Bull Earthquake Eng (2012) 10:1109–1131
DOI 10.1007/s10518-012-9353-z

ORIGINAL RESEARCH PAPER

23 November 1980 Irpinia–Basilicata earthquake (Southern Italy): towards a full knowledge of the seismic effects

F. T. Gizzi · M. R. Potenza · C. Zotta

Received: 7 July 2011 / Accepted: 5 April 2012 / Published online: 16 May 2012

Abstract This paper overviews the procedures and tools used for a systematic study of the macroseismic consequences caused by a strong earthquake that struck Southern Italy. The event referred to the 23 November 1980 (Io = X MCS, Ms = 6.9) which affected the Campania and Basilicata regions. Two aspects are addressed here: to broaden the knowledge of the macroseismic field and delineate damage maps of the sites affected on an urban scale. The target area of this study is the Basilicata region about which the current macroseismic information is poor. This research study, based only on unpublished documentary sources, supplies about 50 new assessments and about 30 new re-assessments of the macroseismic site intensity (MCS scale) as outputs. Moreover, about 80 thematic maps showing the damage pattern of the sites affected are also supplied. It is the first time that a large earthquake has been the subject of such extensive studies from a macroseismic point of view, with special attention to the analysis of damage effects at town scale.

Keywords Macroseismic intensity · Damage maps · Documentary sources · Site effects

1 Introduction

Seismic history informs us that in the past Italy experienced numerous strong earthquakes that caused deep changes in the urban, socio-economic, and natural contexts.

The 23 November 1980 Irpinia–Basilicata (Southern Italy) event is one of these also because it is among the strongest earthquakes ever occurred in Italy.

This event, consisting of at least three main rupture episodes occurred at 0, 18 and 40 s from the first shock, was assigned a surface-wave magnitude Ms = 6.9 (Pantosti and Valensise 1993).

Electronic supplementary material The online version of this article (doi:10.1007/s10518-012-9353-z) contains supplementary material, which is available to authorized users.

F. T. Gizzi (✉) · M. R. Potenza · C. Zotta
Institute for Archaeological and Monumental Heritage, National Research Council,
C.da S.Loja, 85050 Tito Scalo, PZ, Italy
e-mail: f.gizzi@ibam.cnr.it

Primary and secondary effects brought about changes in the environment such as the 15 km-long co-seismic faulting at the surface and the trigger or re-movement of numerous and sometimes wide landslides (e.g.: Senerchia, Buoninventre, Caposele, Calitri, San Giorgio La Molara, and Grassano) (Westaway and Jackson 1984; Cotecchia 1986; Del Prete 1993; Esposito et al. 1998).

A wide area of Campania and Basilicata recorded serious damage, especially the provinces of Avellino, Potenza, and Salerno.

Destructive effects affected an area of about 3,500 km^2 causing about 2,900 dead, while felt effects hit a very wide area, from South to North, from Sicily to Liguria (Fig. 1).

Fifteen localities were almost destroyed (Is $\geq$ IX MCS), including Sant'Angelo dei Lombardi, Laviano, Lione, Santomenna, Senerchia, Pescopagano, and Balvano. Fifty-five towns suffered serious injuries, 780 were damaged with different degrees of severity. On a total of approximately 1,850,000 buildings involved in the event 75,000 were destroyed, 275,000 seriously damaged and 480,000 slightly damaged.

This event was considered by the scientists as a natural laboratory for in-depth studies concerning different fields. Thanks to these research activities, the 1980 earthquake is now possibly the largest event best documented in Italy and in the Mediterranean area: the literature is rich in contributions dealing with the study of seismogenetic sources, macroseismic aspects, the hydrogeological and geotechnical phenomena associated with the shake, the geological and seismotectonic features of the epicentral region (for a review of the most important papers related to the seismic event see Valensise 1993).

However, from a macroseismic point of view, the knowledge of the natural phenomenon is still far from being comprehensive. Indeed, the available macroseismic field shows many gaps, especially in its South-East portion. Moreover, no detailed information is available in literature about the damage pattern in the towns.

To partially fill these gaps this paper describes the results of a thorough study based only on unpublished technical sources. In details, assignments of macroseismic intensity (MCS scale) were performed for the sites for which the parametric data were unavailable. Moreover, the re-assessment of the intensity was also carried out for some locations for which the degree of damage was already available. The study was completed by the detailed investigation concerning the pattern of effects at town scale.

The target area is the Basilicata region, located in a portion of Italy characterized by a high seismic hazard and heavily affected by the consequences of the 1980 earthquake.

This research study supplies about 80 new or re-assessed macroseismic intensities for locations in Basilicata and about 80 thematic maps showing the spatial distribution of the seismic effects at urban scale.

The work is divided into two sections: the first deals with the features of the written sources analysed, the second reports the methodological approach and the results concerning both the assessment of the macroseismic intensity and the detailed "reconstruction" of the urban damage effects for which all the elaborations are downloadable, as *pdf* files, at the Springer Electronic Supplementary Service.

2 The documentary sources

Getting new macroseismic information concerning the Basilicata region was possible thanks to two main typologies of technical sources (≪ Master Sources ≫) preserved in local archives: the ≪*Scheda A*≫ and ≪*Scheda B*≫ (the ≪Survey Cards≫) drawn up in the aftermath of the earthquake, and the reports and maps elaborated within the framework of the ≪*Piani di Recupero*≫ (≪Plans of Recover≫) of the historical centres, scheduled by a law governing the rebuilding phase (Law n. 219/81).

