669 lava field covered *ca.* 40 $km^2$, was the widest and longest (*ca.* 17 km) historic or pre-historic lava flow and affected the highly urbanised and agriculturally productive area on the lower southeast flank of the volcano (Branca et al., 2013).

Between the afternoon of March 11th and the afternoon of March 12th, several eruptive fissures trending NNW-SSE opened between about 950 m and 700 m a.s.l. The main vent of the eruption formed between heights *ca.* 850 m and 775 m a.s.l. (Figs. 2a and 3). There was prolonged and violent explosive activity that generated the large scoria cone called at the time '*Monte della Ruina*' and later Mts. Rossi. During the first three days the effusion rate rapidly increased to around 640 $m^3$ $s^{-1}$, producing a lava field that divided into two branches around the morphological barrier of the Monpilieri cone (Fig. 2a). At this time lava covered an area of *ca.* 4 $km^2$, destroying in its wake several towns, villages and smaller settlements (*casali*), including La Guardia and Malpasso. Lava surrounded Mascalucia and reached the towns of San Pietro and Camporotondo (Branca et al., 2013). After two weeks the lava field covered 72% of its eventual total area and some 42 % of the total volume of lava had been emitted by this stage of the eruption (Branca et al., 2013), further destroying several settlements and some small villages including Gravina (Fig. 2b). During this time the growth of a complex network of lava tubes promoted a lengthening of the lava field and the development of a another branch towards the SE, which on March 29th reached and then destroyed the town of Misterbianco (Fig. 2c) (see Azzaro and Castelli, 2013)[5]. At the beginning of April the lava field covered an area of *ca.* 37 $km^2$ corresponding to the 93 % of its final total (Fig. 2c) (Branca et al., 2013). From this time the lava field almost stopped growing in area, but began to increase in thickness due to overlapping flows fed from ephemeral vents. Only the SE branch stretched towards and threatened the city of Catania. On April 4th this branch destroyed many farms in the rural hinterland of Catania and reached a small marsh in the vicinity of Gurna di Nicito (Fig. 2c). About a month after the eruption began, the south eastern branching flow was threatening the western walls of Catania which are located *ca.* 15 km from the vent (Fig. 2d). The city walls stopped and then diverted the lava to the south, which on April 23rd reached the sea. Between the second half of April and the beginning of June, lava tubes fed the expansion of a lava delta into the sea and this extended the coastline by approximately 800 m, thus increasing the total length of the flow field to *ca.* 17 km (Fig. 2d). During this phase of the eruption, lava both partially overtopped the city walls and broke into Catania on its north-west and southern boundaries (see inset on Fig. 2d). These flows were not well supplied with lava and produced only limited damage (Guidoboni et al., 2014).

Between March and May, fire fountain and Strombolian activity from the main vent produced a long-lasting eruptive column that reached a height of between 5 and 7 km during the first few days of the eruption (Mulas et al., 2012). Prolonged explosive activity generated widespread pyroclastic fall deposits composed of scoriaceous lapilli and ash. These pyroclastic deposits varied in thickness from several metres close to the vent, to only *ca.* 10 cm at a distance of 5 km (Walker et al., 1975). An almost continuous ash fall occurred across the entire south-eastern and north-eastern flanks of the volcano and also reached north-east Sicily, Calabria and Greece (Guidoboni et al., 2014). Towards the close of the eruption, probably between July 4th and July 9th, limited landslides occurred at the summit crater, but did not significantly alter the morphology of the summit cone according to field observations made in August and reported by Borelli (1670) (see also Guidoboni et al., 2014). Therefore, a summit caldera collapse did not occur at the end of the eruption as reported by Nicotra and Viccaro (2012, pp. 812), but only small landslides on the slopes of the summit cone.

Whereas the 1669 event is well-known from a purely volcanological perspective, the seismic activity which accompanied the eruption is scarcely described at all in the scientific literature. A study by Boschi et al. (1995) of the strongest earthquakes occurring in Italy since Roman times, reports only the mainshock on March 10th (23:25 GMT). He argues that this earthquake was responsible for the total destruction of Nicolosi, having a maximum intensity of IX-X (MCS) and being associated with an unusually extensive area of damage which affected the southern flank of the volcano. More recently Guidoboni et al. (2014) have published a chronological sequence of the seismic events associated with the 1669 eruption. These authors have re-assessed the intensity of the March 10th mainshock at VIII-IX (MCS), and have also reported other damaging events. They do not discuss the seismological characteristics of historical sources, but just provide a list of shocks felt in nearby localities, with their estimated macroseismic intensities.

A more detailed analysis of the seismicity relating to this eruption has recently been carried out as part of a wider historical investigation of the earthquake catalogue for Etna (CMTE Working Group, 2014). In this context, Azzaro and Castelli (2015) have reconstructed the 1669 seismic sequence in considerable detail. This has involved:

a. analysing historical documents not previously consulted, including coeval journalistic sources (Azzaro and Castelli, 2013);
b. critically examining information reported in 'first-hand' accounts (e.g. diaries, chronicles, official records and travellers' reports) and
c. comparing historic macroseismic features with those of more recent earthquakes that are instrumentally constrained. This sequence of earthquakes appears to possess features typical of a pre- and syn-

[5] This is the original site of Misterbianco (Fig. 3) and is not the 'new site' shown on today's topographic maps.

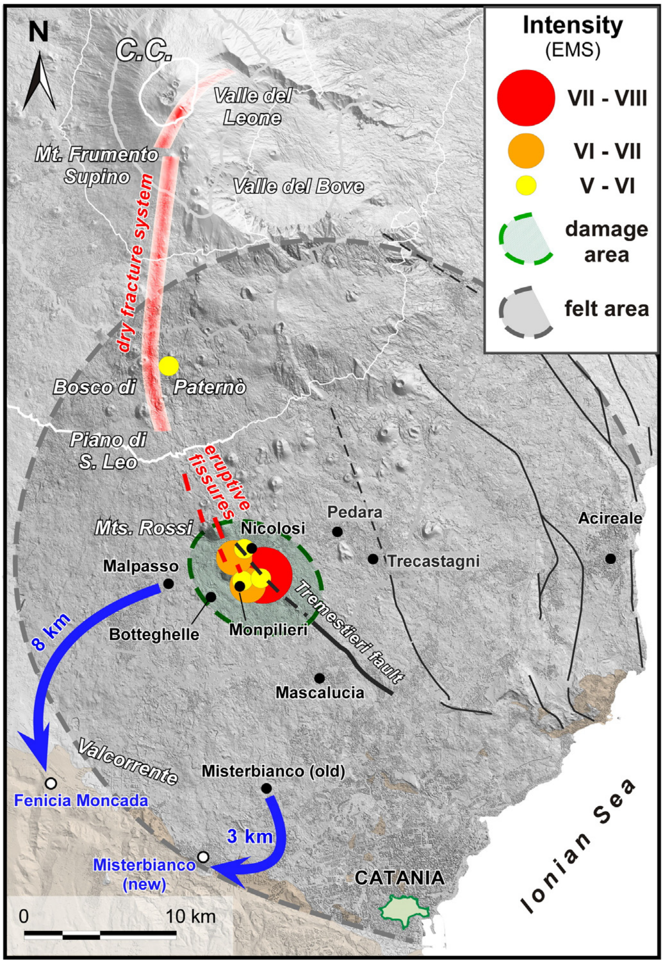


**Fig. 3.** Epicentral map of the principal earthquakes accompanying the 1669 eruption. Active faults are shown by solid lines, and the sedimentary basement is indicated by the brown ornament (from Azzaro et al., 2012). Blue arrows indicate changes in the locations of the settlements of Malpasso and Misterbianco to the new sites which were rebuilt from scratch. The pattern of the upper fracture system is reconstructed from Borelli (1670).

eruptive swarm, with deeper focused events that occurred up to March 9th being associated with magma ascent. Subsequently shallower earthquakes preceded the opening of the eruptive fissure on March 11th. Ground deformation, related to magma ascent, produced a long series of dry fractures along the upper south-east flank from Mt Frumento Supino to Piano di San Leo and along the eastern base of the summit cone up to the Valle del Leone (Fig. 3). Small landslides occurred at the summit crater during the formation of this uppermost fracture field (Guidoboni et al., 2014).

In detail the seismic swarm began on February 25th, when an earthquake hit the middle southern flank of Etna, producing damage to the rural settlements in the *Bosco di Paternò* (i.e. the forested region above Nicolosi). On March 8th seismicity resumed with events shaking settlements located across the southern flank including the city of Catania (Fig. 3). The wide area over which the earthquakes were felt as well as the lack of significant macroseismic effects[6], indicate that these events had moderate energy ($M < 3.5$) and focal depths in the range 5–10 km. Moreover, since seismic intensity was at a maximum around Nicolosi, it is evident that these earthquakes originated on the middle slopes of the volcano in an area that was subsequently affected by the opening of the eruptive fissure (Fig. 3).

On March 10th and 11th the characteristics of seismicity changed with several earthquakes producing very localised damage and values of macroseismic intensity reaching VII-VIII (EMS). Nicolosi and its surroundings were impacted severally, but the area over which the effects of the earthquakes were felt was of limited extent. These features are suggestive of: shallow focus; relatively high magnitudes of $3.2 < M < 4.3$ and an association both temporally and causally with the opening of the eruptive fissure. The strongest shocks were accompanied by surface faulting in the epicentral area and may be related to the activation of the Tremestieri fault (Fig. 3), as has also been observed in more recent times (Azzaro, 1999). In fact the northern segment of this important volcano-tectonic structure extends as a concealed fault close to the village of Nicolosi, whilst upslope it is connected to the termination of the 1669 eruptive fissure in the area of Mts. Rossi (Azzaro et al., 2012).

Finally, from March 13th until the end of the eruption, earthquakes drastically decreased both in number and energy. Events were widely distributed over the southern and south-eastern flanks of the volcano and did not produce any significant macroseismic effects. In all ten major earthquakes are identified together with a large number of minor events, many of which were multiple shocks and occurred on the same day. These cannot be recognized individually, information about them remains vague and they cannot be referenced to a single locality.

