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A FORESHOCK-MAINSHOCK PAIR: THE 9 JANUARY (MW6.1) - 11 JANUARY (MW7.3) 1693 EARTHQUAKES CASE (SOUTHEASTERN SICILY). PART I. A REAPPRAISAL OF THE SEISMIC SEQUENCE

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In the past, south-eastern Sicily was affected by strong earthquakes such as the 1169, 1542 and 1693 events, with intensity Io up to XI (MCS) and magnitude Mw up to 7.3 (Rovida *et al.*, 2016).

Our study focuses on the area of maximum damage of the 1693 foreshock-mainshock pair (9 and 11 January, Mw≈6.1 and Mw≈7.3, respectively). During this sequence, numerous secondary effects (liquefaction, landslides, fractures and ruptures), described by historical accounts, caused important landscape modifications in the eastern side of south-eastern Sicily. These effects are poorly considered in the reconstruction of the event seismic sources, which are affected by uncertainties and speculation. The ambiguity of the macroseismic field is mainly due to the vicinity to the sea and to the fact that damage of the main shock arise from the summation of the two shocks. Furthermore, accounts report exhaustive descriptions only for the second event (January 11). Consequently, the seismogenic sources of the 1693 foreshock-mainshock are still poorly constrained and several source models where proposed in literature by the inversion of the macroseimic field, often with significant differences (e.g. Sirovich and

Pettenati, 2001; Barbano and Rigano, 2001). Furthermore, given the absence of clear evidence of surface faulting and relevant faults in the area of maximum effects, various Authors proposed several faults located nearby as sources of these earthquakes (DISS Working Group, 2018 and references therein).

In order to contribute to the debate, we performed a revision of the macroseismic data of the 1693 shocks by using data retrieved from the CFTI5Med catalogue (Guidoboni *et al.*, 2018) and recomputed the seismic sources by using the boxer method (Gasperini *et al.*, 1999). In summary, we reanalysed historical reports and reassessed intensities by using the European Macroseismic Scale (Grüntal, 1998), localized some of the more than 1800 aftershocks that contribute to the destruction of eastern Sicily, and mapped in detail environmental effects, after their careful classification.

The January 9 foreshock is usually described in the historical sources along with the main shock of January 11. Only few accounts report detailed effects for some localities. Given the heavy damage and fatalities that were caused in some of them (Table 1), it is likely that in near localities there were damage as well. Therefore, the macroseismic field is likely incomplete (Fig. 1a). The shock mainly damaged the eastern side of Hyblean Plateau and was felt in Palermo, Messina and in the Malta Islands.

Tab. 1 - Localities for which historical sources report victims caused by the 9 January foreshock.

Locality	IEMS	Fatalities	Historical Sources
Augusta	8-9	200	AGS, 1693
Avola Vecchia	8-9	500	Dell'Arte, 1699
Noto Antica	8-9	200	Tortora, 1712
Giarratana Vecchia	8	many	Dell'Agli, 1886
Siracusa	7-8	3 + 100*	Memoriale, ms 1698
Palazzolo Acreide	7-8	mortality of people	ACMPA, 1693
Catania	8	10	Amico, XVII cent.
Lentini	8-9	4	Burgos, 1693
Melilli	8-9	Some	ACMM, 1693
Brucoli	7-8	4	AGS,1693
Vizzini	8	mortality of people	Boccone, 1687
total		More than 1021	

* in the countryside

The January 11 earthquake was undoubtedly the largest shock of the 1693 sequence, which continued for more than two years (e.g. Boccone, 1697). It nearly destroyed about forty towns in the area between Catania, Siracusa and Ragusa, most of them already damaged by the January 9 shock, and more or less damaged most of the Sicilian towns and villages as far as Messina, Palermo, and the Maltese Islands. It was felt in northern Calabria, along the Africa coast and probably also in Greece.

The wide extension of the damaged area, the great amount of victims (more than 60000 in total), the numerous environmental effects in southeastern Sicily, make it one of the most destructive events in the Italian seismic history. The January 11 shock generated a strong tsunami that hit the Ionian coasts of Sicily, from the Messina Straits to the southern coast and, according to some coeval sources as far as the Malta Islands (De Soldanis, 1746).