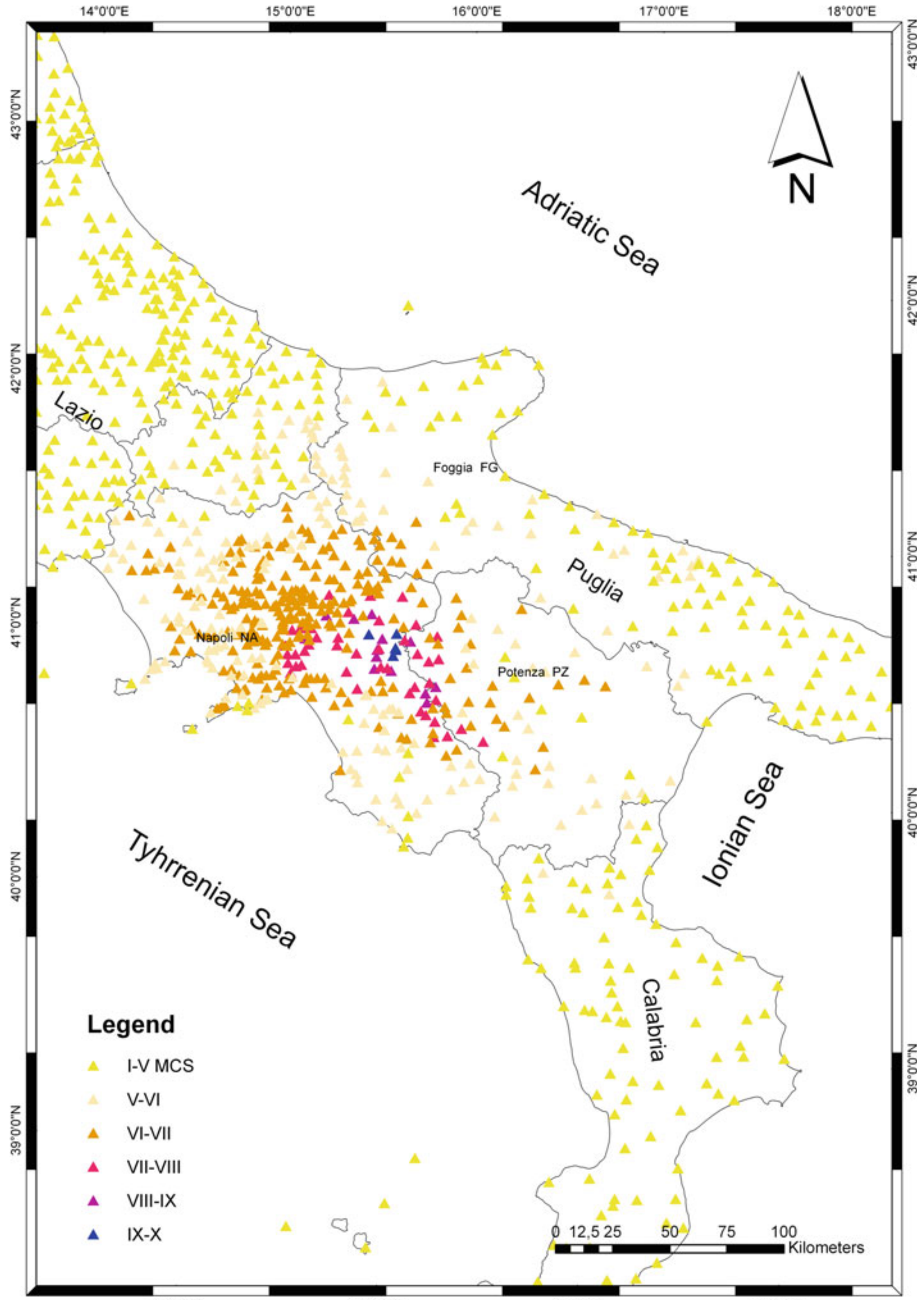
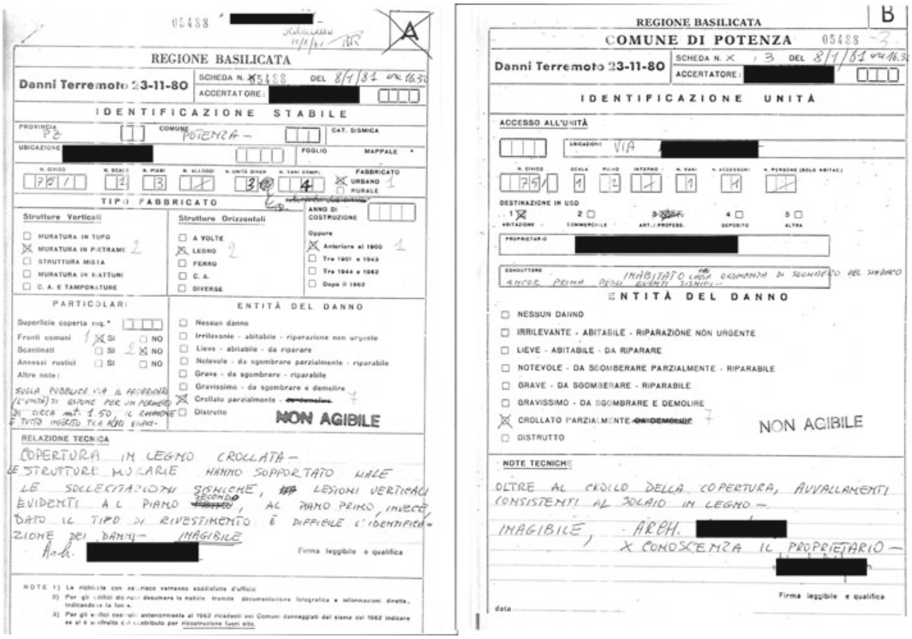


Fig. 1 Macroseismic field of 23 November 1980 earthquake according to data available before this research (intensity data from Boschi et al. 2000)



05488 [redacted]

A

REGIONE BASILICATA

Danni Terremoto 23-11-80 | SCHEDA N. 05488 DEL 8/1/81 ore 16.50

ACCERTATORE: [redacted]

IDENTIFICAZIONE STABILE

PROVINCIA PZ | COMUNE POTENZA – | CAT. SISMICA

UBICAZIONE [redacted] | FOGLIO | MAPPALE

N. CIVICO 75/ | N. SCALE 1 | N. PIANI 3 | N. ALLOGGI | N. UNITÀ DIVER. 3 | N. VANI COMPL. 4 | FABBRICATO ☒ URBANO ☐ RURALE

TIPO FABBRICATO

Strutture Verticali
☐ MURATURA IN TUFO
☒ MURATURA IN PIETRAME
☐ STRUTTURA MISTA
☐ MURATURA IN MATTONI
☐ C. A. E TAMPONATURE

Strutture Orizzontali
☐ A VOLTE
☒ LEGNO
☐ FERRO
☐ C. A.
☐ DIVERSE

ANNO DI COSTRUZIONE
Oppure
☒ Anteriore al 1900
☐ Tra 1901 e 1943
☐ Tra 1944 e 1962
☐ Dopo il 1962

PARTICOLARI
Superficie coperta mq.*
Fronti comuni ☒ SI ☐ NO
Scantinati ☐ SI ☒ NO
Annessi rustici ☐ SI ☐ NO
Altre note:
SULLA PUBBLICA VIA IL FABBRICATO (L'UNITÀ) SI ESPONE PER UN PERIMETRO DI CIRCA mt. 1.50 IL CAMMINO È TUTTO INSERITO TRA ALTRI EDIFICI

ENTITÀ DEL DANNO
☐ Nessun danno
☐ Irrilevante - abitabile - riparazione non urgente
☐ Lieve - abitabile - da riparare
☐ Notevole - da sgombrare parzialmente - riparabile
☐ Grave - da sgombrare - riparabile
☐ Gravissimo - da sgombrare e demolire
☒ Crollato parzialmente - ~~da demolire~~
☐ Distrutto

NON AGIBILE

RELAZIONE TECNICA
COPERTURA IN LEGNO CROLLATA – LE STRUTTURE MURARIE HANNO SOPPORTATO MALE LE SOLLECITAZIONI SISMICHE, LESIONI VERTICALI EVIDENTI AL PIANO SECONDO, AL PIANO PRIMO, INVECE, DATO IL TIPO DI RIVESTIMENTO È DIFFICILE L'IDENTIFICAZIONE DEI DANNI – INAGIBILE

Arch. [redacted]

Firma leggibile e qualifica

B

REGIONE BASILICATA

COMUNE DI POTENZA 05488 -3-

Danni Terremoto 23-11-80 | SCHEDA N. 3 DEL 8/1/81 ore 16.30

ACCERTATORE: [redacted]

IDENTIFICAZIONE UNITÀ

ACCESSO ALL'UNITÀ

UBICAZIONE VIA [redacted]

N. CIVICO 75/ | SCALA 1 | PIANO 2 | INTERNO | N. VANI 1 | N. ACCESSORI 1 | N. PERSONE (SOLO ABITAZ.)

DESTINAZIONE IN USO
1 ☒ ABITAZIONE | 2 ☐ COMMERCIALE | 3 ☐ ART./PROFESS. | 4 ☐ DEPOSITO | 5 ☐ ALTRA

PROPRIETARIO [redacted]

CONDUTTORE INABITATO CAUSA ORDINANZA DI SGOMBERO DEL SINDACO ANCOR PRIMA DEGLI EVENTI SISMICI –

ENTITÀ DEL DANNO
☐ NESSUN DANNO
☐ IRRILEVANTE - ABITABILE - RIPARAZIONE NON URGENTE
☐ LIEVE - ABITABILE - DA RIPARARE
☐ NOTEVOLE - DA SGOMBERARE PARZIALMENTE - RIPARABILE
☐ GRAVE - DA SGOMBERARE - RIPARABILE
☐ GRAVISSIMO - DA SGOMBRARE E DEMOLIRE
☒ CROLLATO PARZIALMENTE ~~DA DEMOLIRE~~
☐ DISTRUTTO

NON AGIBILE

NOTE TECNICHE
OLTRE AL CROLLO DELLA COPERTURA, AVVALLAMENTI CONSISTENTI AL SOLAIO IN LEGNO –
INAGIBILE, ARCH. [redacted]
X CONOSCENZA IL PROPRIETARIO – [redacted]

Firma leggibile e qualifica

data

Fig. 2 Forms used to survey the damage caused by 1980 earthquake. The ≪*SchedaA*≫ (on the *left*) refers to the whole building. Conversely, the ≪*SchedaB*≫ reports the consequences suffered by each single flat of the housing

The documents consulted are mainly preserved in the Basilicata region archive. Nevertheless, considering that for a few locations neither ≪Cards≫ nor ≪Plans≫ could be found, the search was completed with the documentation preserved in the local archives of the municipalities.