The implications of volcano-related seismicity for future hazard planning are further considered in Section 7.

## 4. Physical and social impacts of the 1669 volcanic event

### 4.1. Lava flows

The *ca.* 0.6 $km^3$ of lava emplaced during the four months of the 1669 eruption, covered an area of 40 $km^2$, radically altered the morphology of the landscape, and influencing the history and the subsequent urban development of the lower southeast flank of Etna and, in particular, that of Catania its principal settlement. Before the 1669 eruption Catania could be described as a 'white town' (Giarrizzo, 1986) because of its location on light coloured sedimentary rocks, that crop out to west and south of the city and which look over the Plain of Catania[7]. In addition the network of stream channels gives the city a predominance of 'white' features, which contrast with the black volcanic landscape. The 1669 eruption effectively severed the link between Catania and this part of its hinterland (Giarrizzo, 1986) and lava, particularly the SE branching flow which surrounded the western margin of the city, erased all traces of the drainage network, effectively isolating the city from the Plain of Catania (Pagnano, 1992). In turn these lava flows later influenced the development of the urban fabric and economy of Catania (see Section 6 and Guidoboni et al., 2014). The city changed from being a 'white' to a 'black' town dominated by an architecture composed of dark lava blocks (see Giarrizzo, 1986).

The physical and the social impacts of the 1669 volcanic event may be divided into two distinct phases, which are related to the development of the lava flow field (Branca et al., 2013). The first phase corresponds roughly to the initial three weeks of the eruption (11 March – 4 April). In fact at the beginning of April lava flows caused the most significant damage to the cultivated land of the south-east flank and to the rural hinterland of Catania, since they had already covered an area of *ca.* 37 $km^2$. During this time several towns were totally destroyed, the principal ones being: Malpasso, subsequently reconstructed on a new site as Fenicia Moncada (see Section 5); Camporotondo; San Pietro Clarenza and Misterbianco, also reconstructed on a different site (Fig. 4). Other smaller villages and settlements were partially or totally destroyed. The

[6] Intensity did not exceed degree V (EMS) and caused no damage.

[7] Although the Plain of Catania is a fertile important agricultural region today, this is after major investment from the 1950s onwards in flood control, drainage and malaria eradication (King, 1973, pp. 33). At the time of the eruption it was neither extensively cropped nor settled.

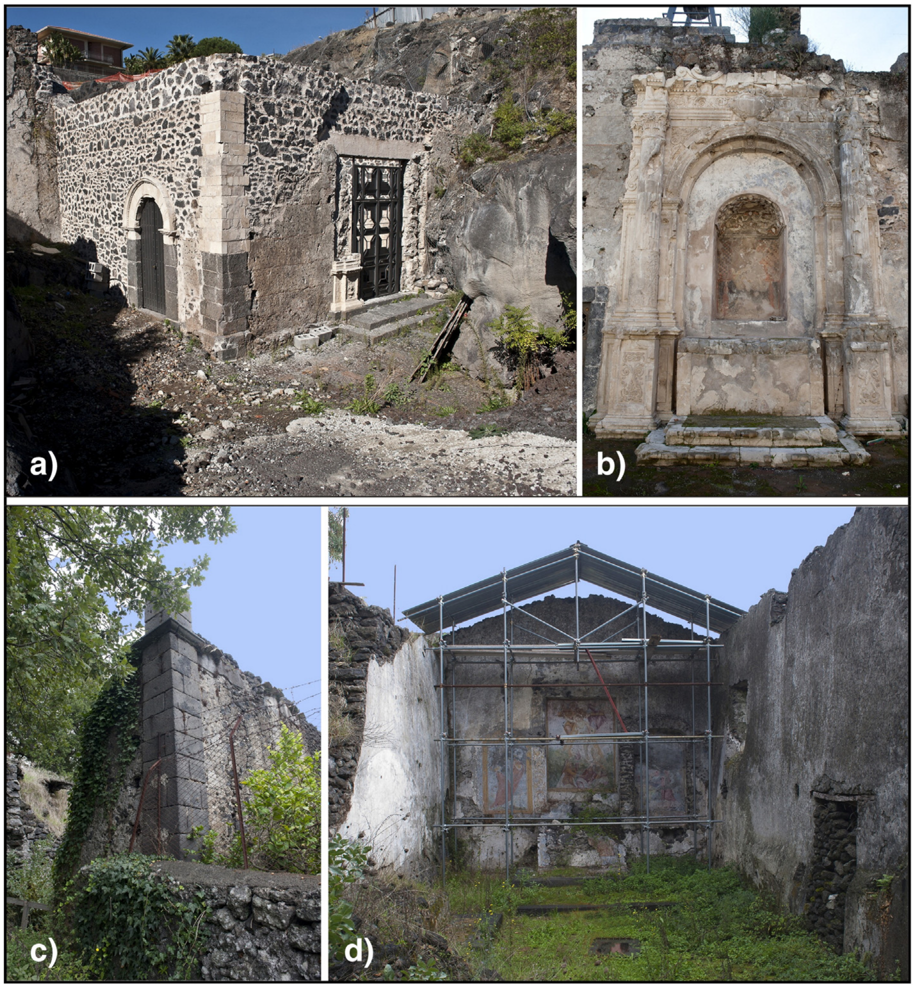


**Fig. 4.** 'Old' Misterbianco (i.e. *Misterbianco vecchio*) and the original parish church (i.e. *Chiesa Matrice*), unearthed from beneath the 1669 lava flow (Photographs by R. Azzaro). a) The front of the church, richly decorated with limestone from the Syracuse area. In the background to the left, a new building overhangs this important archaeological site. b) Details of an altar on the left-hand side of the nave. The grey colour to the right is due to the alteration of limestone by hot lava. c) Ruins of the *Chiesa della Madonna del Soccorso*, that was originally located near to the settlement of Botteghelle and which was buried under the lava flow. The edifice survived the 1669 eruption because it was being placed on a *dagala* (i.e. an area surrounded by lava). d) Details of the interior of the *Chiesa della Madonna del Soccorso*.

inhabitants of the towns and villages destroyed or threatened by lava began to evacuate to Catania because the city was considered a safe place far removed from the eruptive vents (Guidoboni et al., 2014). During this phase the civil and ecclesiastical authorities in Catania organized the hospitalization of injured refugees making demands to the Viceroy Francisco Fernandez de la Cueva for economic help generally and, more specifically, for assistance with intervention measures (Scalisi, 2013).

By the end of March, with the active lava front located at a distance of *ca.* 5 km from Catania, the principal response became religious. The perception that disasters are under the control of supernatural forces, with suffering being visited on sinful humanity, is not confined to *pre-industrial societies*, but transcends religious tradition, time and culture (Chester and Duncan, 2009). It was a particularly striking feature of disasters in southern Italy and especially in the Etna region, that religious responses are both prominent and expressed in elaborate ways when people have to cope with volcanic eruptions and earthquakes (Chester et al., 2008). By 1669 religious interpretation was a long-established tradition, beginning before the classical era when the Sikel God, Hybla, was associated with the mud volcano at Paternò while in the first century CE Lucilius Junior records people making offerings to the mountain in order to appease the Gods and so control its eruptions (Hyde, 1916). In Christianity any attempt to reconcile ideas of a loving God with the reality of human suffering is known as *theodicy* and before the eighteenth century enlightenment the most prominent model was that losses had to be accepted because they were a legitimate expression of divine wrath. All that the inhabitants of Etna could do was appeal to God in prayer and supplication, and attempt propitiation through liturgical actions. Positive features of disasters were to be found in heroic acts and virtues of self-sacrifice, public service and social cohesion (Chester et al., 2005), which were often both lauded at the time and quickly became part of the folk memory of the region. The attempt by Diego Pappalardo and some inhabitants of Pedara to divert lava, which is discussed below, is an example of both: an heroic act and one that has been praised ever since; and an early example of a pragmatic response rather than passive acceptance of divine retribution.

As far as attempts to propitiate divine wrath were concerned there are examples of religious services being held in most of the affected settlements of which the most elaborate were in Catania. As the English aristocrat the Earl of Winchilsea (1669, pp. 4) noted:

> *'As the fire approached, the religious everywhere appeared with much devotion, carrying in procession their relics especially those of St. Agatha, the famous Martyr of Catania, in which they reposed no small confidence, followed by great multitudes of people, some of them mortifying themselves with whips, and other signs of penance, with great*

*complaints and cries, expressing their dreadful expectation of the events of those prodigious fiery inundations'*.[8]

By the beginning of April as the eruption continued entering the second phase (4 April – 11 July), the local authorities were no longer able to cope with the emergency, because they had to deal with a combination of panic, riots and looting. Brigands and robbers preyed on evacuees from Catania, often taking their most valued possessions (Rodwell, 1878). A troop of Spanish cavalry was dispatched to deal with this lawlessness, gallows were erected and the guilty were summarily executed. There was a real possibility that Catania would have to be abandoned, especially since the population was now threatened by the south-eastern branching flow (Scalisi, 2013)[9]. For these reasons the Viceroy appointed a Vicar-General 'for the fire of Mongibello', Prince Stefano Riggio, who was both to manage the emergency and oversee the protection of Catania.

By the second half of April lava had reached the city walls for the first time and directly threatened the survival of Catania, the third largest city of the Kingdom of Sicily and Naples. The western and southern walls were reinforced, shored up and the gates blocked. Lava flows destroyed several important structures dating from Roman times to the immediate south west of the walls, but the walls resisted the weight of lava which continued to accumulate. At this time, not only did the Vicar-General decide to establish an evacuation camp some 3.5 km to the north east of the city at Ognina (Fig. 2c), but many of the principal aristocratic families also moved to other towns and cities in Sicily (Scalisi, 2013). Towards the end of April the lava entered the city for the first time, while in May and June lava destroyed some parts of its southern and north west quarters (Figs. 2d and 5).

