Earthquake sources and seismic hazard in Southeastern Sicily

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Abstract
A study of some earthquakes ($M > 5.3$) affecting Southeastern Sicily was performed to define their seismic sources and to estimate seismic hazard in the region. An analysis of historical reports allowed us to reassess intensities of the 1542, 1693, 1818, 1848 and 1990 earthquakes by using the new European Macroseismic Scale '98. The new intensity data were used to define parameters and the orientation of seismic sources. The sources obtained were compared with the ones computed using the MCS intensities retrieved from the *Catalogue of Strong Italian Earthquakes*. The adopted procedure gives results that are statistically significant, but both the epicentre location and source azimuth, in some cases, are strongly affected by the azimuthal gap in the intensity distribution. This is evident mainly for the 1693 January earthquakes. For these earthquakes the macroseismic data uncertainty gives significantly different solutions, and does not allow the events to be associated with known active faults. By handling the new estimated intensity data and using the site seismic histories, the seismic hazard for some localities was calculated. The highest probability of occurrence, for destructive events ($I = 10$), was obtained in the area between Catania, Lentini and Augusta, suggesting that the seismogenic sources are located near the Ionian coast.

Key words *historical seismicity – source parameters – seismic hazard – SE Sicily*

1. Introduction

The seismic source definition in Southeastern Sicily is very much a debated problem. Although several recent papers (*e.g.*, Monaco *et al.*, 1997; Bianca *et al.*, 1999; Sirovich and Pettenati, 1999; Azzaro and Barbano, 2000) have tackled the subject, there are not enough elements to accurately define seismogenic structures. This is due both to the lack of clear and unquestionable surface faulting evidence and to the very poor number of instrumentally recorded high magnitude earthquakes. Only recently has a local seismic network been installed in the area, available location algorithms do not allow accurate location of small magnitude earthquakes and the very few focal mechanisms are not reliable (*e.g.*, Scarfì *et al.*, 2001), so that detecting active tectonic structures from these data is not yet an easy task. However, 1986-1995 instrumental data (Salvi *et al.*, 1996) show events more frequently occurring along the eastern coastal sector, where the 1990 earthquake $M_s = 5.3$ also took place (Amato *et al.*, 1995). Evidence of surface faulting was found on Mt. Etna, to the north of the study area (*e.g.*, Azzaro, 1999; Azzaro *et al.*, 2000a,b), but related to very shallow and moderate earthquakes in an active volcanic zone.

Moreover, several problems arise when the historical macroseismic data have to be interpreted. A study of the most significant earthquakes ($M > 5.3$) which affected SE Sicily was been performed to acquire further elements useful to determine seismic sources and to assess

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seismic hazard in the region. The analysis and critical review of historical sources, quoted mainly in the *Catalogue of Strong Italian Earthquakes* (CFTI, Boschi *et al.*, 1995, 1997, 2000) and in DOM4.1 (Monachesi and Stucchi, 1998), allowed us to reassess intensities using the new European Macroseismic Scale (EMS-98, Grünthal, 1998). The new intensity data have been used to define parameters and orientation of seismic sources according to the methodology described by Gasperini *et al.* (1999). The same data have also been employed to evaluate seismic hazard with the procedure proposed by Magri *et al.* (1994) who utilise seismic site catalogues.

2. Intensity assessment

The inadequate and generic information reported in the historical sources concerning the earthquake effects, often does not allow intensity to be assessed correctly, especially when modern macroseimic scales are adopted. Indeed, in order to use such scales, we need to know building types, damage grade and the number of damaged buildings (Grünthal, 1998), for a good intensity assessment. To take into account macroseismic data uncertainty, intensity ranges (*e.g.*, 9-10) were often assigned. Moreover, the estimates were made using a sort of «interpretation coherence» of the information reported in historical sources. Reports for different localities were, in fact, compared and the same intensity was assigned to the localities showing similar descriptions. Although data interpreted with different scales should not be directly compared, we have not generally detected significant variations with respect to the estimate reported in the CFTI using the MCS scale. In the following, the studied earthquakes are briefly described with particular emphasis on new information.

2.1. *The December 10, 1542 earthquake*

On 1542 December 10 the main shock of a seismic period that started *«die ultimo mensis novembris»* (the last day of November) and lasted 40 days (Chronaca Siciliana, 16th century), occurred. Damage caused by the 1542 earthquakes extended from the Ionian coast – where several localities (*e.g.*, Sortino, Melilli, Lentini) were nearly totally destroyed – as far as Caltagirone and was also strongly felt in almost all the island (Li Gresti, 1992; Boschi *et al.*, 1995, 2000). The total number of deaths is unknown but it exceeded 147. The detailed information about damage, reported in the Chronaca Siciliana (16th century), allowed us to improve the intensity estimate in many localities such as, for instance, in Mineo where *«Si rovinarono grandissima quantità di casi e palazzi e la metà del castello, morirono circa trenta person»* (a lot of houses and palaces and half of the castle were ruined, about 30 people died). This damage description can be ascribed to an intensity 9 EMS-98. With respect to CFTI, new information regarding damage in Ragusa (Garofalo, 1980) was found. The differences detected in the intensity evaluation for Occhiolà (Fazello, 1560), Scicli (ASR, 1542a,b) and Vizzini (Chronaca Siciliana, 16th century) are reported in table I.

2.2. *The January 9, 1693 earthquake*

This earthquake belongs to a long seismic period during which many localities in Eastern Sicily were destroyed and usually it is described together with the mainshock of January 11 (AGdS, 1693; Burgos, 1693). The January 9 shock caused heavy damage in many localities of SE Sicily. Since new sources were found (Boschi *et al.*, 2000), some localities (Spaccaforno, Palazzolo, Scicli, and Malta), most of them with damage ($I \geq 7$), have been added (table II) to the previous macroseimic field (Boschi *et al.*, 1997). Despite such improvements it still appears to be incomplete. According to a Memorial of the 1693 earthquakes (Franzò, 1693), in Spaccaforno (Ispica) the earthquake *«lesionò e aprì le fabbriche»* (cracked and opened the walls). As regards the town of Palazzolo, an historical chronicle (ACMP, 1693) preserved in the archive of the mother church, describes the event so: *«molto conquasso delle fabbriche e mortalità di gente»* (buildings shattered with mortality of people). Damage in Sci-

Table I. The December 10, 1542 earthquake. Localities and intensities according to CFTI and this work.