The ≪Cards≫, used both to assess the macroseismic intensity and delineate the damage maps, were drawn up for all the buildings damaged, both the urban and rural ones. This study, however, analyses only the ≪Cards≫ compiled to evaluate the effects on the housings localised in the urban centres (damage maps, see below).

The surveys of the housings affected, began in the aftermath of the main shock of 23 November and were completed in the early 1981. The aim of the surveys was to distinguish *inhabitable* from *habitable* dwellings and put in field the actions of the rising Civil Protection (the establishment of the Civil Protection as a National Service occurred in 1992, was made faster just in consequence of the 1980 catastrophic earthquake that highlighted the limits of the rescue organization).

Teams of technicians (engineers, architects, and surveyors) entrusted to assess the damage subdividing town in neighbourhoods. The surveys were carried out in two phases: the first was aimed to evaluate the conditions of the entire building (block of owner-occupied flats) and involved the compilation of the ≪*Scheda A*≫. The second phase focused on verifying the effects on each housing, and then compiling the ≪*Scheda B*≫ (Fig. 2).

The ≪*Scheda A*≫ is organized in four main fields such as administrative data (town, owner, street, etc.,), building typology (tuff, rubble stones, bricks, and reinforced concrete), building age and the level of damage according to a pre-fixed scale.

The main field of the ≪ *Scheda B* ≫ is the damage scale, consistent with the ≪*SchedaA*≫.

Eight were the pre-fixed damage levels that the technicians could assign to the affected buildings. The attribution of a certain degree implied an action to be undertaken such as repairing works, evacuation, or demolition:

1. no damage;
2. insignificant damage—habitable—not urgent repairing works;
3. slight—habitable—to be repaired;
4. notable damage—to be partially evacuated—repairable—;
5. heavy—to be evacuated—repairable—;
6. very heavy—to be evacuated and demolished—;
7. partial collapse—to be demolished—;
8. destroyed.

The attribution of a degree "notable" implied the presence of some cracks in walls and floors. "Heavy" effects were assigned by technicians when deep cracks occurred in the supporting structures. The enlargement of cracks passing through the walls with a possible danger of collapse produced an attribution of a "very heavy" degree, the phase before the start of the collapse. The total collapse of a building was classified as "destroyed".

From a technical point of view the ≪*Scheda A*≫ summarises the *predominant damage* to the whole building; conversely the ≪*Scheda B*≫ reports the consequences suffered by each *single flat* of the buildings. That being stated, it must be emphasized that both macroseismic intensity assessment and the reconstruction of the consequences in towns were made by considering the classification reported in the ≪*Scheda B*≫.

As mentioned above, the ≪*Piani di Recupero*≫ of the historical centres were the other sources used to analyze the effects of the earthquake. In details, these sources were taken into consideration only to outline the damage patterns at urban scale.

The ≪Plans≫ were compiled according to the law 219/81 issued in consequence of the catastrophic event to set rules for the preservation and development of the ancient portion of the towns. This type of sources, indirect in nature, were considered when the ≪Cards≫ were no longer found in the archives.

In order to carry out actions to recover the historical centres by public funding, the law 219/81 laid down the arrangement of technical elaborations useful to know both the actual conditions of the buildings and plan a suitable strategy of intervention. The "Damage map" of the historical centres was among the technical results provided by the Plans. These maps were compiled by the technicians after examining the ≪Cards≫.

Obviously, the procedure to analyse the effects implied the assessment of the completeness and reliability of all the documents analysed, with particular attention to the "Plans" to be considered as an indirect sources. To this aim other sources of independent information were consulted such as:

a. aerial photos taken in the aftermath of the event;
b. terrestrial photos regarding the effects on private buildings or monuments;
c. newspapers.

The aerial photos were taken in the aftermath of the earthquake by the Italian Military Geographic Institute (end of November-beginning of December) and were useful to verify the information reported for some of the most affected towns localized in the mesoseismic area (Castelgrande, San Fele, Pescopagano, Bella, and Balvano in the province of Potenza).

Considering the flight altitude from which the photos were taken, the observation of the images made it possible to distinguish clearly also small areas affected by "partial collapses" or "destructions".

Numerous photos preserved in the archive of the Superintendence of the Architectural Heritage of Potenza were also of great help. The photos were taken by the technicians of the Superintendence in the weeks following the earthquake in order to document the damage suffered by the monuments, buildings of special interest (old mansions, churches, etc.,) and dwellings of the historical centres. Obviously, special attention was paid to survey the towns located in the mesoseismic area (Muro Lucano, Ruvo del Monte, Balvano, and Pescopagano). Each photo reports the location (street, square, etc.) of the buildings portrayed. This made it feasible to correlate and validate the effects reported by the ≪Master Sources≫.

Local newspapers issued in the weeks following the earthquake were useful for identifying the effects on locations for which no other source of information was found (e.g.: the village of Montalbano Jonico, in the province of Matera).

Summarizing, the cross-correlated analysis of all typologies of data confirms the good quality of the information this research is based upon.

3 Assessment of the macroseismic intensity

The first large-scale macroseismic investigations on the 1980 earthquake were entrusted to the ≪*Gruppo Macrosismica*≫ (Macroseismic Group) of the ≪*Progetto Finalizzato Geodinamica*≫ (Geodynamical Oriented Project) sponsored by the National Research Council. The analysis started in the aftermath of the event, involving 1,285 localities among which 64 municipalities (on 131) belonging to the Basilicata Region.

On one hand, the macroseismic data for the area with minor effects were mainly obtained through the response to the questionnaires sent to teachers and gendarmeries. On the other hand, for 306 sites included in the mesoseismic area, the damage was directly surveyed by teams of researchers including seismologists, geologists, and engineers. The results of the investigations performed by the *Gruppo* converged in the ≪Atlas of Isoseismal Maps of Italian Earthquakes≫ as intensity data points and isoseismal map (Postpischl et al. 1985).

The whole data set of the ≪Atlas≫ information is the core of the recent parametric-descriptive ≪Catalogue of Strong Italian Earthquakes≫ (afterwards ≪Catalogue≫ or ≪CFTI≫, Boschi et al. 2000). Further macroseismic studies were performed in the frame of the same ≪Catalogue≫. These new research data, that were drawn on from more recent catalogues (CPTI Working Group 2004), made it possible to add about one hundred locations to the data of the ≪Atlas≫, thus increasing the total number of sites assessed up to about 1,400. However, no new attribution was carried out for the Basilicata municipalities, except for a re-assessment of a little number of intensity data points thanks to the statistical data included in published sources and information gathered from newspapers (for a complete list of references see the CD-ROM digital version of the ≪Catalogue≫).

All this considered, it emerges that nowadays only for about 49 % of the Basilicata municipalities (64 on 131) is assigned a macroseismic intensity. The lack of intensity attribution causes an evident gap especially in the South-East portion of the macroseismic field.

To fill this lack of data, the ≪Survey Cards≫ were examined to assess (or re-assess, as respect to the data points included in the ≪Catalogue≫) the intensity for numerous locations of Basilicata so to improve the knowledge of the macroseismic field.

The macroseismic scale adopted to parameterize the effects is the Mercalli-Cancani-Sieberg (MCS) with twelve degrees (Sieberg 1932). This choice was mainly made to make the new set of data comparable to those already available in the ≪Catalogue≫.

The approach followed to evaluate the intensity consisted in comparing the consequences reported in the ≪Cards≫ with a set of effects listed in the scale and deciding which one represented the best match. This criterion is not rigorously correct because, as it is known, the MCS scale was compiled to analyze the effects of earthquakes which are contemporary to the observer.