At this time and in order to stem lava advance, restraining walls were built in the most threatened areas of Catania. A contemporary account by English merchants provides a description of this intervention:

*At this our last being at Catania we found the people busy in barricading the ends of some streets and passages, where they thought the fire might break in; and this they did by pulling down the old houses thereabout, and laying up the loose stones in a manner of a wall, which they said would resist the fire as not being mixt with lime: though it was the great weight and force of that fiery matter in pressing forward, and not its burning that overthrew buildings, as plainly appeared in the Convent of Benedictins (sic), and in the town-walls, where the great deluge of fire did pour it self, it not breaking into the city, but pouring it self over the walls, as hath been* said… (Anon, 1669, pp. 1032–33)

In addition to attempts to halt the advance of the lava within Catania using barricades, a priest – Diego Pappalardo – led a group of men from Pedara to breach the levées of the flow near to the vent. This action was intended to produce a diversion of the active lava and, thereby, 'starve' the flow front, so causing lava advance to cease (Chester et al., 1985). Citizens from the town of Paternò then drove the men from Pedara off the flow, the breach 'healed' and the lava continued on its original course. This is an interesting initiative for several reasons. First, it is an early – perhaps the earliest – account of an attempt to divert a lava flow, secondly it took place a century before Enlightenment thinking began to ascribe disasters to extreme natural events nature that had the potential to be managed and, thirdly, the men from Pedara were led by a priest. Diego Pappalardo who presumably saw nothing incompatible between his role as a Minister of God, embracing a theology of divine responsibility and a citizen concerned to use rational intervention to reduce losses.

[8] The Earl of Winchilsea (1628–1689) was at the time Ambassador to Constantinople and was returning home at the time of eruption. The quotation is reproduced using modern English spelling.

[9] As we have argued elsewhere (Chester et al., 2012, 2015), panic, rioting and looting are very rare reactions to disaster and are symptomatic of the scale by which law and order had broken down.

Even though, the advance of lava within Catania was very limited there was great anxiety and the authorities considered abandoning the site and re-locating the city (Scalisi, 2013). This option was not adopted because:

a. The fifteenth century walls of the town, designed by the military engineer Antonio Ferramolino from Bergamo and financed by citizens of Catania, resisted the impact of the lava. The walls assumed the role of barrier and saved the city from total destruction.
b. Intervention within the city successfully contained and limited the damage.
c. Decisions made by Vicar-General, Stefano Riggio, enabled the conflicting interests of the various local and central authorities to be managed (Scalisi, 2013).

In summary, the principal impacts of the first phase of eruption were the successful escape of *ca*. 20,000 inhabitants from settlements destroyed by the lava. Most of whom moved to Catania, a city in which *ca*. 27, 000 people were already residing. This causing both a breakdown in law and order, and threatened the pre-existing social order (Guidoboni et al., 2014). During the second phase when Catania itself was directly affected by lava, its partial abandonment caused a loss of industrial production and a major reduction in commercial activities, both of which hastened the collapse of the city's economy.

### 4.2. Tephra fall

The intense and prolonged explosive activity at the main vent produced a total volume of $4.22 \times 10^7$ $m^3$ (Mulas et al., 2012) of tephra which caused the temporary loss of cultivated land on the lower south-eastern flanks of Etna due to the destruction of vineyards, orchards and olive groves. Grassland pasture disappeared under a thick layer of lapilli and cattle had to be moved to safer places (Azzaro and Castelli, 2013). Tephra fall also caused damage to houses in several towns on the eastern sector of the volcano and along the Ionian coast (Guidoboni et al., 2014). The area between Nicolosi and Pedara was particularly badly affected and was covered by pyroclastic deposits several metres thick, and in the villages of Pedara and Trecastagni the roofs of many houses collapsed. Intense tephra fall over so lengthy a period and on such a large scale, made the management of the emergency by the authorities in Catania much more complicated, not least because of its impact on the agricultural economy of the region and, hence, on the food supply.

### 4.3. Earthquakes

The seismicity accompanying the 1669 eruption had little long or even medium-term impact on the people of Etna. Many of the localities damaged by seismic activity before the eruption were destroyed by lava only a short time later (i.e. often after just one or two days), because they lay in the path of the large lava fan which was subsequently erupted from Mts. Rossi. The only exception was the village of Nicolosi, which had repeatedly suffered heavy damage from the volcanic earthquakes and in 1669 was later buried by several metres of tephra.

The seismic swarm was particularly intense during the first day of the eruption, from March 10th to 11th, and at least six earthquakes produced slight to moderate damage (V-VI ≤ $I_{max}$ ≤ VI-VII) in both Nicolosi and some neighbouring settlements including Monpilieri and Botteghelle (Fig. 3). The mainshock occurred on March 10th (23:25 GMT) and produced severe damage in Nicolosi. The parish church suffered collapse of its roof and many houses needed to be shored up. Azzaro and Castelli (2015) have estimated that the effects in Nicolosi corresponded to an intensity of VII-VIII EMS, after filtering the descriptions of damage in some contemporary accounts to take into account the role of strong fore-shocks in

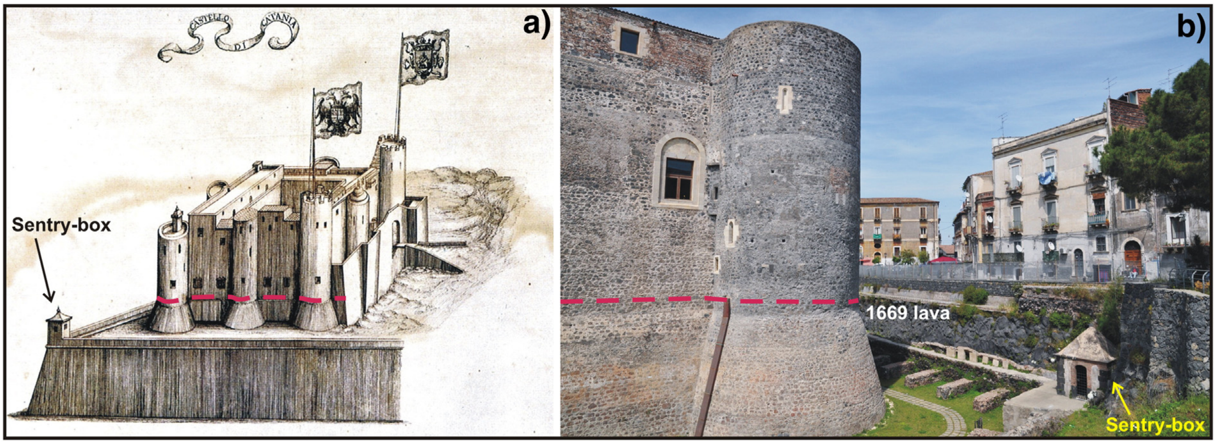


**Fig. 5.** a) Perspective from south-east of the Ursino Castle in Catania (from a contemporary illustration by Francesco Negro *ca.* 1637, in Pagnano, 1992). It shows the walls of the San Giorgio bastion with a sentry-box dating from the 16th century. b) Image of the south-east corner of the Ursino Castle after the excavation carried out in 2009. Photograph by S. Branca. The red dashed lines, (a) and (b), indicate the position of the top of the lava flow when it was alongside the castle walls.

causing earlier damage and so increasing the vulnerability of many buildings. Therefore in contrast to Boschi et al. (1995) and Guidoboni et al. (2014) who estimated higher intensities of IX-X and VIII-IX MCS, Azzaro and Castelli's interpretation represents a correction of the over-estimation that resulted from the cumulative effects of precursory minor shocks. The principal earthquake which occurred in the 1669 eruption was in fact similar in size to the strongest earthquakes that have originated in the same area during subsequent centuries (CMTE Working Group, 2014).

It should be noted that some localities on the southern flank that were reported as being severely affected (Boschi et al., 1995; Guidoboni et al., 2014) by the shocks occurring between March 8th and 11th, may only have suffered felt earthquakes which caused no damage (Fig. 3). There is no evidence that Catania suffered any damage by earthquakes during the 1669 eruption.

In conclusion, the social impact of the seismic swarm was significant in areas proximal to the fissure. People were forced to leave their homes, either living outdoors, or in impromptu shelters. The