The new macroseismic field (Fig. 1b) shows few differences with respect to the one available in CFTI5Med (Guidoboni *et al.*, 2018). The key changes concern the intensity assessment in some localities. Indeed, we selected to assess the same intensity to all the localities with the

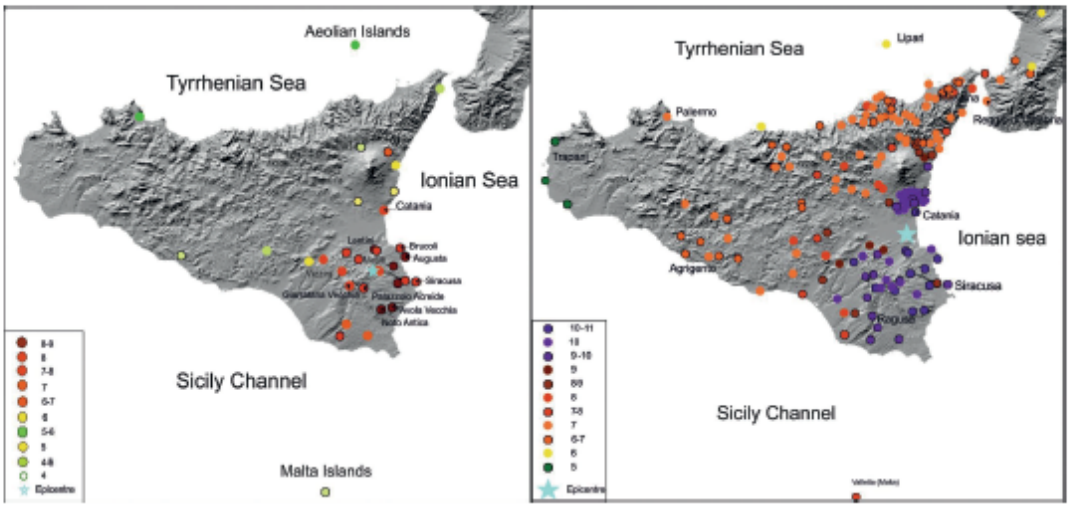

Fig. 1 - Left: the January 9 foreshock. In the reported localities there were fatalities (see table 1). Right: the January 11 January foreshock. Intensity estimated by using EMS-98 scale.

similar description. Furthermore, since building number and vulnerability are unknown and we cannot estimate the correct value according to the EMS-98, we assigned 10-11 instead of 11 MCS in towns with total destruction, and 10 when the accounts report that some buildings did not collapse. This uncertain assessment takes also into account the cumulated effects of the previous strong shock.

Through the revision of the macroseismic data of the 1693 main shocks, we obtained that the 9 January earthquake source is located near Sortino (Fig. 1a), adjacent to the epicenter reported by the CPTI5 catalogue (Rovida *et al.*, 2016). On the other hand, the source of the 11 January earthquake seems to be located northward, compared to literature data. Indeed, the assessment of I = 10-11 rather than I = 11 implies a significant change in the earthquake location. Using CFTI5Med data the epicenter is constrained by only the five points of I = 11, and it is located near the 9 January shock, whereas using our data location is evaluated by using all points of I = X and I = X-XI and is located in the coastal area south of Catania (Fig. 1b). The location of the 11 January shock northernmost with respect to the 9 January shock, as already proposed by Azzaro and Barbano (2000) and Barbano and Rigano (2001), is also supported by the destruction of the village located north of Catania that were not damaged by the 9 January shock. However, cumulative damage effects bias the macroseismic field of the main event. Therefore, considering that the 11 January was followed by a strong tsunami, its source could be located off shore.

The destruction followed by the 11 January shock makes difficult to estimate intensity and epicenters of the thousands of aftershocks that followed the events. Only few sources report day, time and effects of these shocks and most of them were not written in the area of destruction, where survivors were busy cleaning up debris, burying wounded and dead and getting water and food.

In the CPTI5 catalogue are recorded ten events, most of them retrieved from Boschi and Guidoboni (2001). We estimated epicenters of some of the strongest shocks for which in the historical sources are reported at least four localities (Fig. 3a). The quality of location and intensities values is poor because the estimation of damage for almost completely destroyed sites is difficult.

A lot of historical accounts (e.g. Boccone, 1697; Bottone, 1718; Bonaiuti, 1793) report the numerous and widespread seismogeological effects, such as landslides, damming, liquefactions, ground deformations and hydrological anomalies mainly caused by the main shocks. The