Therefore, there may be problems in parameterizing the seismic consequences since the descriptions available in written accounts seldom fit those of the macroseismic scale. This can lead to divergent assessments of the damage when they are made either by different investigators or the same researcher but at different times (Stucchi 1993; Ferrari and Guidoboni 2000).

Generally, as we go back in time written accounts show an increase in vagueness of the descriptions, and therefore problems of interpretation become more complex to solve.

However, considering both the age of the event and the features of the sources analyzed for the 1980 earthquake, problems in intensity classification were reduced. Moreover, the features of the sources helped to follow an objective criterion of intensity attribution, allowing an easy repeatability of the entire procedure.

The conversion of the information into a macroseismic parameter was made by preferring the traditional operator's expertise to automatic and computer-aided procedures (e.g.: Vannucci et al. 2000).

Generally speaking, the attribution of a certain degree of the MCS scale implies firstly the identification of the things on which the earthquake acts: human beings or animals, objects, buildings, and natural environment considered on the whole as "sensors". Once a range of MCS degree is fixed, as intensity increases a greater proportion of certain sensor(s) is involved and the entity of its involvement grows progressively. For example, for the I-to-VI range as intensity increases more and more people feel the shaking and fear gets stronger. For intensity greater than V as intensity grows, the number of buildings involved grows progressively and damage becomes stronger.

All these features of the scale are quite well described in tables 102 and 103 attached to the work by Sieberg (1932). These tables can be considered as a sort of an operational tool.

Considering that the written accounts examined here report the effects on the buildings, the minimum intensity considered is the VI degree (the threshold from which the damage starts), as will be discussed below.

Once identified the "sensors", in order to attribute the intensity it is necessary to know both the *damage level* and the *quantity* (percentage) of the buildings affected as respect to their total number.

The *damage levels* scheduled in the MCS scale are five: slight, moderate, heavy, destruction, and collapse. The significance of the extreme terms of these lists is made clear in the descriptions of the scale, instead the significance of adjectives such as "heavy" and "destruction" can be only gathered by examining the latest MSK and EMS-98 scales whose damage levels are quite similar to those indicated in the MCS scale (Table 1).

As regards the *quantities*, degrees VI and VII are defined by the use of adjectives (rare and numerous, respectively); higher degrees are identified by the percentages of the total number of buildings hit by the earthquake (e.g.: destruction of 1/4 of buildings is the criterion for assigning the VII degree).

On the one hand the percentages are self-explicative, on the other hand the adjectives (rare, a few, very few; many, numerous; most) need to be interpreted from a quantitative

Table 1 Damage levels in the MCS scale

MCS damage level	MCS descriptions	Correspondence to cards damage level
Slight (1)	Cracks in the plaster that falls from the ceiling and walls. Tiles or stones of the chimney-pot may fall	Insignificant-slight
Moderate (2)	Small cracks in the walls. Rather big parts of the plastering and stucco work, and of bricks break off; tiles fall. Many chimney-pots are damaged by cracks, falling tiles and stones; ruined chimney-pots fall on the roof damaging it. Badly fixed decorations fall from towers and high buildings	Notable
Heavy (3)	This damage brings about heavy cracks to walls causing a temporary uninhabitableness	Heavy
Destruction (4)	Very heavy cracks that pass through the wall. Partial collapse of portions of wall. This damage involves a danger of collapse	Very heavy-partial collapse
Collapses (5)	Total or almost total collapse	Destroyed

The correspondences with damage levels as scheduled in the card surveys are also indicated

Table 2 Table summarizing the cumulative mean percentages of affected buildings adopted in order to assess the MCS intensity

	Damage levels					
I (MCS)	**1**	**2**	**3**	**4**	**5**	**MCS**
	2–3	**4**	**5**	**6–7**	**8**	**Survey cards**
V–VI	(25 %)	(5 %)				
VI	*5 %* (50 %)	*5 %* (25 %)	(5 %)			
VII		*50 %*	(25 %)	*5 %*		
VIII			*50 %*	**25 %**	*5 %*	
IX			*75 %*	**50 %**	**25 %**	
X				**75 %**	**50 %**	
XI					**100 %** (75 %)	
XII					**100 %**	

Correspondences between the damage levels listed in the MCS scale and Survey Cards are also supplied. In bold the *quantitative* data as indicated in the descriptions of the MCS scale; in Italic, the interpretation of the quantities indicated as *adjectives* in the scale. In brackets the data deriving from inferences because not indicated in the scale or considered unfit (from Molin et al. 2008 modified). It is worth noting that quantities referred by the MCS scale must be considered as cumulative (e.g.: for IX degree, 75 % of damage 3 also includes 50 % of damage 4 that in its turn includes 25 % of damage 5)

point of view. Usually, also according to what indicated in other macroseismic scales such as the MSK and EMS-98 ones, the adjectives “rare”, “few”, “very few”, and “isolated” are traditionally associated to a mean value of 5 %, “many” to a mean value of 50 %; “most” to a mean value of 75 % (Molin et al. 2008) (Table 2).

By examining the damage level together with the quantity, it emerges that the occurrence of damage without dangers to inhabitants is the condition to attribute an intensity of VI degree. Damage involving almost the same levels of VI MCS, but affecting a minor percentage of buildings, is the criterion to assign a V–VI degree. Diffuse effects and very sporadic collapses involve an assignment of intensity of VII degree. Dwellings widely and seriously damaged and not rare collapses suggest an attribution of VIII degree. A significant percentage of buildings made uninhabitable leads to an evaluation of the damage as IX degree. Finally, a growing percentage of collapses leads to the assignment of X or XI MCS.

Once clarified the criteria for the attribution of the MCS intensity, it was necessary to consider information on damage in the documents consulted.

The first step was to recognize the agreement between the damage levels scheduled in the scale and those fixed in the ≪Cards≫.

Reminding the descriptions made in the Sect. 2 concerning the features of the written accounts, the eight classes fixed in the ≪Cards≫ were grouped and reduced to five. Indeed, the two damage levels indicated in the documents as "Insignificant" and "Slight" can be considered as corresponding to the "Slight" MCS class. Similarly, the "Very heavy" and "Partial collapse" levels can be correlated with the "Destruction" category fixed in the macroseismic scale (Table 2).

Afterwards, the percentage of the affected buildings was evaluated for each level of damage. In order to do this, the number of buildings hit for each class of effects was first identified and then divided by the "total number of habitable housings" deduced from the census made by the Italian Institute of Statistics in 1971 or 1981 (ISTAT 1971, 1981).

The reliable number of total buildings at the time of the earthquake was considered to be as the highest value found between the census of the 1971 and that of 1981. Indeed, for towns that suffered heavy consequences (I > VII degree), the census carried out in 1981 (i.e. a few months after the event) underestimates the number of "habitable housings" because a significant portion of these was made inhabitable by the earthquake and, therefore, non-computable during the statistical survey. In this case the 1971census was considered as more suitable.

Conversely, the 1981 census is the most appropriate to be considered for the locations hit by minor effects. Indeed, considering the limited consequences of the earthquake in these sites, the number of inhabitable residences not included in the 1981 census can be evaluated as negligible with respect to the number of constructions that would not be computed if adopting the 1971 census as reference because in the 1970s there was a rapid growth of the urban agglomerations that would appear only in the statistical survey of 1981.

Once computed the percentages for each level of damage, the comparison of these data with the descriptions given by the MCS scale allowed us to attribute the intensity to each place.

A macroseismic intensity classification was performed for numerous unclassified towns. Moreover, some data were re-assessed for locations already included in the ≪Catalogue≫. More specifically, the new attributions concern 51 municipalities (34 in the district of Potenza and 17 in the district of Matera), and the re-assessment concerns 32 municipalities (23 in the district of Potenza and 9 in province of Matera) (see Fig. 3 and Appendix A in supplementary material).

On the whole, the attributions involved the degrees from V–VI to IX of the MCS scale, thus increasing the macroseismic database of the ≪Catalogue≫ up to about 1,450 sites (Fig. 4).