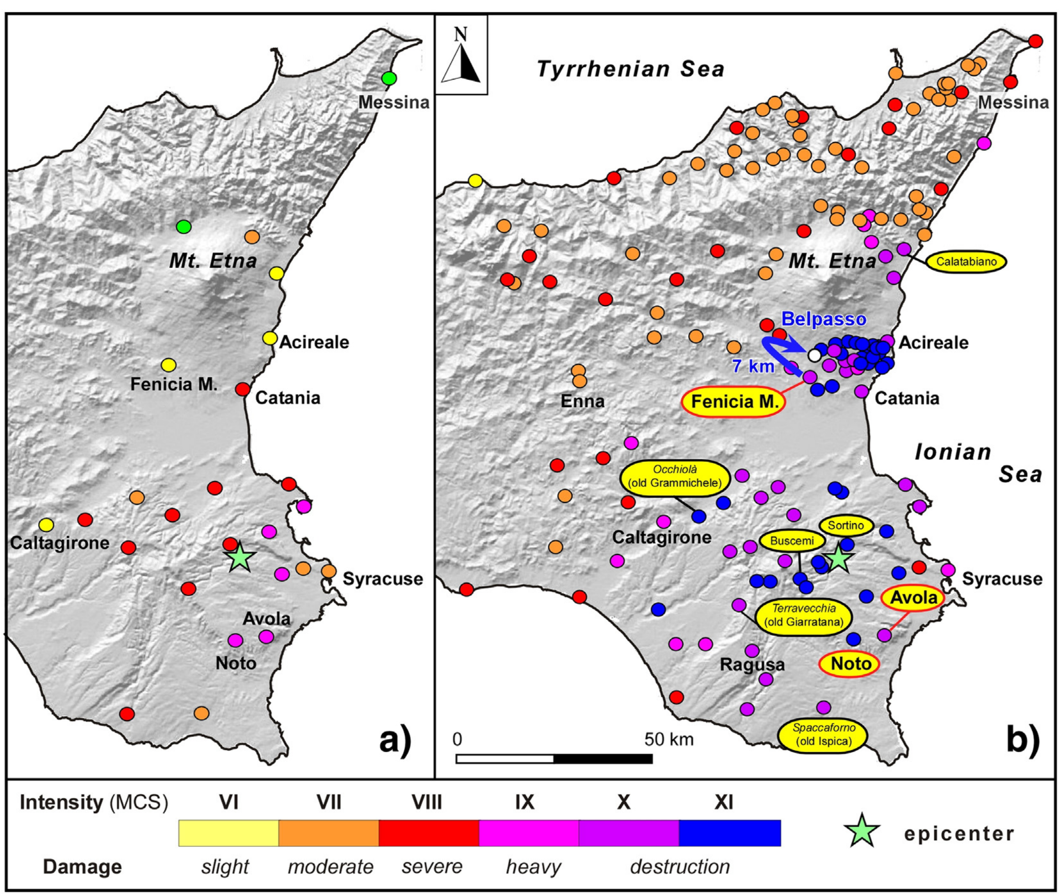


**Fig. 6.** Intensity maps of the 1693 Val di Noto earthquakes. Legend illustrates the relation between the intensity degrees in the Mercalli-Cancani-Sieberg (MCS) scale and the corresponding grade of damage. a) January 9th foreshock (epicentral intensity $I_0$ VIII-IX MCS, moment magnitude $M_w$ 6.2). b) January 11th mainshock ($I_0$ XI, $M_w$ 7.4). The principal localities abandoned and reconstructed on new sites are also highlighted in yellow (red edges mark case-histories discussed in the text).


**Fig. 7.** A contemporary illustration of Catania in 1686 (in *Teatro geografico antiguo y moderno del Regno de Sicilia* of Carlos Castillas) showing the urban fabric seventeen years after the 1669 eruption.

earthquakes served to initiate evacuation of areas which were subsequently threatened by lava. Many buildings which survived the lava were actually undamaged by seismic activity.

## 5. The 1693 Val di Noto earthquakes

### 5.1. Physical impact

Just twenty four years after the 1669 eruption, the Etna region and particularly the city of Catania, was again at the centre of a catastrophe. The year 1693 was an *annus horribilis* for Sicily. At the beginning of the year two strong earthquakes struck the eastern part of the island totally destroying some forty towns in the area between Catania, Syracuse and Ragusa and causing damage stretching from Messina, across the centre of Sicily to Malta (Azzaro et al., 1999; Condorelli, 2006). The January 9th foreshock (M 6.2) heavily damaged the Syracuse area (I = VIII–IX MCS according to Guidoboni et al., 2007), with intensity values of over VIII reaching as far as Catania (Fig. 6a). In the Etna region effects were more subdued and intensities were lower (i.e. V–VI). Two days later on January 11th the mainshock (M 7.4 I = X–XI MCS) completely destroyed the previously affected localities and caused devastation (I = X MCS) over much of the Etna region, with severe damage extending as far as north-eastern Sicily (Fig. 6b). A tsunami also had a severe impact on the Ionian coast from Messina to Syracuse (Tinti et al., 2001; Gutscher et al., 2006). The death toll was enormous, with an estimated mortality figure exceeding 50,000. Whereas the physical characteristics and social impacts of the 1693 earthquakes are well known due to a large volume of both contemporary reports and more recent studies (Guidoboni et al., 2007, and references therein), their seismo-tectonic interpretation is still a matter of debate. The various proposed hypotheses of epicentral location, place the seismic source either offshore in the Ionian Sea, or alternatively, inland on the Hyblean Foreland (Azzaro and Barbano, 2000; Visini et al., 2009; Polonia et al., 2012, and references therein).

As far as Catania is concerned, the 1693 earthquakes struck those parts of the medieval city that had survived the effects of the 1669 eruption. The city was characterised by a network of narrow and tortuous streets, a main road crossing the settlement and a built-up area surrounded by a system of defensive walls (Fig. 7). The first event on January 9th (I = VIII MCS) caused some damage which included: extensive wall cracking; detachment of roofs and partial collapses, with some buildings having to be shored up. The second event on January11$^{th}$ was the largest known earthquake to hit Catania whose buildings were now in a weakened state and, with only a few exceptions such as the Ursino castle and the Benedettini Monastery both of which had survived the effects of the 1669 eruption (Azzaro et al., 1999), the city was reduced to rubble. The effects of the tsunami were also severe, with waves entering the city through gates located in front of the port and flooding the streets to a distance of 350 m from the coast (Boschi and Guidoboni, 2001; Tinti and Tonini, 2013). The intensity of the January 11$^{th}$ event in Catania has been estimated at X MCS (Guidoboni et al., 2007), but this figure represents the cumulative effect of the two shocks which occurred very close in time.

### 5.2. Social impact in eastern Sicily

In the week following the earthquake and tsunami, law and order broke down catastrophically which, as mentioned in Section 4 is a relatively rare event in major world disasters. Anarchy was manifested not only in looting and plunder, but also in almost complete economic disruption, widespread social dislocation and unplanned evacuation of many of

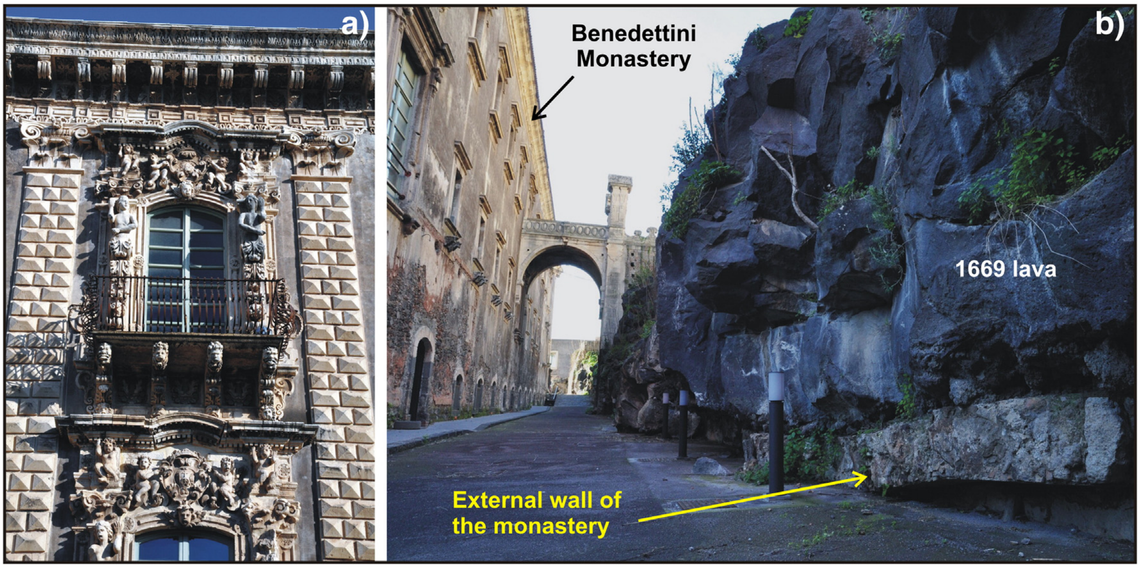


**Fig. 8.** a) Detail of the front elevation of the Benedictine (i.e. *Benedettini*) monastery that was reconstructed at the beginning of the XVIII century and following the 1693 earthquake. It represents an amazing example of the late Sicilian Baroque style. b) Rear elevation of the monastery showing 1669 lava which affected it at the end of April. Photographs S. Branca.

the city's inhabitants. Temporary shelters were built outside the city in order to avoid epidemics because thousands of bodies remained buried under the rubble. As with the 1669 eruption so in 1693 some ascribed the earthquake to a divine cause, whereas the authorities were keen to handle the emergency in more practical ways (Condorelli, 2006). The Viceroy, Juan Francisco Pacheco Téllez-Girón (1649–1718), the Duca (i.e. Duke) di Uzeda, and the government in Palermo reacted quickly by sending supplies, forces and an official representative. He was Giuseppe Lanza, Duca di Camastra (1630–1708), who was invested with plenipotentiary powers to co-ordinate the reconstruction of the *Val di Noto*[10]. The first act of the Duke was to exempt the worst affected areas from taxes, and by late February/early March public safety had been restored, food and other supplies were re-established and measures had been introduced to protect public health. Many evacuees returned.

In the towns and villages of the fertile *Val di Noto* the catastrophe of 1693 provided an occasion for social and cultural rebirth, with Sicilian Baroque styles acting as a unifying theme (Fig. 8) (Blunt, 1968; Dufour and Raymond, 1994). The most important Baroque architect of the reconstruction was the eminent (and expensive) Giovanni Battista Vaccarini (1702–1768), although from the middle of the eighteenth century some architects were adopting a neo-classical style (Anon, 2013a). Indeed the reconstruction of the severely damaged towns and villages of the *Val di Noto* was the culmination of the greatest period of settlement improvement and land reorganisation which was taking place in Sicily during the 16th and 17th centuries (Ligresti, 2000). By the beginning of the 16th century the requirement for settlements to be located on hill tops had diminished[11] and new towns and villages could be built with lower building density, were more 'open' plan and where their location on plains or within valleys allowed better integration with transport routes. This in turn increased trade and improved the quality of life, with water in particular being far easier to supply.