Locality	*I* (MCS)	*I* (EMS-98)	Locality	*I* (MCS)	*I* (EMS-98)
Melilli	10	10	Syracuse	8	8
Occhiolà (Grammichele)	10	9-10	Augusta	8	8
Lentini	9-10	9-10	Catania	8	8
Sortino	9	9	Licodia Eubea	8	8
Mineo	8-9	9	Militello	8	8
Avola Vecchia	8-9	8-9	Modica	8	8
Buccheri	8-9	8-9	Scicli	8	7-8
Ferla	8-9	8-9	Malta	7	7
Giarratana V.	8-9	8-9	Agrigento	6-7	6-7
Monterosso Almo	8-9	8-9	Licata	6-7	6-7
Palazzolo Acreide	8-9	8-9	Palermo	5	5
Vizzini	8	8-9	Trapani	F	4-5
Caltagirone	8	8	Sciacca	F	4
Noto Antica	8	8	Ragusa	NC	7-8

Table II. The January 9, 1693 earthquake. Localities and intensities according to CFTI and this work.

Locality	*I* (MCS)	*I* (EMS-98)	Locality	*I* (MCS)	*I* (EMS-98)
Augusta	8-9	9	Militello	7	7-8
Avola Vecchia	8-9	8-9	Syracuse	7	7-8
Floridia	8-9	8-9	Spaccaforno (Ispica)	7	7
Melilli	8-9	8-9	Linguaglossa	6-7	5-6
Noto Antica	8-9	8-9	Acireale	5-6	5
Lentini	8	8-9	Caltagirone	5-6	5-6
Catania	8	8	Mascali	5-6	5-6
Francofonte	8	8	Paternò	5-6	5
Giarratana	–	8	Messina	5	5
Sortino	8	8	Randazzo	5	4-5
Vizzini	8	8	Malta	5	4-5
Scicli	8	7-8	Agrigento	4-5	4-5
Occhiolà (Grammichele)	7-8	8	Lipari	4	4
Brucoli	7-8	7-8	Palermo	4	4
Palazzolo	7-8	7	Monteleone (V. Valenzia)	4	4
Belvedere	7	7-8			

cli is reported in a manuscript of Campis (1694), which gives information on partial collapses and victims. New information about Giarratana, «*alcune case crollarono, restando schiacciate alquante vittime*» (some houses collapsed, crushing several people) is reported in Dell'Agli (1886). Information describing that this shock was felt in Malta has also been discovered in an unpublished French report (De Mattei, 1957).

2.3. *January 11, 1693 earthquake*

The January 11 earthquake produced the largest known seismic catastrophe in Eastern Sicily's history. Although many coeval reports and recent studies are available, the interpretation of this earthquake is difficult because it affected a large coastal area and was preceded by a strong foreshock. It totally destroyed about forty towns in the area between Catania, Syracuse and Ragusa, already damaged by the January 9 shock, and it heavily damaged all the other localities as far as Messina, the interior of Sicily and Malta.

As regards this event, differences are detected only in the intensity evaluation, whereas the number of localities forming the macroseismic field is still the same with respect to the one available in CFTI. The main change, although apparently not relevant, concerns the intensity assessment for Floridia, Melilli, Occhiolà (Grammichele) and Sortino (fig. 1). For these locali-

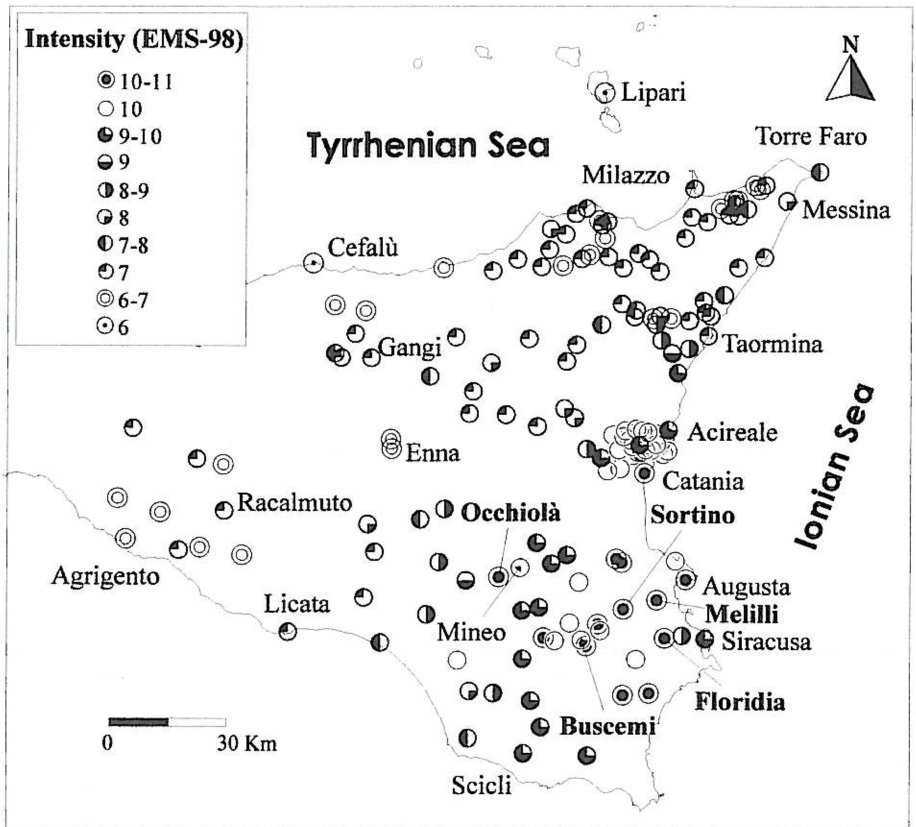

Fig. 1. Intensity map of the January 11, 1693 earthquake. This study.