As for the new attributions they mainly concern the V–VI and VI degrees (49 data points, corresponding to about 96 % of the total attributions); the assessments of the VII degree are subordinate (Fig. 5).

The new data concern the municipalities located in the following areas of Basilicata (Fig. 4):

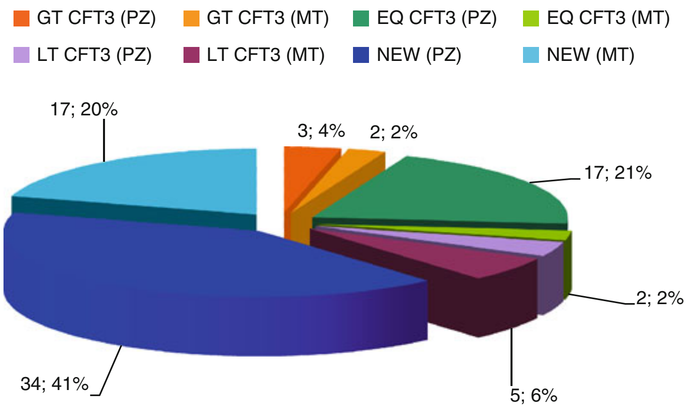


Fig. 3 Distribution of new and re-assessed macroseismic intensity data in the provinces of Potenza (PZ) and Matera (MT) (*New* new intensity data; re-assessed data: *GT* intensity greater than CFTI, *EQ* intensity equal to CFTI, *LT* intensity less than CFTI)

1. in the south, where the V–VI degree effects prevail,
2. in the south-east, where the VI degree effects prevail,
3. in the south-west and north-east, where "anomalous" effects of VII degree can be found (Rapolla and Tramutola villages).

As for the reassessment in most of the municipalities (19, ∼59 %) considered the intensity attributed to these by the ≪Catalogue≫ has been confirmed by analyzing the sources consulted in this study. Conversely, (13, ∼41 %) sites have been involved in changes: in 5 sites the degree has been seen to increase whereas in 8 locations the intensity was reduced in comparison with the data reported by the ≪Catalogue≫.

The increase in intensity mainly concerns changes from VI to VII and V to V–VI MCS. Decreasing values concern changes from VI to V–VI MCS and VI–VII to VI MCS (Fig. 6).

On the one hand, the towns where the intensity has risen are scattered in the whole region, from the north to the south. On the other hand, the towns where intensity has remained unchanged are localized in quite a narrow area in the central part of the region.

Summarizing, the changes in intensity regard a few sites affected by little damage whose macroseismic data included in the ≪Catalogue≫ are taken, as said above, from the elaboration of questionnaires and not from direct surveys, as carried out for compiling the ≪Cards≫. Other differences between the formerly assigned and the present reassigned intensities can be explained by the observation that the questionnaires were compiled with a purpose different from that declared for the compilation of the ≪Cards≫. Finally, the ≪Cards≫ may report cumulative effects on the buildings caused by the aftershocks because the surveys continued for several months after the main shock.

4 Damage maps at urban scale and their use

It is known that macroseismic data play a key role in supporting the analysis of local seismic response because they contribute to analyze the geological/geophysical features of a site (e.g.: Cifelli et al. 2000; Guidoboni et al. 2003; Cara et al. 2008).

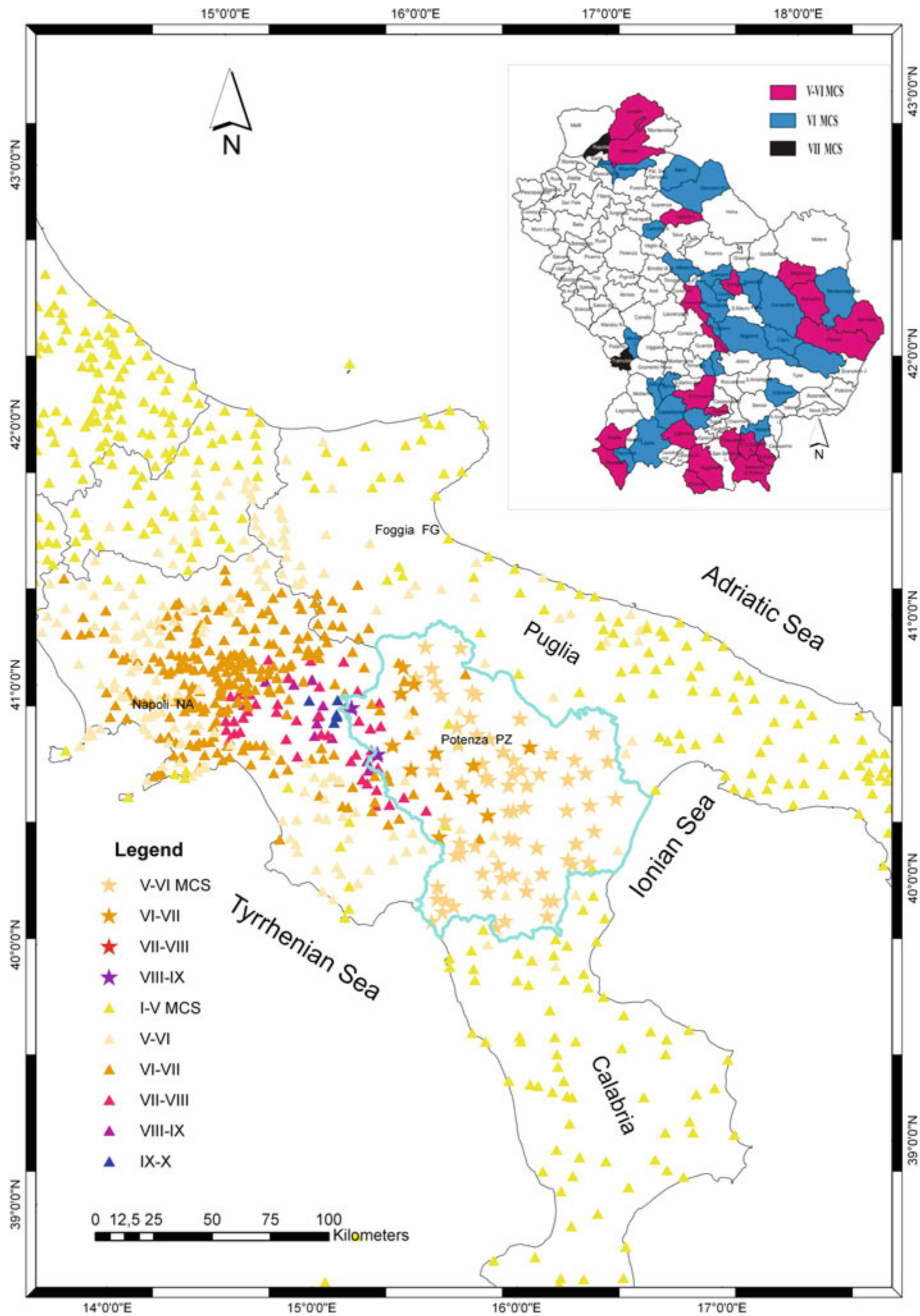


Fig. 4 Macroseismic field of 23 November 1980 earthquake as inferred by merging data already available (plotted as *triangles*, Boschi et al. 2000) and the new information examined by this research (data shown as *stars*). The *box* located at the *top* identifies the municipalities of Basilicata for which the assessment of the intensities was performed

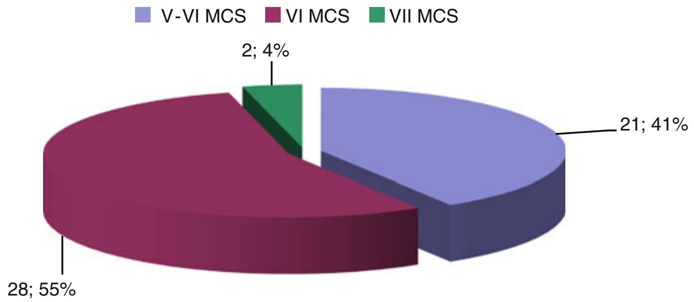


Fig. 5 Pie chart of the new macroseismic data made during this study. The most of the attributions concern the VI and V–VI degrees