**Table 2**
Population change in town and villages affected by the 1669 eruption. Based on information in Ligresti (1984).

| Towns and Villages | 1651 | 1681 | 1714 | 1798 |
|---|---|---|---|---|
| *Destroyed* | | | | |
| Monpilieri | 200 | 394 | 459 | 292 |
| Camporotondo | 1,600 | 593 | 181 | 565 |
| S. Pietro Clarenza | 625 | 496 | 492 | 235 |
| Misterbianco | 2,657 | 1,333 | 1,891 | 3,076 |
| *Damaged* | | | | |
| S. Giovanni Galermo | 492 | 352 | 458 | 737 |
| *Destroyed/severely affected by volcanic earthquakes* | | | | |
| Gravina | 935 | 634 | 768 | 1,103 |
| Mascalucia | 1,035 | 998 | 1,570 | 2,506 |
| Nicolosi | 980 | 844 | 1,338 | 3,530 |
| Pedara | 1,588 | 1,582 | 1,952 | 2,063 |
| Trecastagni | 3,200 | 3,264 | 2,806 | 2,406 |
| Totals | 13,312 | 10,490 | 11,935 | 16,513 |

No data are available for La Guardia or Malpasso/Belpasso.

Most of the towns and villages that were destroyed or damaged by the earthquake were rebuilt *in situ*, sometimes re-using materials that were already present. Building plans were either re-used or changed. Some settlements for a variety of social and economic reasons were rebuilt from scratch in different locations[12] (Fig. 6b). Two of the more interesting and well researched examples are Noto (Tobriner, 1982) and Avola (Dufour and Raymond, 1993), which are located on the Hyblean plateau to the south of Catania.

## 6. Recovery

From the accounts presented in Sections 4 and 5, it is evident that the 1669 eruption and the 1693 earthquake caused devastation in the Etna region. With respect to the former: lava covered *ca.* $40 \times 10^6$ m$^2$ of land,

[10] The three historic subdivisions of Sicily were: the Val di Mazara, covering the west of the island; the Val Demone, the north east and the Val di Noto the south east (Fig. 1a). Catania was located in the extreme south east of the Val Demone with the border of the Val di Noto running just a few kilometers to the south of the city (Puleo, 2010).

[11] In Sicily agricultural settlement is not generally diffuse and farmers often reside in large *agro-towns* or peasant cities, travelling to their agricultural holdings on a daily and sometimes on a twice daily basis (King and Strachan, 1978). Many have been traditionally located on hill tops. A few settlements are known to have been continuously occupied since pre-Hellenic *Sical* times , but many have no certain date of foundation. The French geographer Alfred Demangeon has argued that *agro-towns* were founded as a result of several interlocking factors, which included natural conditions (e.g. defence and cooler less malarial conditions than the plains), plus ethnic and social linkages between the inhabitants, however his principal insight was that *agro-towns* continue to exist because of social and economic inertia, since they served to alienate and separate farmers from their land and so reduced agricultural efficiency - not least as a result of lengthy journeys to work (Demangeon, 1927, pp. 4).

[12] Avola and Noto were reconstructed on new sites, Catania and Syracuse were entirely rebuilt on their old sites, but the latter maintained its medieval plan, while Ragusa was partly built on a new but neighbouring site to a new plan (Anon, 2014a).

all located below 800 m and including some of the most productive agricultural holdings on the volcano and the settlements of Camporotondo, La Guardia, Malpasso, Monpilieri, Misterbianco and S. Pietro Clarenza. Several small villages were totally destroyed as the flow field developed; San Giovanni Galermo and the western portions of Catania were heavily damaged (Branca et al., 2013) and volcano-tectonic earthquakes destroyed Nicolosi and nearby settlements (Azzaro and Castelli, 2015).

In contrast to earthquakes, lava sterilizes the land over which it passes for hundreds of years and when the British traveller Patrick Brydone (1773, pp. 160) visited the region in the latter part of the Eighteenth century the land was barren and even today, although there is limited vine cultivation on pyroclastic *andisols* near to Nicolosi, the skeletal azonal soils of the 1669 lavas only support grazing below 600 m and remain sparsely vegetated at higher altitudes (Chester et al., 1985, 2010). In an agricultural economy this meant that the scope for economic recovery was severely limited, with population data (Table 2) capturing the level of rural dislocation and decline. All the affected towns and villages in the Etna region show either declines in numbers resident or only marginal increases in the immediate aftermath of the eruption (Ligresti, 1984). Indeed with the single exception of Misterbianco (Sangster, 2013), the population of villages destroyed by the eruption was still below 1651 levels at the close of the Eighteenth century. In contrast over the period 1651–1681 the population of Sicily as a whole increased by nearly 50,000, or by around 5% of the 1651 figure of 1.1 million (Ligresti, 2002, pp. 26). Many of the displaced people re-located to other settlements in which they had kinship ties (Chester et al., 2010) virtually all, for instance, fleeing from Monpilieri to Massa Annunziata and, in the case of Camporotondo, many made their way to and remained in Catania (Anon, 2014b) whose population was swollen by refugees.

As discussed in Section 4, in the cases of Misterbianco and Malpasso/Fenicia Moncada, reconstruction occurred slowly on new sites located at some distance from their pre-eruption locations, while elsewhere rebuilding was equally slow, being far from complete by the time of the 1693 earthquake. For instance: Pedara experienced a slowing in its hitherto rapid population and urban growth and in Nicolosi reconstruction of earthquake damaged buildings did not begin until four years after the eruption (Anon, 2013a). Eventually Camporotondo was rebuilt slightly to the south of its original position, S. Pietro Clarenza 1 km to the east, while S. Giovanni di Galermo did not change its location, but had to deal with the ruined S. Antonio quarter which placed a brake on development to the west of its historic core (Azzaro and Castelli, 2013).

The damage caused by tephra fall to buildings in the area between Nicolosi and Pedara and to agriculture on the lower south east flanks more generally was immediate but the impact short-lived. Tephra was cleared, the roofs of buildings were repaired and agriculture was quickly re-established. Indeed tephra fall on young lava flows will lead to quicker soil development thereby facilitating agricultural development in the longer-term (James et al., in press).

Concerning the recovery of the main town, Catania, following the eruption the local authorities requested the Spanish administration to undertake the construction of new infrastructure that would equip the city for improved political and economic competitiveness (Scalisi, 2013). By late September and less than three months after the end of the eruption the viceroy, Stefano Riggio, granted licenses for the construction of a new neighbourhood and port. This disaster was viewed by the local and Spanish authorities and by the population, therefore, as an opportunity for social and urban development with which to facilitate the economic recovery of the city.

As noted in Section 5, the death toll in the 1693 disaster probably exceeded 50,000 and, whereas the effects of the eruption twenty four years earlier were confined to that portion of Catania's hinterland which coincided with the southern flank of Etna, the earthquake devastated a much more extensive area of eastern Sicily across most of the *Val di Noto* and including the southern part of the *Val Demone*.

For the Etna region a report by Vincentius Bonajutus (1694, pp. 9–10), noted major damage and deaths in Fenicia Moncada (see Section 4.3), Jaci (i.e. Acireale), Licodia[13], Mascali, Massa Annnunziata, Pedara, Trecastagni and Viagrande, to which more recent sources have added Aci Catena, Maletto and Piedimonte. In Catania damage was so severe that it is easier to list the few buildings that remained: the choir and some side chapels within the cathedral; the Santa Maria della Rotonda church; the Ursino castle; part of the city walls and a few houses (Azzaro et al., 1999). Estimated deaths range from the more probable 11,000 to 20,000 out of the total population of Catania of between 23–27,000 (i.e. mortality rates in the range 41–87%). Major decisions about the re-development of the city were taken between May 1693 and June 1694, by a commission (*Consiglio*) under the close guidance of the Duke of Camastra, which comprised the leading surviving members of the aristocracy and the church. At this time of aristocratic and theocratic pre-eminence, nobody from a bourgeois or craft guild background was included in the commission. The option of relocating the city was rejected and it was decided to rebuild on the same site, but using a new plan. The old medieval pattern of narrow streets was highly dangerous because in 1693 many people were killed, not just by collapsing buildings, but also because they could not escape using streets that were blocked by debris. The new town plan was notable for its wide streets, that were aligned in a 'grid pattern', and by the insertion of squares. This planned re-development represented a considerable achievement in anti-seismic design (Dato, 1983). Less satisfactory was the fact that sites were levelled and many new buildings were constructed in part on rock but also on debris and rubble, not ideal foundations for a city at risk from future earthquakes (Azzaro et al., 1999 – see Section 4). Between 1694 and 1695 and coinciding with the return of Catania to local administrative control, rebuilding the city's defences became a new planning priority. The Royal Engineer, Colonel Don Carlos von Grunemberg, who was an expert in the planning and building of fortifications, was sent to the region.

As people returned to Catania, temporary shelters were not demolished but were re-occupied by the poor and returning refugees, the areas in which the shelters were located gradually evolving into deprived suburban neighbourhoods. This also occurred more recently, following the 1883 Casamicciola earthquake (Ischia, Naples). What were originally shacks that housed refugees, constitute what is today the nucleus of the Perrone quarter which is located in the eastern part of Casamicciola (Luongo et al., 2006). Since the 1669 lava flow covered most of the land to the west of the city, new districts were built outside the defensive walls, mainly to the north and towards the sea. During the first few years of reconstruction labour demand was very high and, since *ca.* 63% of Catania's population had perished, drafts of migrant workers were required with around 30% coming from Calabria on the mainland (Condorelli, 2006).

Reconstruction was almost complete by the last decade of the 18th century (Dufour and Raymond, 1992). Across the hinterland of Catania, re-establishment of settlements was often complex. Whereas Nicolosi was rebuilt on the same site (Barbano et al., 2001a, 2001b), in the case of Belpasso the village was re-located in 1669 and was re-sited again in 1693. The original settlement, which was called Malpasso, was founded in 1456 by the Moncadas, Princes of the 'State of Paternò and Malpasso', and was sited some 1.5 km to the west of Monpilieri (Fig. 3). After the village was completely buried by lava in 1669, some refugees camped near to Valcorrente and established a new settlement which they called Fenicia Moncada. They built the settlement in *en echelon* formation, adopting a plan which had been developed in the reconstruction of other town and villages across the *Val di Noto* (Caruso and Perra, 1995). The site of Fenica Moncada was on the extreme south-western periphery of the Etna region, at a height of 250 m and looked across the Plain of Catania. From a hazard perspective it is notable that the site was well adjusted, being sited on sedimentary rocks and

[13] Now known as S. Maria di Licodia.