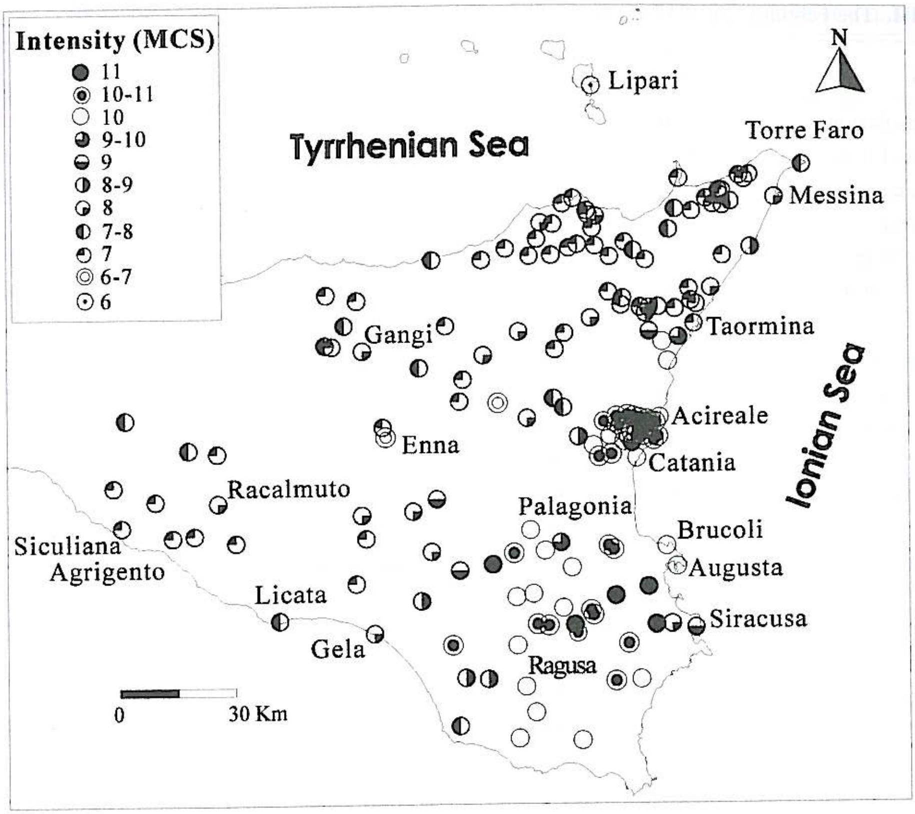

Fig. 2. Intensity map of the January 11, 1693 earthquake. Data from CFTI.

ties the historical sources report *«distruzione totale»* (total destruction), but building typology and vulnerability are unknown, so it is difficult to estimate the exact intensity value according to EMS-98. For such reasons, intensity 10-11 has been assigned instead of the 11 MCS (fig. 2). The same intensity value has also been assigned to all those localities having the same damage description. This uncertain assessment should also take into account the possible overestimation due to the combined effects of the January 9 shock damage. The assessment of 10-11 rather than 11 implies a considerable change in the earthquake location as will be discussed later. Intensity 10 EMS-98 has been assigned to Buscemi and to many other localities, mainly located in the Etna area, since historical sources do not report total destruction but that some buildings *«rimasero in piedi»* (remained standing) (*e.g.*, Boccone, 1697).

2.4. *February 20, 1818 earthquake*

The 1818 earthquake caused damage and ruin in many localities of the Etna eastern flank and considerable effects from Catania as far as the Tyrrhenian coast. It was also felt throughout Sicily. This pattern is different from those of typical low magnitude-shallow depth Etna events which usually damage narrow zones (Azzaro and Barbano, 2000). Being a crustal regional event, it is important for the hazard estimation of the area. This earthquake also induced secondary

Table III. The February 20, 1818 earthquake. Localities used to estimate azimuth.

Locality	*I* (MCS)	*I* (EMS-98)	Locality	*I* (MCS)	*I* (EMS-98)
Aci Consolazione	9-10	9-10	Linguaglossa	8	8
Aci Santa Lucia	9-10	9-10	Macchia	8	7-8
Aci Catena	9	9-10	Malvagna	8	7-8
Aci Platani	9	9	Mascali	8	8
Aci San Filippo	9	9	Mascalucia	8	8-9
Aci Sant'Antonio	9	9	Massa Annunziata	8	8
Maletto	8-9	8-9	Monacella	8	7-8
San Gregorio	8-9	8-9	Milo	8	7-8
Trecastagni	8-9	8	Nunziata	8	7-8
Tremestieri Etneo	8-9	8-9	Pedara	8	7-8
Valverde	8-9	8	Piedimonte Etneo	8	8-9
Aci Bonaccorsi	8	8-9	Pisano	8	8
Acireale	8	8	Randazzo	8	7-8
Bongiardo	8	7-8	Regalbuto	8	8
Borrello	8	8	San Giovanni G.	8	8-9
Calatabiano	8	7-8	San Leonardello	8	7-8
Camporotondo E.	8	8	S. Maria La Strada	8	7-8
Castiglione di S.	8	7-8	Sant'Agata Li Battiati	8	8
Centuripe	8	7-8	Sant'Alfio	8	7-8
Dagala	8	7-8	Viagrande	8	8
Fiumefreddo di S.	8	7-8	Zafferana Etnea	8	8
Gravina di Catania	8	8	Belfiore	–	7-8
Carminello	–	7-8	San Nicolò	–	7-8

surface faulting along different trending faults (*i.e.* Acicatena, Trecastagni and Pozzillo) located on the Mt. Etna eastern flank (Azzaro, 1999).