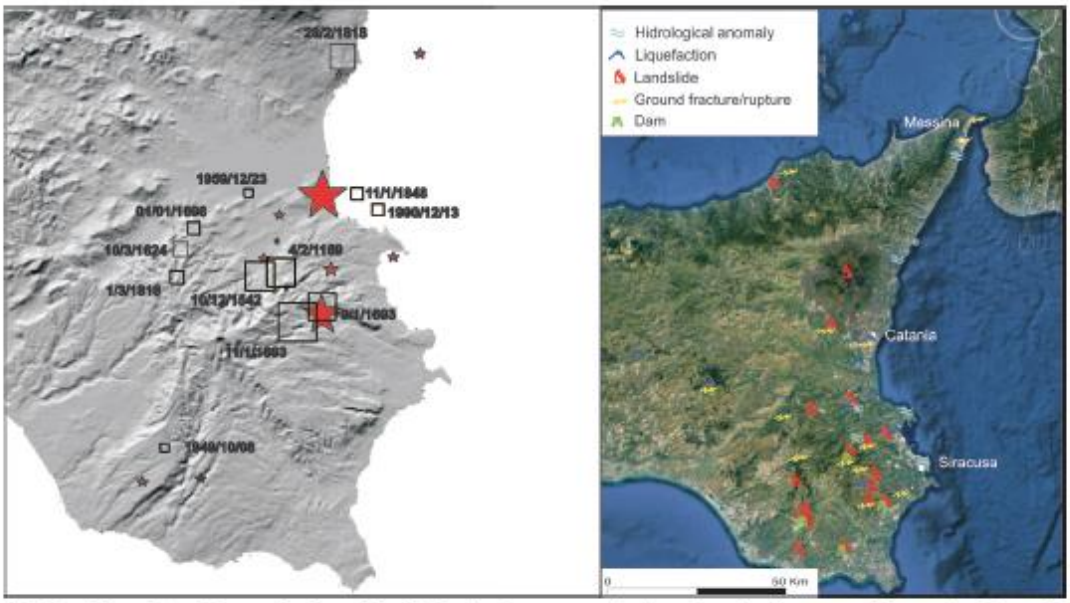

Fig. 2 - A) Location of some shocks of the 1693 seismic sequence (red stars) and epicenters of the earthquakes with Mw > 5.1 from CPT15 catalogue (Rovida *et al*., 2016). B) Detailed relocation of the 1693 environmental effects.

detailed relocation of the environmental effects (Fig. 2b) shows that most of them mainly occurred in the sector embracing the eastern Hyblean area and the Catania plain, suggesting that the sources of the 1693 earthquakes are located in this area.

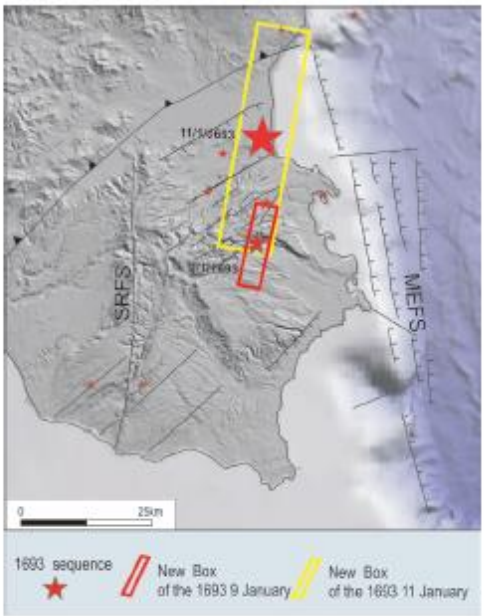

Fig. 3 - Main faults in southestern Sicily; inferred epicentres of 1693 seismic sequence; the rectangles represent the surfaces projection of the faults obtained by using the Gasperini *et al*. (1999) method for the foreshock-mainshock pair.

We used the new macroseismic intensity data to assess location, physical dimensions, and orientation of the seismic sources of foreshock-mainshock pair (Fig. 3), by using the Gasperini et al. (1999) method.

With respect to the CPTI15 catalogue we obtained slight small values of the equivalent magnitude, Mw = 6.1 for the foreshock and Mw = 7.1 for the main shock, respectively.

The main difference with respect to previous studies regards the modelling of the seismogenic sources, considered separately for the two main shocks. Both sources are oriented NNE-SSW, suggesting that a fault with this orientation ruptured, enucleating south near Sortino at first and then northwards in the Catania Plain or offshore.

Epicentres of historical earthquakes, maximum damage of the foreshock-mainshock pair, aftershocks of the 1693 sequence, maximum frequency of environmental effects and source models from macroseismic intensity data are all aligned along a NNE-SSW direction, suggesting that the seismogenic source should have been a fault with this orientation located in the eastern

Hyblean sector. With the aim of investigating the fault responsible of the 1693 seismic sequence, we performed a multidisciplinary investigation in the area of the most numerous and relevant environmental phenomena and damage. This mainly consists of geological and geomorphological studies and morphometric analysis of four rivers flowing in the area (Pirrotta and Barbano, 2018 this volume).

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