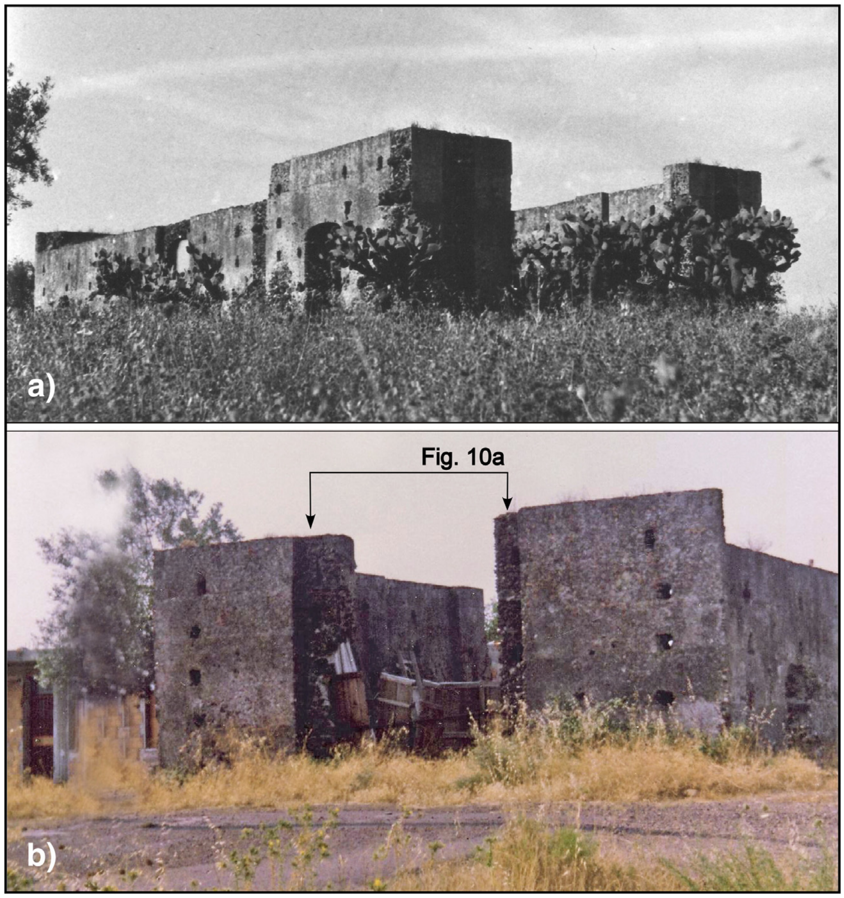


**Fig. 9.** Ruins of Fenicia Moncada. Today any archaeological evidence has been destroyed by urbanization. a) The parish church (*chiesa matrice*) in 1970s. The church, built in the main square, the *Piazza Grande*, was completed in 1682. b) The St Anthony's Church (*Chiesa di S. Antonio*) in the 1980s. Arrows indicate the position of the jambs of the main entrance shown in Fig. 10a. Photographs by V. Bruno.

sufficiently far enough away from Etna to make it unlikely to be affected by future eruptions. In the event the site proved to be unsuitable, because it was pestilential and so exposing its inhabitants to malaria. At the time of the 1693 earthquakes Fenicia Moncada had a population of around 1600 of whom 14 lost their lives. Although it was not entirely destroyed, the decision was taken to transfer the village, which was renamed Belpasso, back to the slopes of the volcano, not far from the now buried village of Malpasso. Today few traces remain of Fenicia Moncada since its site is covered by more recent residential development (Fig. 9). The current Belpasso is located 2.5 km to the south west of Malpasso. It was designed according to a plan by which the village is divided into four by two orthogonal axes and, at the intersection of the main roads, a round open space for community activities was established. The plan used to build Belpasso may be traced back to the


**Fig. 10.** Belpasso. a) The portal of the original church of St. Antony which was removed from Fenicia Moncada following the 1693 earthquakes and was re-mounted in the church that was rebuilt in the new settlement. b) Details of a lintel which commemorate the building of the old church in 1678 (bottom) and new church in 1773 (top). Photographs by R. Azzaro.

famous example of the *Quattro Canti* (i.e. the Four Corners), the crossroad at the heart of Palermo's historic district (Caruso and Perra, 1995). The history of Malpasso/ Fenicia Moncada/Belpasso is an interesting example of the ways in which a single community reacted to the extreme events of 1669 and 1693 (Fig. 10).

Slow recovery is often cited as being typical of the ways in which *pre-industrial* societies cope with disasters (White, 1974; Chester et al., 2012), this being due in large measure to a lack of capital accumulation in traditional agricultural economies. This was certainly the case following the 1669 eruption, but recovery after 1693 was quite different. Progress began almost immediately with a rapid first phase of building mostly comprising houses and shops (1694–1796); later more substantial privately owned dwellings, public and religious structures were constructed; with a final phase occurring after 1750. Reconstruction was virtually complete by the last decade of the eighteenth century. By 1737 Catania's population reached 26,000 – probably higher than its pre-earthquake total – and was 45,000 by the century's close. In Catania, planning included new squares and wide streets, these initiatives being a reaction to the frequent observation that many people perished because of buildings collapsing into narrow streets so preventing their escape (Condorelli, 2006). The high quality of the buildings comprising the 'new' largely Baroque city was commented upon by Patrick Brydone (1773) when he visited Catania in 1770, and as the century wore on wealthy elites in both church and State were able to follow fashionable European trends and adopt neo-classical styles for some buildings.

How the reconstruction was paid for, not only by elites, but also by artisans and labourers, has been studied in detail by Condorelli (2006, 2012). The deaths of people in such large numbers dramatically increased capital stock per capita and boosted wage rates[14], drawing in labour from outside the region (see Section 4.3) and providing large tranches of disposable income for local people to invest in housing. The early years of reconstruction when labour demand was high, coincided with both a boom in 'popular' house construction and the emergence of local magnates who became wealthy by controlling the building supply, transport and construction sectors of the economy. In the case of elites untimely deaths as a result of the earthquakes meant a concentration of funds in fewer hands. For the clergy, who in the seventeenth century accounted for around 4% of the population of Sicily (Ligresti, 2002) and members of religious orders, loss of buildings caused concentration of wealth with, for instance, the number of convents in Catania being reduced at a stroke from 14 to just 6 (Condorelli, 2006). For secular elites similar concentration occurred through inheritance because wills now had far fewer beneficiaries. Subsequently rents from newly constructed houses and shops released funds which allowed further reconstruction to take place, with most new churches and monasteries being funded by rental income.

There are parallels between the economic impacts of the 1693 Sicilian and the 1755 Lisbon earthquakes (Pereira, 2006, 2009)[15]. Following the 1755 earthquake wage costs rose dramatically, funding a building boom, redistributing wealth and allowing the Marquês de Pombal (1699–1782) – virtual dictator of Portugal at the time – to tackle the vested interests of elites within the church and inquisition. Economic dependency on trade with Britain was also greatly reduced. 'In spite of the terrible casualty toll and significant wealth losses, in the long run the 1755 earthquakes was beneficial to the Portuguese economy' (Pereira, 2006, pp. 34). A similar comment applies to Catania and its region.

[14] Condorelli (2006), estimates that wages accounted for 35% of the average costs of construction.

[15] There are also possible parallels with the great fourteenth century European plague known as the *Black Death*, some but not all historians arguing that a steep rise in wage rates was due to the massive reduction in the number of workers available. This placed feudal peasants in a financially strong position which ultimately hastened the end of feudalism (Anon, 2013b).

## 7. Conclusion

In an important paper reviewing resilience to disasters in traditional *pre-industrial* societies, Gaillard (2007) argues that successful coping depends on four factors:

a. the nature of the hazard;
b. the pre-disaster socio-cultural context and resilience capacity of the affected community;
c. the geographical setting;
d. the policies of rehabilitation adopted by the authorities.

On Etna during the late seventeenth century, contrasts in the effectiveness of the responses to and the time it took to recover from the 1669 eruption and 1693 earthquake, were largely determined by the nature of the hazard and its geographical setting. The 1669 event did not kill or injure, yet in terms of economic losses was the most devastating of historical eruptions. Although it affected a spatially limited area, inundation by lava meant that land was effectively sterilized for centuries and, in a *pre-industrial* agriculturally-based economy, recovery could not occur quickly without outside assistance. As figures quoted in Section 6 show, for some time the worst affected *comuni* were only able to support reduced population numbers from the region's severely depleted post-eruption agricultural base. Later employment diversity occurred. Much of the stone used in re-building came from quarries located on the 1669 lava and farmers found alternative employment in pastoralism, as wage labourers and/or working plots of land located outside the worst affected area (Chester et al., 2010). With the exception of Nicolosi, much of the damage caused to buildings by volcanic earthquakes was effectively masked, because most of the settlements affected were quickly covered by lava flows. Vulnerability to volcanic earthquakes of traditional buildings, which are often constructed of rubble-stone, remains a serious concern. In the latter part of the *pre-industrial* era from 1792 to 1923, losses from volcanic earthquakes often occurred, were particularly severe and produced victims in 1865, 1894, 1911 and 1914 (Guidoboni et al., 2007), with buildings similar to those impacted in 1669 being severely damaged or destroyed (Bottari et al., 1985; Ligresti, 1995). Indeed today most settlements in the Etna region contain large numbers of traditionally constructed houses, public buildings and churches that do not comply with contemporary building codes, which have only been enforced at the *comune* level of administration since 1981 (Faccioli et al., 1999; D'Amico et al., in press). The situation on Etna is an excellent example of an historical legacy increasing present-day vulnerability, a situation known to hazard researchers as 'residual un-ameliorated vulnerability' (Alexander, 1997, pp. 292).