The rereading of a source quoted in the CFTI allowed us to insert the villages of Carminello, Belfiore and S. Nicolò, located in the Etna area close to Acireale, in the list of the damaged localities (table III). Further information on this event has been found through the critical review of the sources describing another event occurring in March 1 and located in the Vizzini-Licodia area. It was possible in fact, by analysing the effects reported for several Hyblean localities (Lentini, Militello, Francofonte, Vizzini, Licodia Eubea, Mirabella, Ramacca, and Palagonia) to collect information of slight damage ($I \leq$ VI-VII), due to the February 20 shock. Despite such improvements, the macroseismic field of this earthquake is incomplete towards the west in the Etna Volcano area and towards the south in the Catania plain where there are no inhabited places.

2.5. *The January 11, 1848 earthquakes*

This was the most recent shock producing relevant damage in Eastern Sicily, especially in Augusta, where two thirds of the buildings collapsed and 30 people died (Ferruggia Russo, 1852). Catania suffered major and widespread damage (Cristoadoro, 1848). In Syracuse and Noto a few buildings suffered cracks and partial

Table IV. The January 11, 1848 earthquake. Localities and intensities according to Boschi and Guidoboni (2001) and this work.

Locality	*I* (MCS)	*I* (EMS-98)	Locality	*I* (MCS)	*I* (EMS-98)
Augusta	8-9	8-9	Comiso	5-6	5
Catania	7	7-8	Ferla	5-6	5
Dagala	7	6-7	Floridia	5-6	5
Macchia	7	6-7	Ispica	5-6	5
Mascalucia	7	6-7	Melilli	5-6	5
Massa Annunziata	7	6-7	Modica	5-6	5
Moscarello	7	6-7	Palazzolo Acreide	5-6	5
Motta Sant'Anastasia	7	6-7	Priolo Gargallo	5-6	5
Nicolosi	7	6-7	Solarino	5-6	5
Noto	7	6-7	Sortino	5-6	5
Pedara	7	6-7	Riposto	5	5
Syracuse	7	6-7	Messina	4-5	4
Aci Castello	6	6	Acate	4	4
Acireale	6	6	Chiaramonte Gulfi	4	4
Mineo	6	5	Pachino	4	4
S. Giovanni La Punta	6	6	Ragusa	4	4
Viagrande	6	6	Rosolini	4	4
Avola	5-6	5	Scicli	4	4
Belvedere	5-6	5	Vittoria	4	4
Canicattini Bagni	5-6	5	Caltanissetta	3	3
Cassaro	5-6	5			

collapse. The macroseismic field of this earthquake has been improved (table IV) with respect to that of DOM4.1 using the new sources and further information reported in Boschi and Guidoboni (2001). Some towns and villages, located in the Etna area, such as Viagrande, Acireale and Acicastello, had slight damage (Ferruggia Russo, 1852). Mascalucia, Nicolosi and Pedara suffered relatively heavier damage, but these localities had already been damaged during the 1832 November shock (Azzaro *et al.*, 2000a). Moreover, in these localities and in Dagala, Macchia and Moscarello the damage was aggravated by the poor quality of buildings made of dry stonewalls. Therefore in these localities intensity VI-VII EMS-98 has been assigned.

2.6. *December 13, 1990*

The 1990 earthquake is the only significant event of the Hyblean region for which recent seismological data are available. Although of moderate magnitude ($M_s = 5.3$) it caused deaths and widespread damage in Augusta and in the Lentini area (Boschi *et al.*, 1997, 2000). The epicentre of such a shock was instrumentally located in the Ionian Sea a few kilometres offshore from Brucoli (Amato *et al.*, 1995).

The location of this event is rather modified although only small changes have been made in the intensity values (table V), as will be hereafter shown.

Table V. The December 13, 1990 earthquake. Localities used to estimate azimuth.

Locality	I (MCS)	I (EMS-98)
Augusta	7-8	7-8
Carlentini	7	7
Lentini	7	7
Melilli	7	7
Militello	7	6-7
Mineo	7	6-7
Stazione di Brucoli	6-7	7

3. Source parameter definition

Using the macroseismic intensities estimated in this study, the location, source dimensions and orientation of the earthquakes, have been computed according to the procedure proposed by Gasperini *et al.* (1999). They based the model on the assumption that the elongation of the associated damage pattern reflects the source orientation of significant earthquakes. The authors represent the source as an oriented rectangle, the length and width of which are obtained from the moment magnitude, through empirical relationships. Table VI compares the source parameters obtained using EMS-98 intensities with the ones computed using MCS intensities retrieved from the CFTI. The adopted methodology has generally given statistically significant results, and highlights how both epicentre locations and source orientations are strongly affected by intensity distribution.

The comparison shows that the greatest changes in the epicentre location and source dimension are obtained for the January 11, 1693 shock (fig. 3).

The epicentre is obtained through the Gasperini and Ferrari (1995, 1997) procedure which locates the shock using the localities with the maximum observed intensities. This implies that, if MCS data are considered, the epicentre is constrained by only 5 points of $I = 11$ and located in the Mt. Iblei area, whereas if

Table VI. List of the studied earthquakes. * Parameters evaluated using intensities obtained in the present study; ⁺ parameters evaluated using intensity data from CFTI and Boschi and Guidoboni (2001). N_{Tot} is the total number of data available for the given earthquake; N_{Ep} is the number of data used for computing the epicentre; I_0 is the epicentral intensity; N_R the number of radii used to compute M_e; M_e is the equivalent moment magnitude inferred using the distribution of felt intensities, according to Gasperini and Ferrari (1997). N_{Az} is the number of data used for computing the source azimuth. The table also reports the standard deviation of the computed azimuths and the significance levels of the Rayleigh and Kuiper tests.