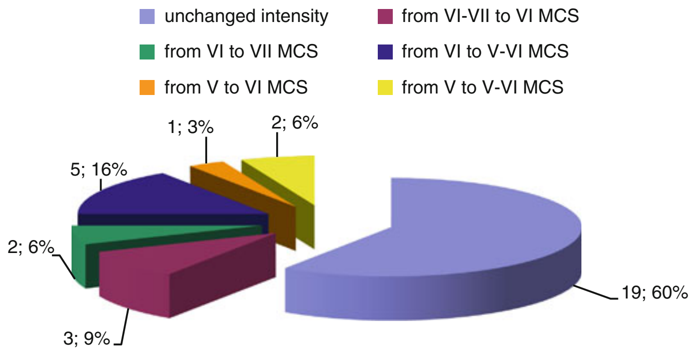


Fig. 6 Pie chart of towns for which the re-assessments of the macroseismic intensity were carried out. In most of the municipalities the intensity attributed in previous study was confirmed (60 %). As regards the sites involved in changes, in most of the sites (8) the effects were seen to increase

In detail, it emerges that it is important to consider the effects already experienced by municipalities especially for recent earthquakes, for which the documents usually show high quality and completeness of information.

However, from an overall view of the literature it emerges that the knowledge of the consequences for the towns struck by the recent 1980 earthquake is very poor.

Studies were performed in the framework of the ≪*ProgettoFinalizzatoGeodinamica*≫ with the aim of analyzing the effects on some of Campania's and Basilicata's most heavily damaged towns such as Ruvo del Monte, Vietri di Potenza, and Pescopagano in the province of Potenza (Cantelli et al. 1983a,b; Faccioli and Siro 1983). Other researchers analysed the consequences of the natural event in some towns among which Atella in the province of Potenza and Tricarico, Grassano, and Grottole in the province of Matera (Radina and Vignola 1981; Maggiore et al. 1984; Rendell 1985; Baldassarre and Francescangeli 1986). However, a systematic study has never been carried out.

Ascertained that the data related to the effects on urban scale are lacking, an in-depth study of the "Master Sources" was carried out with the purpose of delineating damage maps for almost all the towns of Basilicata. The outputs of this piece of research are downloadable, as *pdf* files, at the Springer Electronic Supplementary Service (see Appendixes B and C).

This section overviews the procedures and tools used for this purpose.

First of all, it should be underlined that for this analysis both the ≪Survey Cards≫ and "Plans" were taken into account (Fig. 7). Another noteworthy aspect is the threshold of damage considered in order to delineate the damage maps. Indeed, given the territorial extension of the study, a reduction in the amount of data to be processed was necessary. In order to do this only the damage episodes classified at least as "notable" were considered. Therefore, the analysis of the effects was restricted to five levels of damage, from ≪Notable≫ to ≪Destroyed≫, willingly neglecting the lowest levels (from ≪No damage≫ to ≪Slight≫). This choice does not hinder the practice needed to emphasize the areas most affected by the earthquake in the thematic maps. Indeed, these are the sectors where in-depth surveys should be addressed to gather information on possible site effects.

On the one hand, the ≪Survey Cards≫ were available for 78 towns (about 60 % of the sites), on the other hand the ≪Plans≫ facilitated the gathering of data for about 30 sites (about 23 %). For about 20 Basilicata municipalities no data were considered due both to the fact that some municipals suffered damage below the threshold considered for the damage analysis (≪Notable≫) and for some locations no source of information recording the effects was found.

The ≪Master Sources≫ allowed mainly to elaborate maps illustrating the pattern of damage at urban scale. In a few case, the limited number of buildings affected by the earthquake allowed only to compile a statistical table of damage that was considered for intensity macroseismic assessment (Fig. 8).

Figure 8 shows that the ≪Survey Cards≫ were useful for delineating the thematic maps in the least damaged areas (province of Matera and south-east area of the province of Potenza); conversely, the "Plans" made it possible to sketch the damage patterns for the villages located in the mesoseismic area (north-west of the province of Potenza).

In order to delineate the damage maps by using the ≪Cards≫ all the damage episodes referred to by the ≪Scheda B≫ were located on the aerial views taken in 2003. The choice to use recent photos was primarily due to the unavailability of photos previous to 1980 with a drawing scale suitable to identify the affected areas. Moreover, the choice was also suggested to appreciate the changes imposed by the earthquake in certain areas of the town affected by a fixed level of damage (for example rebuilding after very heavy effects).

The location of the buildings on a recent map was not easy for villages most affected by the earthquake because they underwent in-depth changes in the urban frame and toponymy during the rebuilding phase (e.g.: villages of Balvano, Tricarico). In these cases it was necessary to perform an analysis of the toponymy by analysing both the cartography coeval to the event (cadastral or phototogrammetric) and local historiography.

Once each damage episode was located correctly, the areas characterized by a certain *homogeneous* level of damage were graphically delimited (Fig. 9).

The criteria for the analysis of the ≪Cards≫ were similar to those followed to handle the ≪Plans≫.

A regional overview of the maps shows that the towns localized in the mesoseismic area experienced, as expected, a coexistence of a large number of levels of damage (Balvano, Baragiano, Barile, Bella, Brindisi di Montagna, Picerno, Satriano di Lucania, and Tito in the province of Potenza). Conversely, differences in levels of effects diminish in far-field areas except for some towns localized in the Matera district (e.g.: Tricarico, Grassano, Grottole, Ferrandina, and Pisticci).

To highlight the differences or analogies between the pattern of effects caused both by the 1980 earthquake and other historical events, some towns of Basilicata were considered more in depth. In particular, the analysis performed for Potenza, Melfi, Rionero in Vulture,