As a result of the civil unrest that it engendered, it has often been asserted that further attempts to divert lava had to wait until the 1983 eruption[16], when co-ordinated action was under the auspices of the State (Chester et al., 1985, pp. 323). More detailed recent historical research has shown that attempted diversion quickly became part of the *pre-industrial* response on Etna, with diversion being attempted during many post-1669 eruptions, in particular in 1832, 1879 and 1923 (Chester et al., 2012, pp. 78).

In contrast to the 1669 eruption, the 1693 earthquake affected an extensive area of south-east Sicily and, although it was far more serious in terms of mortality and morbidity, there was no land sterilization or barrier to long-term recovery. Reduction in population numbers freed money for investment and recovery, which was effective and relatively rapid. The transfer of inhabitants of Fenicia Moncada to the site of Belpasso, close to the former settlement (Malpasso), testifies to how people in a small community do not wish to lose their identity with a particular place, despite its hazardousness.

[16] Diversion was also attempted in 1992, 2001 and 2002.

As noted in Section 5, the 1669 and 1693 disasters were viewed by central and local government as opportunities to plan new settlements and, in the case of Catania, virtually to build a new regional capital, which were significantly more resilient to future extreme events. By the nineteenth century many of the lessons of the late seventeenth century had been largely forgotten and there were many examples of: poor seismic design of individual buildings; and the location of new residential and commercial areas, together with zones of urban expansion, which placed more people at greater risk from future eruptions and earthquakes. Only recently new regulations to prevent the construction of buildings along strike of seismically active faults, have been put in place (Azzaro et al., 2010). The lessons of the 1669 and 1693 disasters clearly did not influence planning in the 20th century with urbanization spreading across the lower southern flank of the volcano without regard to either volcanic hazard or the presence of seismically active faults.

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## References


Alexander, D., 1997. The study of Natural Disasters, 1977–1997: Some reflections on a changing field of knowledge. Disasters 21 (4), 284–304.

Alparone, S., Maiolino, V., Mostaccio, A., Scaltrito, A., Ursino, A., Barberi, G., D'Amico, S., Di Grazia, G., Giampiccolo, E., Musumeci, C., Scarfì, L., Zuccarello, L., 2015. Instrumental seismic catalogue of Mt. Etna earthquakes (Sicily, Italy): ten years (2000–2010) of instrumental recordings. Ann. Geophys. (in press).

Anon, 1669. "Some inquisitive English merchants". An answer to some inquiries concerning the eruptions of Mount Aetna, An. Philos. Trans. R. Soc. Lond. 14, 1028–1034.

Anon, 2004. A very brief history of Sicily. In: Anon (Ed.), Stanford Excavations at Monte Polizzo, Sicily, Stanford University, California (http://www.stanford.edu/group/mountpolizzo/HandbookTOC.htm).

Anon, 2013a. Terra di Colari: Art, Nature and Culture in the Province of Catania. Previca Regionale di Catania.

Anon, 2013b. Plagued by dear labour. The Economist Oct 21st 2013 (http://www.economist.com/blogs/freeexchange/2013/10/economic-history-1).

Anon, 2014a. 1693 Sicily earthquake. http://en.wikipedia.org/wiki/1693_Sicily_earthquake.

Anon, 2014b. Camporotondo Etneo. http://www.provincia.catania.it/servizi/sportelli_informativi/comuni/area_metropolitana/camporotondo/default.aspx.

Azzaro, R., 1999. Earthquake surface faulting at Mount Etna volcano (Sicily) and implications for active tectonics. J. Geodyn. 28, 193–213.

Azzaro, R., 2004. Seismicity and active tectonics in the Etna region: constraints for a seismotectonic model. In: Bonaccorso, A., Calvari, S., Coltelli, M., Del Negro, C., Falsaperla, S. (Eds.), Mt. Etna: volcano laboratory. American Geophysical Union. Geophysical monograph 143, pp. 205–220.

Azzaro, R., Barbano, M.S., 2000. Analysis of the seismicity of Southeastern Sicily: a proposed tectonic interpretation. Ann. Geofis. 43 (1), 171–188.

Azzaro, R., Castelli, V., 2013. L'eruzione etnea del 1669 nelle relazioni giornalistiche contemporanee. INGV, Le Nove Muse Editrice, Catania (232 pp.).

Azzaro, R., Castelli, V., 2015. Materials for a catalogue of Mt. Etna earthquakes from 1600 to 1831. Quaderni di Geofisica 123 (278 pp.).

Azzaro, R., Barbano, M.S., Moroni, A.M., Mucciarelli, M., Stucchi, M., 1999. The seismic history of Catania. J. Seismol. 3, 235–252.

Azzaro, R., Carocci, C.F., Maugeri, M., Torrisi, A., 2010. Microzonazione sismica del versante orientale dell'Etna. Studi di primo livello. Regione Siciliana, Dipartimento della Protezione Civile. Le Nove Muse Ed, Catania (184 pp.).

Azzaro, R., Branca, S., Gwinner, K., Coltelli, M., 2012. The volcano-tectonic map of Etna volcano, 1:100.000 scale: an integrated approach based on a morphotectonic analysis from high-resolution DEM constrained by geologic, active faulting and seismotectonic data. Ital. J. Geosci. 131 (1), 153–170.

Barbano, M.S., Rigano, R., Cappoloni, I., 2001a. The seismic history of Nicolosi (Catania, Italy). In: Glade, T., Albini, P., Francés, R. (Eds.), The use of historical data in natural hazards assessment. Kluwer Academic Publishers, Dordrecht, pp. 235–252.

Barbano, M.S., Rigano, R., Cosentino, M., Lombardo, G., 2001b. Seismic history and hazard in some localities of South-Eastern Sicily. Boll. Geofis. Teor. Appl. 42 (1–2), 107–120.

Behncke, B., Neri, M., Nagay, A., 2005. Lava flow hazard at Mount Etna (Italy): New data from a GIS-based study. In: Manga, M., Ventura, G. (Eds.), Kinematics and dynamics of lava flows. Geological Society of America Special Paper 396, pp. 189–208. http://dx.doi.org/10.1130/2005.2396(13).

Blunt, A., 1968. Sicilian Baroque. Weidenfeld & Nicolson, London.

Bonajutus, V., 1694. An account of the earthquake in Sicilia, on the ninth and eleventh of January 1693. Translated from an Italian letter wrote from Sicily by the Noble Vincentius Bonajutus, and communicated to the Royal Society by the learned Marcellus Malpighius physician to his present holiness. Philos. Trans. R. Soc. Lond. 10, 2–10.

Borelli, G.A., 1670. Historia et meteorologia incendii aetnaei anni 1669 (Reggio Calabria).

Boschi, E., Guidoboni, E., 2001. Catania, terremoti e lave: dal mondo antico alla fine del Novecento. INGV Roma, Bologna SGA, Compositori Ed.

Boschi, E., Ferrari, G., Gasperini, P., Guidoboni, E., Smriglio, G., Valensise, G., 1995. Catalogo dei forti terremoti in Italia dal 461 a.C. al 1980. ING-SGA, Ozzano Emilia (973 pp.).

Bottari, A., Corsanego, A. Lo, Giudice, E., 1985. Some problems on the MSK-scale application: regionalization of the scale and its field use. Boll. Geofis. Teor. Appl. 27 (108), 303–315.

Branca, S., Del Carlo, P., 2005. Types of eruptions of Etna volcano AD 1670–2003: implications for short-term eruptive behaviour. Bull. Volcanol. 67, 732–742.

Branca, S., De Beni, E., Proietti, C., 2013. The large and destructive 1669 AD eruptions at Etna volcano: reconstruction of the lava flow field evolution and effusion rate trend. Bull. Volcanol. 75, 694. http://dx.doi.org/10.1007/s00445-013-0695-5.

Brydone, P., 1773. A tour through Sicily and Malta. W. Strahan and T, Cadell, London.

Caruso, M., Perra, E., 1995. Per una storia della città di Belpasso. Annali del Barocco in Sicilia 2, 115–119.

Chester, D.K., 1993. Volcanoes and Society. Edward Arnold, London.

Chester, D.K., 1998. The Theodicy of Natural Disasters. Scott. J. Theol. 51 (4), 485–505.

Chester, D.K., Duncan, A.M., 2009. The Bible, theology and religious responses to historic and contemporary earthquakes and volcanic eruptions. Environ. Hazards 8, 1–29.

Chester, D.K., Duncan, A.M., Guest, J.E., Kilburn, C.R.J., 1985. Mount Etna: The Anatomy of a Volcano. Chapman and Hall, London.

Chester, D.K., Duncan, A.M., Dibben, C., Guest, J.E., Lister, P.H., 1999. Mascali, Mount Etna Region, Sicily: An example of fascist planning during and after the 1928 eruption. Nat. Hazards 19 (1), 29–46.

Chester, D.K., Duncan, A.M., Guest, J.E., 2005. Responses to eruptions of Etna from the Classical Period to 1900. In: Balmuth, M.S., Chester, D.K., Johnston, P.A. (Eds.), Cultural Responses to Volcanic LandscapeColloquia and Conference Papers 9. Archaeological Institute of America, Massachusetts, pp. 93–107.

Chester, D.K., Duncan, A.M., Dibben, C.R.J., 2008. The importance of religion in shaping volcanic risk perceptions in Italy, with special reference to Vesuvius and Etna. J. Volcanol. Geotherm. Res. 172, 216–228.

Chester, D.K., Duncan, A.M., James, P.A., 2010. Mount Etna, Sicily: Landscape evolution and hazard responses in the pre-industrial era. In: Martini, P., Chesworth, W., Panizza, M. (Eds.), Landscapes and Societies. Springer, Berlin, pp. 235–255.

Chester, D.K., Duncan, A.M., Sangster, H., 2012. Human responses to eruptions of Etna (Sicily) during the late-Pre-Industrial Era and their implications for present-day disaster planning. J. Volcanol. Geotherm. Res. 225–226, 65–80.

Chester, D.K., Duncan, A.M., Kilburn, C.R.J., Sangster, H., Solana, C., 2015. Human responses to the 1906 eruption of Vesuvius, southern Italy. J. Volcanol. Geotherm. Res. 296, 1–18.