Date	Epicentre Lat.	Epicentre Long.	N_{Tot}	N_{Ep}	I_0	N_R	M_e	Fault length (km)	Fault width (km)	N_{Az}	Azimuth (deg)	Rayleigh test	Kuiper test
*1542/12/10	37.227	14.903	28	5	9-10	2	6.8	36.9	14.6	12	88 ± 41	Uniform	< 0.01
⁺1542/12/10	37.214	14.942	27	4	10	1	7.0	51.4	17.4	11	92 ± 37	Uniform	< 0.01
*1693/01/09	37.169	15.005	31	12	8-9	4	6.0	12.9	8.2	6	157 ± 70	Uniform	< 0.1
⁺1693/01/09	37.140	15.033	30	11	8-9	4	6.1	15.1	9.0	5	13 ± 118	Uniform	< 0.1
*1693/01/11	37.415	15.049	179	47	10-11	5	7.1	54.1	17.9	47	11 ± 6	< 0.01	< 0.01
⁺1693/01/11	37.139	15.012	179	5	11	5	7.4	81.0	22.3	63	12 ± 10	< 0.01	< 0.01
*1818/02/20	37.602	15.141	134	6	9-10	5	6.3	19.6	10.3	29	61 ± 36	< 0.1	< 0.01
⁺1818/02/20	37.602	15.141	120	6	9-10	5	6.4	20.7	10.6	43	10 ± 31	< 0.05	< 0.01
*1848/01/11	37.366	15.154	41	2	7-8	4	5.4	5.8	5.3	16	166 ± 6	< 0.01	< 0.01
⁺1848/01/11	37.541	15.094	41	12	7-8	4	5.5	6.4	5.6	17	175 ± 16	< 0.01	< 0.01
*1990/12/13	37.259	15.110	246	5	7-8	7	5.7	8.1	6.4	5	105 ± 19	< 0.01	Uniform
⁺1990/12/13	37.261	14.983	246	6	7	6	5.5	6.2	5.5	6	94 ± 21	< 0.05	Uniform

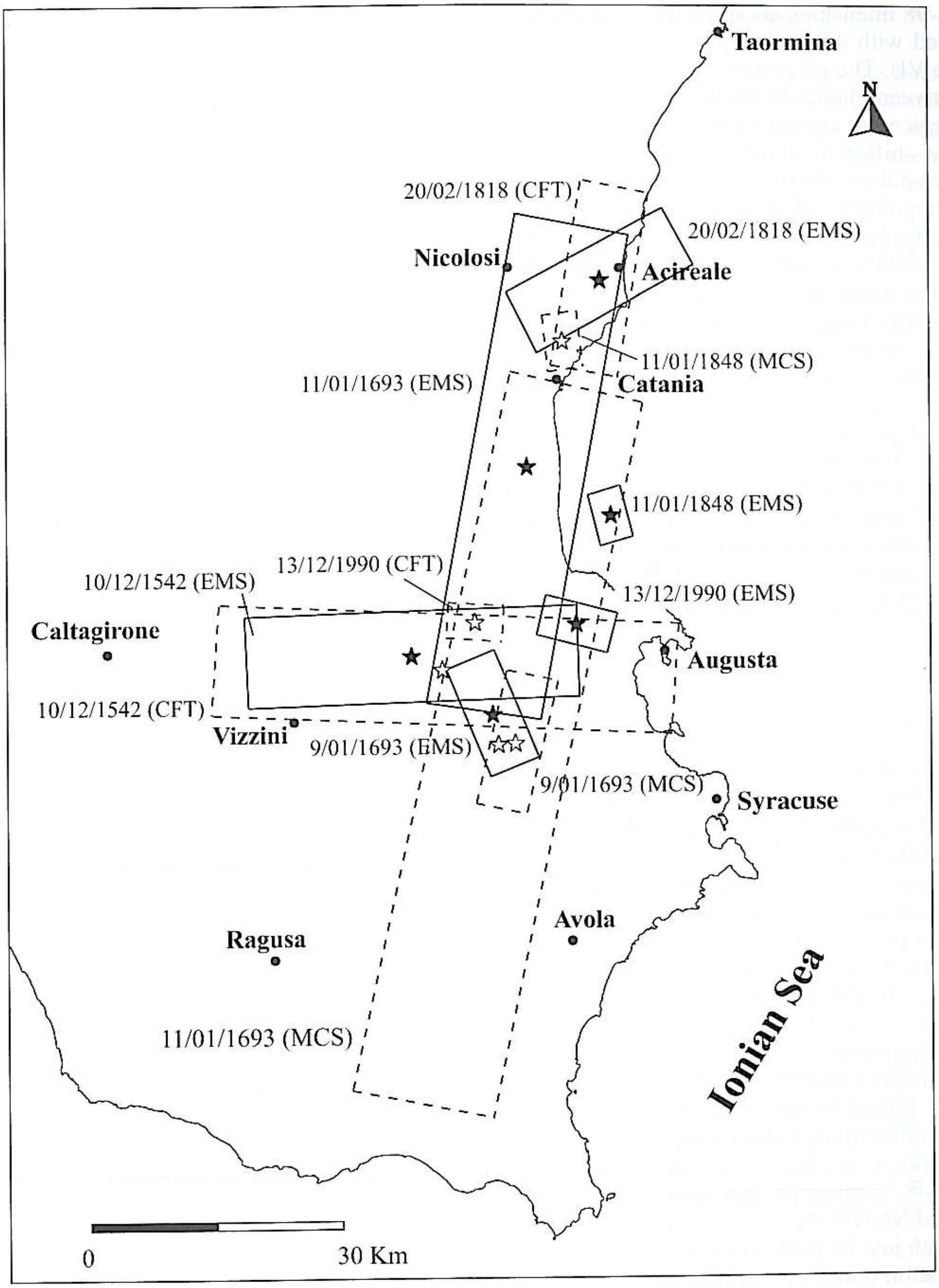

Fig. 3. Epicentral map of Southeastern Sicily earthquakes with $M > 5.3$. The rectangles represent the surface projection of the causative fault obtained using the Gasperini *et al.* (1999) method. Full stars and boxes are, respectively, the epicentres and the sources obtained using intensity data estimated in this study; empty stars and dashed boxes the ones obtained from CFTI and Boschi and Guidoboni (2001) data.