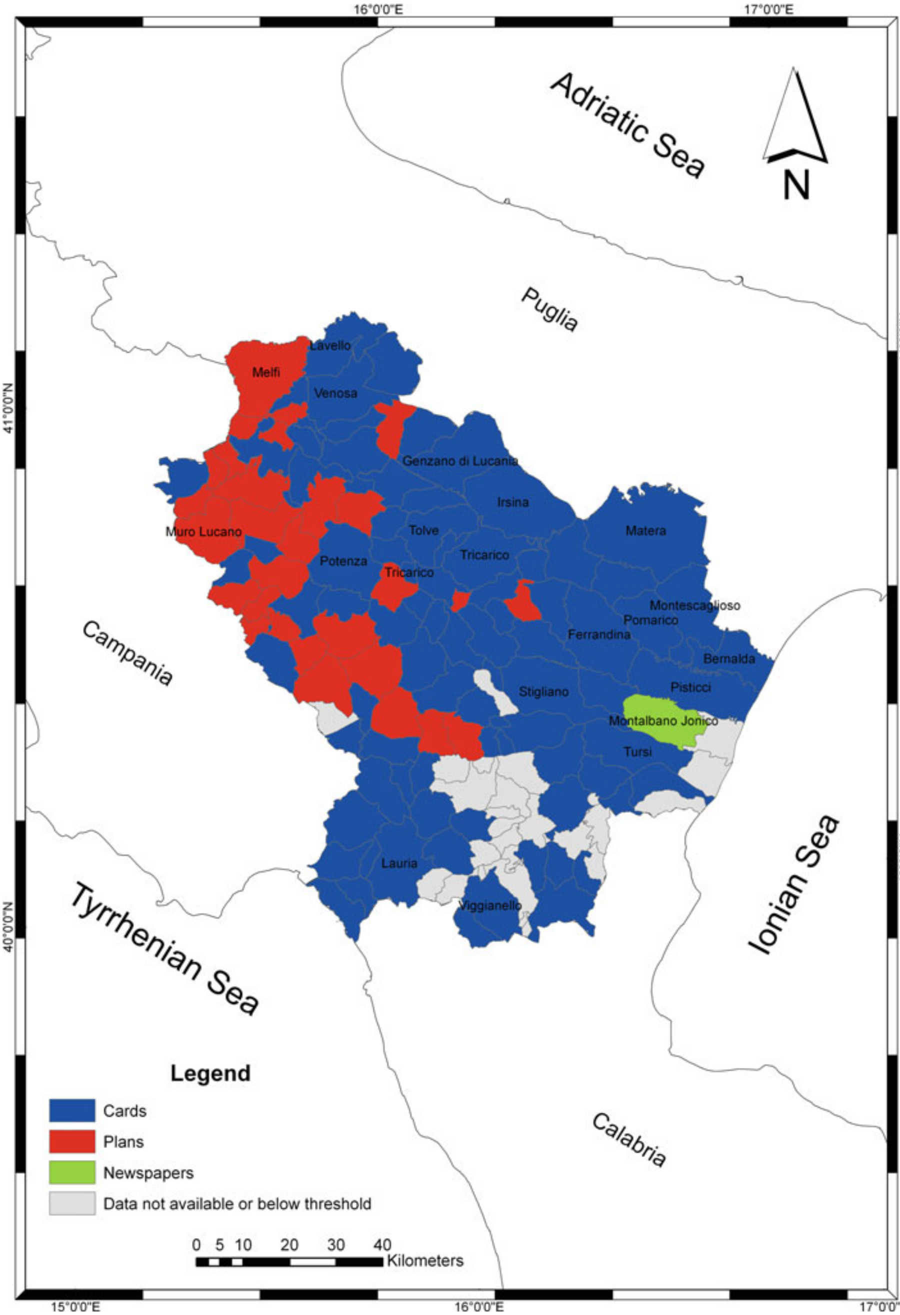


Fig. 7 Written sources considered to delineate the effects for the towns of Basilicata

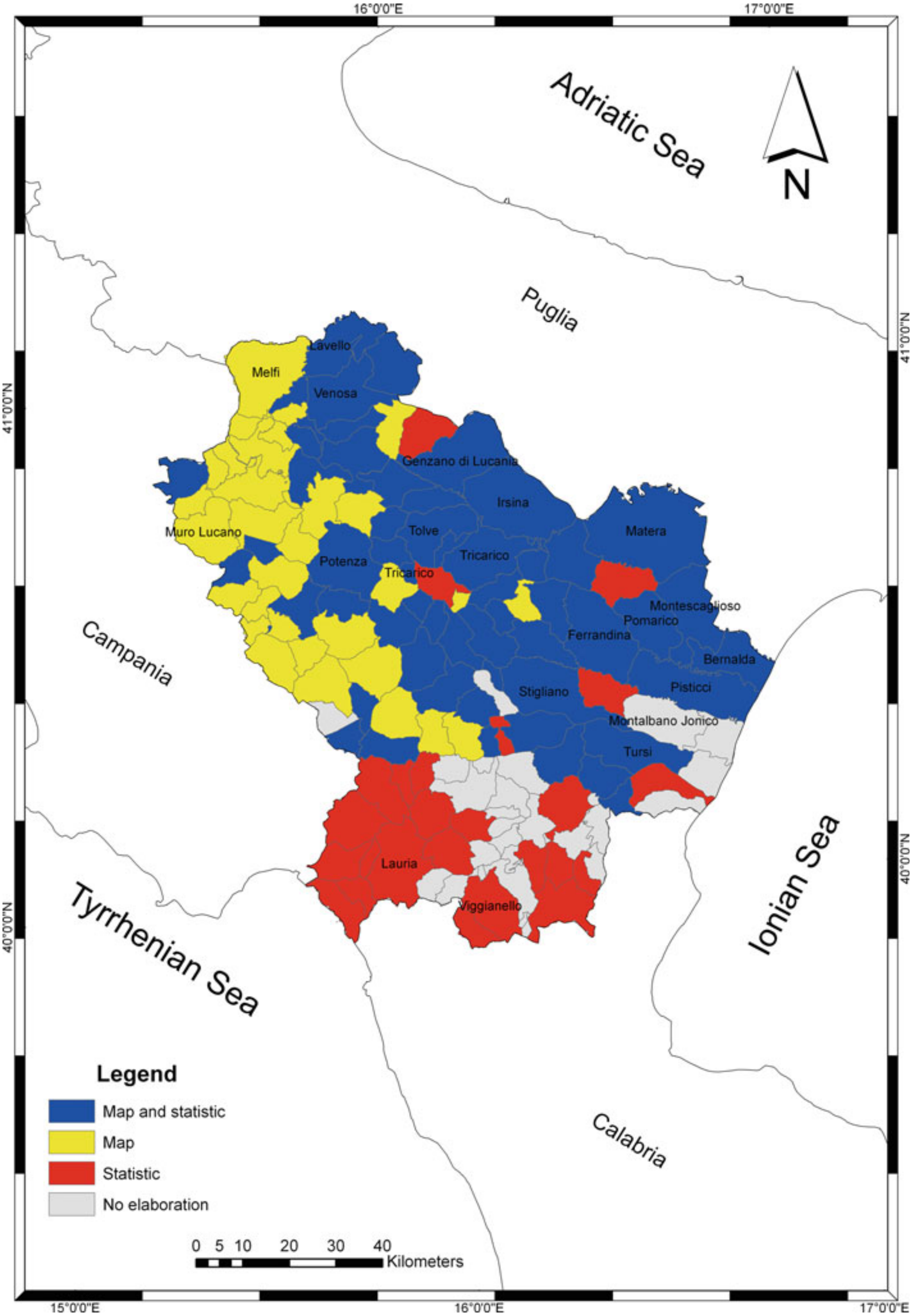


Fig. 8 Outputs for each municipalities of Basilicata. Predominant are the sites for which a twofold elaboration (map and statistic) was carried out. Only for a limited number of little damaged sites it was not possible to obtain any result