CMTE Working Group, 2014. Catalogo Macrosismico dei Terremoti Etnei, 1832-2013. INGV, Catania (http://www3.ct.ingv.it/ufs/macro).

Condorelli, S., 2006. The reconstruction of Catania after the earthquake of 1693. Proceedings of Second International Congress On Construction History (Queens' College Cambridge) vol. 1. Short Run Press (799-815 pp.).

Condorelli, S., 2012. 'U tirrimotu ranni': Lectures du tremblement de terre de Sicile de 1693. Società de Storia Patria per la Sicilia Orientale, Catania.

D'Amico, S., Meroni, F., Sousa, M.L., Zonno, G., 2015. Building vulnerability and seismic risk analysis in the urban area of Mt. Etna volcano (Italy). Bull. Earthq. Eng. (in press).

Dato, G., 1983. La città di Catania. Forma e struttura. Officina Ed, Roma, pp. 1693–1833.

Demangeon, A., 1927. La géographie de l'habitat rurale. Ann. Geophys. 36, 1–23.

Dickie, J., 2000. Darkest Italy. The Nation and Stereotypes of the Mezzogiorno. Macmillan, London, pp. 1860–1900.

Dufour, L., Raymond, H., 1992. 1693. Catania: rinascita di una città. D. Sanfilippo Ed, Catania (308 pp.).

Dufour, L., Raymond, H., 1993. Dalla città ideale alla città reale. La ricostruzione di Avola. Ediprint, Siracusa, pp. 1693–1695 (155 pp.).

Dufour, L., Raymond, H., 1994. 1693. Val di Noto: la rinascita dopo il disastro. D. Sanfilippo Ed, Catania (316 pp.).

Duncan, A.M., Dibben, C., Chester, D.K., Guest, J.E., 1996. The 1928 eruption of Mount Etna, Sicily, and the destruction of the town of Mascali. Disasters 20 (1), 1–20.

Faccioli, E., Pessina, C., Calvi, G.M., Borzi, B., 1999. A study of damage scenarios for residential buildings in Catania city. J. Seismol. 3, 327–343.

Finley, M.I., Mack-Smith, D., Duggan, C.J.H., 1986. A History of Sicily. Chatto and Windus, London.

Gaillard, J.-C., 2007. Resilience of traditional societies in facing natural hazards. Disaster Prev. Manag. 16 (4), 522–544.

Giarrizzo, G., 1986. Catania (storia delle città italiane). Laterza, Roma-Bari.

Guidoboni, E., Ferrari, G., Mariotti, D., Comastri, A., Tarabusi, G., Valensise, G., 2007. CFTI4Med, catalogue of strong earthquakes in Italy (461 B.C.-1997) and Mediterranean area (760 B.C.-1500). INGV-SGA (http://storing.ingv.it/cfti4med/).

Guidoboni, E., Ciuccarelli, C., Mariotti, D., Comastri, A., Bianchi, M.G., 2014. L'Etna nella storia. Bonomia University Press, Bologna, Catalogo delle eruzioni dall'antichità alla fine del XVII secolo (1122 pp.).

Gutscher, M.A., Roger, J., Baptista, M.A., Mirando, J.M., Tinti, S., 2006. Source of the 1693 Catania earthquake and tsunami (southern Italy): new evidence from tsunami modelling of a locked subduction fault plane. Geophys. Res. Lett. 33, L08309. http://dx.doi.org/10.1029/2005GL025442.

Hyde, W.W., 1916. The volcanic history of Etna. Geogr. Rev. 1, 401–418.

James, P.A., Duncan, A.M., Chester, D.K., 2015. Development and spatial distribution of soils on an active volcano: Mt Etna, Sicily. Catena (in press).

Kelman, I., Mercer, J., Gaillard, J.C., 2012. Indigenous knowledge and disaster risk reduction. Geography 97 (1), 12–119.

King, R., 1973. Sicily. David and Charles, Newton Abbot.

King, R., Strachan, A., 1978. Sicilian agro-towns. Erdkunde 32, 110–123.

Ligresti, D., 1984. Sicilia moderna: le cite e gli uomimi. Guida editori, Napoli.

Ligresti, D., 1995. Catania e i suoi casali. Catania, CUECM (212 pp.).

Ligresti, D., 2000. Popolazione, insediamenti, territorio nella Sicilia moderna: 1505–1806. Catania, Amara (330 pp.).
Ligresti, D., 2002. Dinamiche Demografiche nelle Sicilia Moderna (1505–1806). Franco Angeli, Milano.
Luongo, G., Carlino, S., Cubellis, E., Delizia, I., Iannuzzi, R., Obrizzo, F., 2006. Il terremoto di Casamicciola del 1883: una ricostruzione mancata. Napoli 2006, 64.
Milone, F., 1960. Sicilia: La natura e l'uomo. Paulo Boringhieri, Torino.
Mulas, M., Andronico, D., Mundula, F., Cioni, R., 2012. The 1669 Monti Rossi eruption at Mt. Etna Volcano (Italy). Conferenza A. Rittmann, Nicolosi (Catania) 12/14 dicembre 2012, Miscellanea INGV, 15, p. 100 (2039–6651).
Naldi, G., Carus, R., Naldi, G., 2008. Terremoto Calabro Messinese. Instituto Nazionale di Geofisica e Vulcanologia. Alinari, Roma.
Nicotra, E., Viccaro, M., 2012. Unusual magma storage conditions at Mt. Etna (Southern Italy) as evidenced by plagioclase megacryst-bearing lavas: implications for the plumbing system geometry and summit caldera collapse. Bull. Volcanol. 74, 798–815.
Pagnano, G., 1992. Il disegno delle difese. L'eruzione del 1669 e il riassetto delle fortificazioni di Catania. Cuecm, Tip. Leone, Catania (224 pp.).
Pecora, A., 1968. Sicilia. Tipografico Editrice, Torinese.
Pereira, A.S., 2006. The Opportunity of a Disaster: The Economic Impact of the 1755 Lisbon Earthquake. Cherry Discussion Paper DP 03/06, Centre of Historical Economics and Related Research at York. University of York, UK.
Pereira, A.S., 2009. The Opportunity of a Disaster: The Economic Impact of the 1755 Lisbon Earthquake. J. Econ. Hist. 69 (2), 466–499.
Polonia, A., Torelli, L., Gasperini, L., Mussoni, P., 2012. Active faults and historical earthquakes in the Messina Straits area (Ionian Sea). Nat. Hazards Earth Syst. Sci. 12, 2311–2328.
Puleo, T.J., 2010. Baroque disruptions in Val di Noto, Sicily. Geogr. Rev. 100 (4), 476–493.
Recupero, G., 1815. Storia naturale e generale dell'Etna. Dalla Stamperia della Regia Università degli Studia, Catania.
Rodriguez de la Torre, F., 1995. Spanish sources concerning the 1693 earthquake in Sicily. Ann. Geofis. 38 (5–6), 523–535.
Rodwell, G.F., 1878. Etna: A History of the Mountain and of its eruptions. Kegan Paul, London.
Rovida, A., Camassi, R., Gasperini, P., Stucchi, M., 2011. CPTI11, the 2011 version of the Parametric Catalogue of Italian Earthquakes. Milano, Bologna http://dx.doi.org/10.6092/INGV.IT-CPTI11 (http://emidius.mi.ingv.it/CPTI).
Sangster, H., 2013. Hazard responses in the pre-industrial era: vulnerability and resilience of traditional societies to volcanic disasters. Unpublished Ph.D. thesis, University of Liverpool.
Scalisi, L., 2013. Per Riparar L'Incendio. Le politiche dell'emergenza da Perù al Mediterraneo. Huaynaputina 1600 – Vesuvio 1631 – Etna 1669. Domenico San Filippo Editore, Catania.
Scarth, A., 1999. Vulcan's fury: Man against the volcano. Yale University Press, New Haven and London.
Tanguy, J.C., Condomines, M., Le Goff, M., Chillemi, V., La Delfa, S., Patanè, G., 2007. Mount Etna eruptions of the last 2,750 years: revised chronology and location through archeomagnetic and $^{226}Ra$-$^{230}Th$ dating. Bull. Volcanol. 70, 55–83.
Tinti, S., Tonini, R., 2013. The UBO-TSUFD tsunami inundation model: validation and application to a tsunami case study focused on the city of Catania, Italy. Nat. Hazards Earth Syst. Sci. 13, 1795–1816.
Tinti, S., Armigliato, A., Bortolucci, E., 2001. Contribution of tsunami data analysis to constrain the seismic source: the case of the 1693 eastern Sicily earthquake. J. Seismol. 5, 41–61.
Tobriner, S., 1982. The Genesis of Noto, an Eighteenth-century Sicilian City. A. Zwemmer Ltd., London, University of California Press, Berkeley-Los Angeles, California (252 pp.).
Visini, F., De Nardis, R., Barbano, M.S., Lavecchia, G., 2009. Testing the seismogenic sources of the January 11th 1693 Sicilian earthquake (Io X/XI): insights from macroseismic field simulations. Ital. J. Geosci. (Boll.Soc.Geol.It.) 128 (1), 147–156.
Walker, G.P.L., Huntingdon, A.T., Walker, G.P.L., Argent, C.R., 1975. The strombolian scoria fall deposits of 1669 and 1974. United Kingdom Research on Mount Etna 1974. The Royal Society London, pp. 24–26.
White, G.F., 1974. Natural hazards research: concepts, methods and policy implications. In: White, G.F. (Ed.), Natural Hazards: Local, National. Global. Oxford University Press, New York, pp. 3–16.
Earl ofWinchilsea, 1669. A true and exact relation of the Late prodigious earthquake and Eruption of Mount Ætna, Or Monte-Gibello; MONTE-GIBELLO; as it came in a letter written to His majesty from Naples. Together with a more particular narrative of the same, as it is collected out of several relations sent from Catania. Newcomb, London (Lampeter Digital Edition).