EMS-98 intensities are used, the location is estimated with 47 points (I = 10-11 and I = 10) (table VI). The program in fact assigns the data in between classes to the lower intensity class. The epicentre coming from the use of EMS-98 data is shifted by about 30 km towards NE, in the coastal area to the south of Catania (fig. 3). The hypothesis of an epicentre located northward, as already suggested by Azzaro and Barbano (2000), is supported by the observation that the Etna localities were not damaged during the January 9 shock, which is located further south, whereas they were destroyed during the second shock on January 11.

The different equivalent moment magnitudes of the January 11 shock, obtained taking into account both the epicentral intensity and the average distance between macroseismic epicentre and intensity sites (Gasperini and Ferrari, 1997), influence the estimate of source dimensions, computed through the Wells and Coppersmith (1994) relationships. Using the EMS-98 data the source length is about 54 km, whereas it proves to be 84 km on handling the MCS data. The smaller obtained value is analogous to the fault length inferred by Bianca *et al.* (1999) and Azzaro and Barbano (2000) on the basis of seismotectonic considerations. They associated the earthquake with one of the faults of the Malta Escarpment system which shows a comparable dimension (fig. 4).

Conversely, the computed source orientations seem to be in disagreement with all known faults of the region. The azimuth does not significantly change using either MCS or EMS-98 intensities (fig. 3), although it was calculated by considering a very different intensity point number and very distant epicentres (table VI). Therefore the estimate reliability of source orientation is mainly linked to the azimuthal distribution of points rather than to their number.

Suffice it to observe that the parameters of the 1848 earthquake, the source of which is oriented NNW-SSE, seem to be well constrained, although just 16 points are used for the azimuth calculation (table VI). Also in this case, sources computed with MCS and EMS-98 intensities have similar azimuth but epicentres are shifted by about 20 km. The epicentre obtained with MCS data is located near Catania whereas the

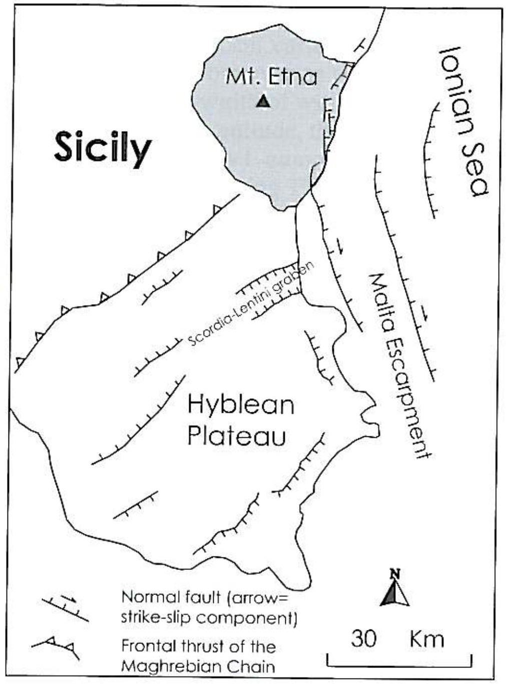

Fig. 4. Tectonic sketch map of Southeastern Sicily modified from Bianca *et al.* (1999).

one obtained with EMS-98 data is located southeastwards in the Catania Gulf (fig. 3).

The source orientation of the 1542 earthquake is compatible with a structure oriented *ca.* E-W, whereas the one of January 9, 1693 can be associated with a NNW trending structure (fig. 3). These solutions are not very different with respect to the ones obtained using MCS intensities. However for both earthquakes, the changes in the macroseismic field (*cfr.* table I and II) caused the epicentre to shift a few kilometres westwards. In both solutions, source azimuth is not well constrained because of the few scattered intensity observations.

As regards the 1818 earthquake, although the epicentres located using EMS-98 data and MCS intensity are coincident, source azimuths prove very different and not well constrained, because of the lack of intensity data in the central and western sector of Mt. Etna. However, both solutions disagree with observed surface faulting evidence.

Lastly, the epicentre of December 13, 1990 earthquake computed with EMS-98 intensity, is shifted toward the coast, a few kilometres away from the instrumental epicentre (Amato *et al.*, 1995) which is located offshore. This result suggests that macroseismic data cannot correctly reproduce seismic sources located offshore because of the asymmetrical macroseismic field. The same consideration could explain the disagreement between some obtained sources and the active structures which are probably located in the coastal proximity.

4. Seismic hazard assessment

The estimate of seismic hazard has been performed using site seismic history, which was compiled taking into account the new intensity data obtained. The site catalogue has been used to compute average return period by adopting the procedure described by Magri *et al.* (1994). This approach is based on the use of a discrete distribution function describing, for each earthquake, the probability that the effects are greater or equal to each possible intensity value of the

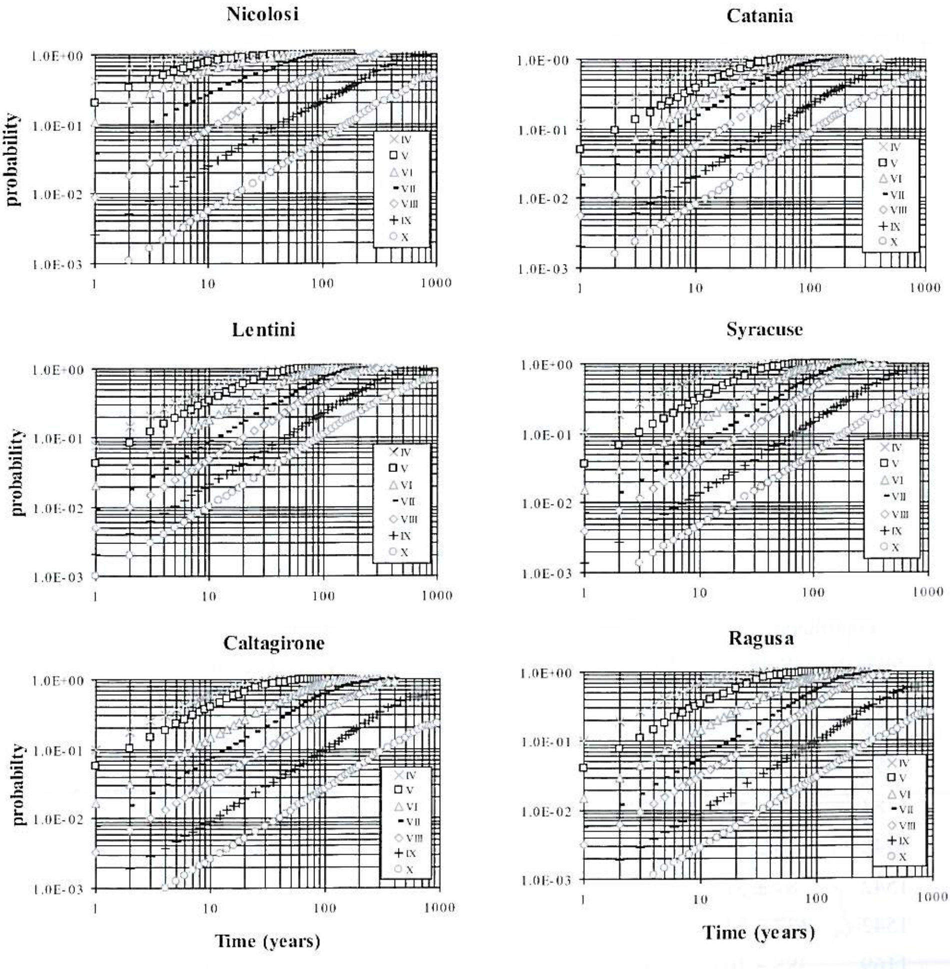

Fig. 5. Probability of occurrence in some Southeastern Sicily localities obtained using the Magri *et al.* (1994) method.

Table VII. Mean return period (years) in some Southeastern Sicily localities.

INT	Mineo		Sortino		Vizzini		Palazzolo A.	
	Complete since	Return period	Complete since	Return period	Complete since	Return period	Complete since	Return period
III	1878	4.3 ± 0.9	1878	5.9 ± 1.2	1892	4.3 ± 0.9	1878	5.5 ± 1.0
IV	1818	7.8 ± 1.9	1818	10.6 ± 2.6	1892	6.4 ± 1.3	1818	9.7 ± 2.3
V	1783	13 ± 3	1783	30 ± 5	1892	11 ± 2.4	1783	18 ± 4.6
VI	1624	31 ± 10	1542	48 ± 16	1693	33 ± 14	1693	38 ± 14
VII	1542	58 ± 20	1542	72 ± 25	1542	77 ± 36	1542	80 ± 36
VIII	1542	97 ± 36	1542	104 ± 37	1542	126 ± 65	1542	122 ± 60
IX	1169	249 ± 151	1169	235 ± 131	1169	318 ± 215	1169	313 ± 207
X	1000	572 ± 380	1000	492 ± 253	1000	639 ± 504	1000	619 ± 426
INT	Modica		Vittoria		Melilli		Chiaramonte G.	
	Complete since	Return period	Complete since	Return period	Complete since	Return period	Complete since	Return period
III	1895	5.6 ± 1.2	1895	5.0 ± 1.0	1878	5.1 ± 1.0	1878	4.9 ± 0.8
IV	1895	8.2 ± 1.9	1895	7.3 ± 1.5	1818	9.7 ± 2.3	1878	7.2 ± 1.3
V	1895	14 ± 3.5	1895	12 ± 2.7	1693	21 ± 5.5	1783	18 ± 5
VI	1848	38 ± 18	1693	56 ± 40	1542	47 ± 18	1542	51 ± 17
VII	1542	116 ± 67	1542	134 ± 100	1542	74 ± 32	1542	89 ± 31
VIII	1542	182 ±127	1542	198 ± 186	1542	117 ± 57	1542	140 ± 54
IX	1169	444 ± 302	1169	540 ± 352	1169	270 ±147	1169	373 ± 269
X	1000	767 ± 682	1000	846 ± 794	1000	532 ± 298	1000	687 ± 630
INT	Giarratana		Grammichele		Avola		Floridia	
	Complete since	Return period	Complete since	Return period	Complete since	Return period	Complete since	Return period
III	1878	4.7 ± 0.8	1878	4.4 ± 0.9	1894	5.9 ± 1.2	1878	5.4 ± 1.0
IV	1878	7.0 ± 1.3	1878	6.5 ± 1.3	1878	9.4 ± 2.0	1878	7.7 ± 1.4
V	1783	18 ± 5	1783	18 ± 5	1783	24 ± 6	1727	20 ± 5
VI	1542	50 ± 17	1542	49 ± 16	1693	47 ± 17	1693	34 ± 10
VII	1542	87 ± 31	1542	84 ± 31	1542	97 ± 45	1542	78 ± 34
VIII	1542	137 ± 54	1542	130 ± 53	1542	145 ± 76	1542	127 ± 65
IX	1169	385 ± 107	1169	357 ± 95	1169	363 ± 238	1169	319 ± 217
X	1000	669 ± 166	1000	643 ± 147	1000	669 ± 533	1000	600 ± 516

adopted macroseismic scale. The probability is calculated using observed site values and for each intensity class, examined independently from each other, the completeness threshold is evaluated. When observed data are lacking, the intensity values are derived through an attenuation law (Magri *et al.*, 1994). In a previous paper (Barbano *et al.*, 2001b) this methodology allowed us to discriminate a spatial variability in the site seismic hazard values in a limited number of localities. Such variations are not so evident when classic approaches are used (*e.g.*, Slejko *et al.*, 1998), because they usually tend to uniform hazard in large areas.

In Southeastern Sicily a very low occurrence probability of high intensity ($I = 9$ and $I = 10$) is observed (fig. 5). Table VII shows that the mean return periods of intensity 10 are usually greater than 500 years, as already observed by Barbano *et al.* (2001b). Relatively short mean return periods (50 ÷ 150 years) are detected for intensity classes $I = 7$ and $I = 8$. Nicolosi shows a high occurrence frequency of low-moderate intensities because of the peculiar Etna seismicity (Barbano *et al.*, 2001a), although the return times for high intensity events are comparable to those of the other localities. In any case, the mean return periods, computed using the site intensities, are generally shorter than the ones obtained with the Cornell method (Slejko *et al.*, 1998). Such a method, for instance, gives VIII as the maximum expected intensity in 475 years in the most Southeastern Sicily localities, whereas our results estimate intensity IX, and sometimes X, for a comparable time interval. On the other hand, the Cornell method postulates for Nicolosi, in the same time span, a maximum expected intensity of X. This is a consequence of using an *a priori* earthquake distribution based on a local seismicity rate that affects hazard assessment. Our estimate in Nicolosi, for intensity X, is 644 years with an extremely high associated error. Actually, in this locality, earthquakes are frequent but not destructive (Barbano *et al.*, 2001a) and intensity X has been observed just once.

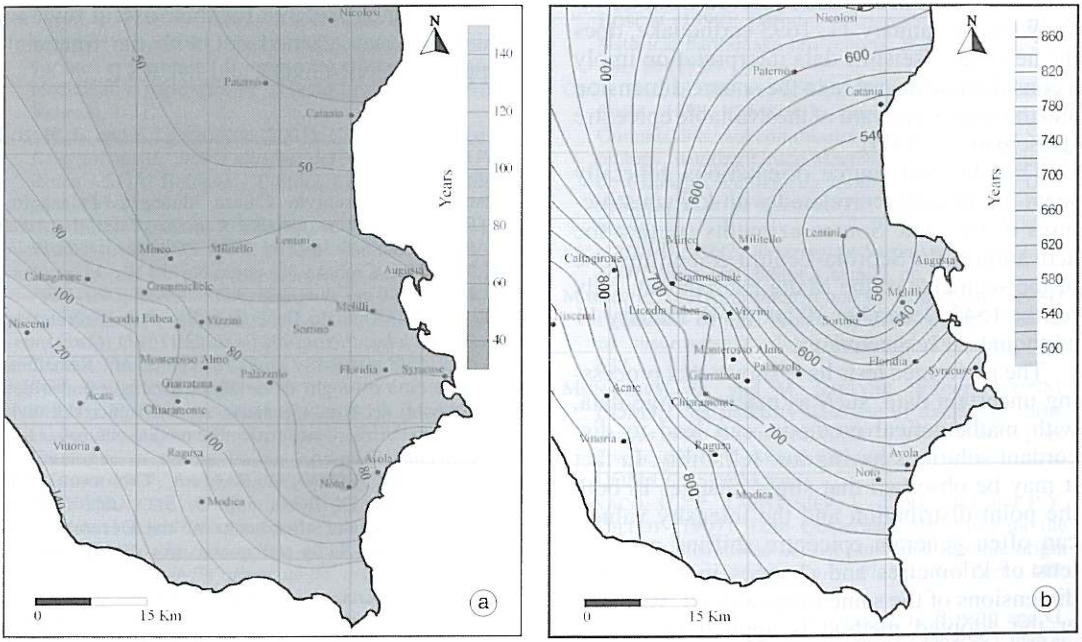

Fig. 6a,b. Mean return period (years) for intensity 7 (a) and for intensity 10 (b).

In fig. 6a,b hazard maps relative to intensities 7 and 10 EMS-98 are shown. The curves have been drawn interpolating the site values of the return period. For intensity 7 (fig. 6a), the maximum hazard values are detected near the Etna area, whereas for destructive earthquakes (I = 10 EMS-98) higher hazard is estimated in the coastal area from Catania to Lentini and Augusta (fig. 6b), as already observed by Barbano *et al.* (2001b).

The shape of the curves elongates in two directions, pointing out a trend which is in agreement with the main structures of the area: the first NNW-ESE, along the Malta Escarpment, the second ENE-WSW compatible with the Scordia-Lentini graben (fig. 4).

5. Conclusions

An attempt to define seismic sources in Southeastern Sicily using the procedure of Gasperini *et al.* (1999) has been made. Seismic sources obtained using EMS-98 intensity data do not show remarkable differences with respect to those computed with MCS data retrieved from CFTI. Only for the January 11, 1693 earthquake, does the new macroseismic data interpretation imply a considerable decrease in the source dimension and the shift northward of the available epicentre (Boschi *et al.*, 2000).

The obtained source orientations generally seem not directly correlated with known structures of the area. Source azimuths suggest the activation of the Scordia-Lentini graben and one of the segments of the Malta Escarpment, only for the 1542 December 10 and 1848 January 11 earthquakes, respectively.

The performed tests have shown that processing uncertain data, such as macroseismic data, with mathematical methods, can lead to discordant solutions having low reliability. In fact it may be observed that slight changes in both the point distribution and the intensity values, can often generate epicentre shifting even by tens of kilometres and changes in the source dimensions of the same range as well. Whenever the adopted method is applied to regions close to coastal areas, the lack of intensity points offshore can determine the epicentre migration inland and, probably modify the source azimuth. This would explain the lack of correlation between the obtained sources and the active structures which are probably located offshore. Caution must therefore be taken when seismic sources obtained with this approach are used to compute the hazard with the classic approaches, such as Cornell's, which usually tend to distribute seismicity uniformly over large areas.

A spatial variability in the site seismic hazard values was highlighted using a method that adopts observed intensities. It is therefore not affected either by the earthquake distribution law, or by the attenuation model and the seismogenic zone shape.

Both the obtained epicentral locations and the evaluated seismic hazard emphasise that the seismogenic structures are mainly located in the coastal sector of Southeastern Sicily.

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