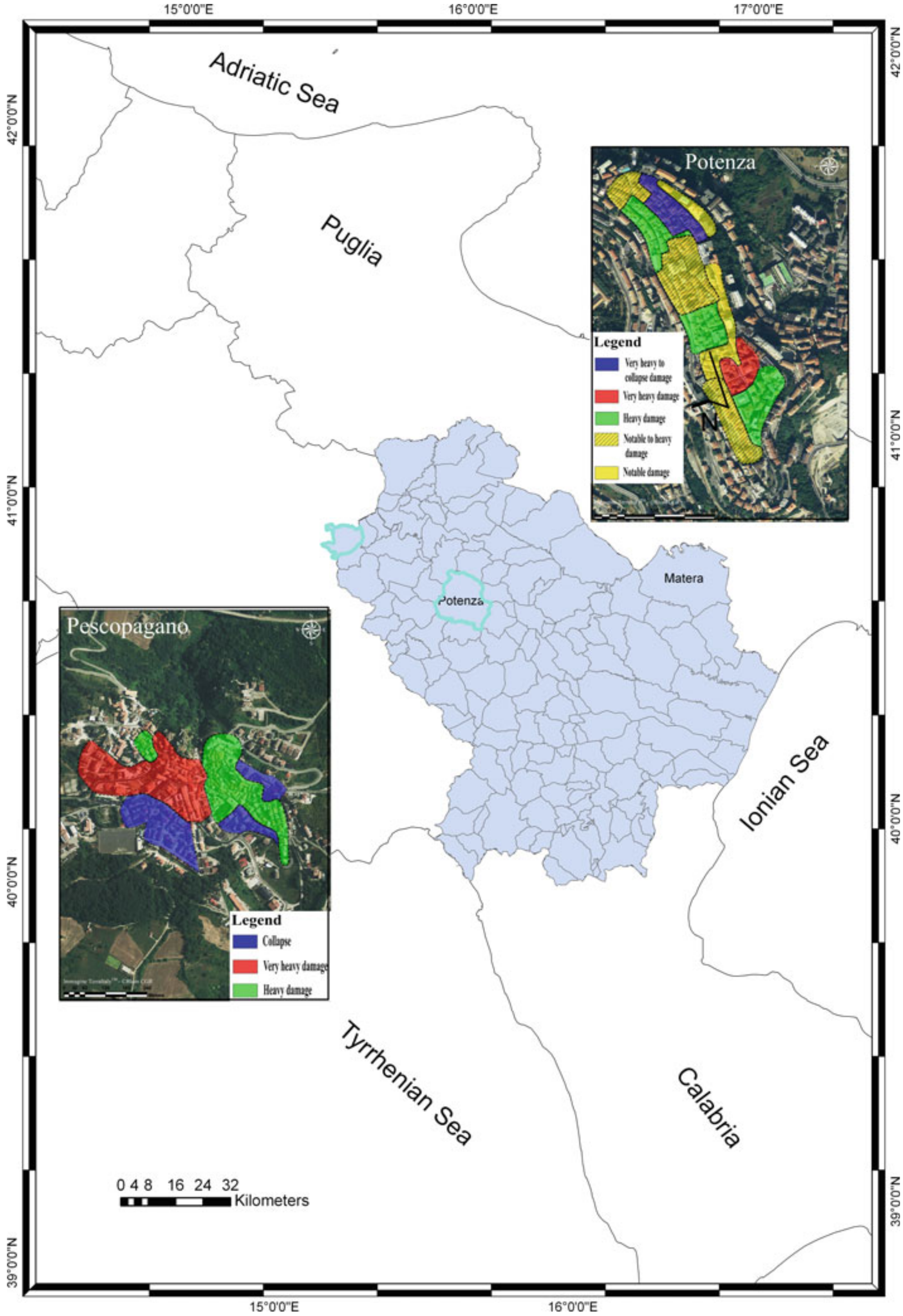


Fig. 9 Example of damage maps supplied as output of this study (all maps can be downloaded, as *pdf* files, at the Springer Electronic Supplementary Service)

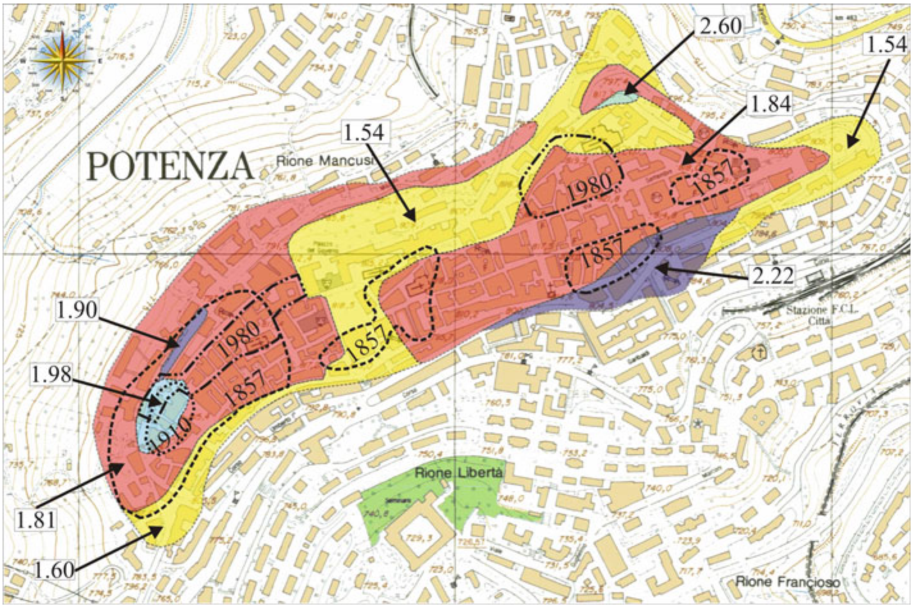


Fig. 10 Potenza historical centre. Areas most affected by the 1857, 1910, and 1980 earthquakes (*broken lines*): the western area of the town suffered systematically an increase of damage for all the three earthquakes. Damage patterns are superimposed on the map of amplifications identified by *coloured areas* (amplifications are supplied as increments of MSK intensity and they are indicated in the *rectangles*. After Dolce et al. (2001), re-drawn). Figure shows a good agreement between the most affected areas and the increments of MSK: heaviest damage occurs roughly where the amplifications are the highest

Castelgrande, and Muro Lucano (in province of Potenza) showed that the areas hit by the highest impact are roughly the same. Moreover, the damage layouts if taken jointly with the geological features of the towns suggest some interesting considerations that will be stated briefly below.

Potenza historical centre lies on the top of a hill made up of sandy-conglomerate overlaid on over-consolidated clays that outcrop all around the relief.

The shear-wave velocity of the sandy-conglomerate is in the range from 150 to 220 m/s whereas the clays show velocity ranging from 600 to 950 m/s (Gizzi et al. 2007). According to Dolce et al. 2001, the contrast of seismic impedance between the two lithologies causes uneven seismic amplifications. Such site effects seem to be confirmed by the patterns of damage caused by the 1857, 1910, and 1980 earthquakes. In fact, the greatest impact on the buildings occurs in the western and eastern parts of the town which are characterized by the highest amplifications (areas in red, blue, and light blue, Fig. 10). Moreover, the areas that were not affected by significant consequences during the three earthquakes exhibit low amplification (areas in yellow, Fig. 10).

Focusing on Melfi, it should be emphasized that the town is located on the top of hill made up of massive lava rock (known as Melfi Haüynophyre) overlying lacustrine and pyroclastic deposits. Figure 11 shows that the town suffered a recurrence of historical effects almost always in two areas. The first one is aligned along NE-SW and it includes the sectors (1, 3, and 4, Fig. 11) where ruins were recorded as a results of the 1851, 1930, and 1980 earthquakes. The second portion is aligned along NW-SE and it was hit hardly by the 1930 and 1980 events (sector 2).

Fig. 11 Melfi historical centre: the quarters most affected by the 1851, 1930, and 1980 earthquakes are superimposed on the lithological map. Greatest damage occurred roughly in the same areas [*Ad* antropic deposits; *Ec* eluvial and colluvial deposits (Holocene); *T* talus (holocene); *Ha* dark gray lava flow (Melfi Haüynophire)—*light gray fill color* indicates maximum thickness of about 10 m (Hal) (557 ± 7 Ky); *L* lapilli fallout (655 ± 7 Ky); *La* lacustrine and alluvial deposits (655 ± 7 Ky); *A* massive ashes (600 Ky)]

Preliminary geological and geophysical investigations show that the considerable consequences caused by the 1930 earthquake in the sector 2 can be explained by the differences in thickness of the lava rock on which Melfi lies. Indeed, results of numerical modelling show that the PGA and Housner Intensity have a significant increase when the thickness of the lava is reduced (portion identified by *Hal*, Fig. 11) whilst the two parameters decrease exponentially when the thickness increases (Parisi et al. 2010). Concerning the damage in the sector 1 (including the southern-western portion of the sector 3) it does not seem to be due to the site effects, but it can be interpreted as the results of both failures under seismic shaking of the vault grottoes on which the buildings are founded and the high vulnerability of the building. In detail, *ad hoc* analysis performed on historical documents allowed the dwellings to be attributed to the vulnerability of class A of the European Macroseismic Scale (EMS-98, Grünthal 1998).

As regards the historical centre of Rionero in Vulture, the geological surveys show the outcrop of ejecta and alluvial sediments. All these deposits are superimposed on a Meso-Cenozoic sediments that marks-out the eastern sector of the town (Fig. 12).

Observing the Fig. 12 it emerges once again that the neighbourhoods affected by the heaviest consequences produced by the 1851, 1930, and 1980 earthquakes are roughly the same. Considering that the technical sources examined do not suggest differences in building vulnerability that justify the clustered effects, it is necessary to investigate the features of the site on which the village is settled on.

Preliminary geophysical investigations based on seismic noise horizontal-to-vertical (H/V) spectral ratio technique (HVSR) were performed to assess the fundamental

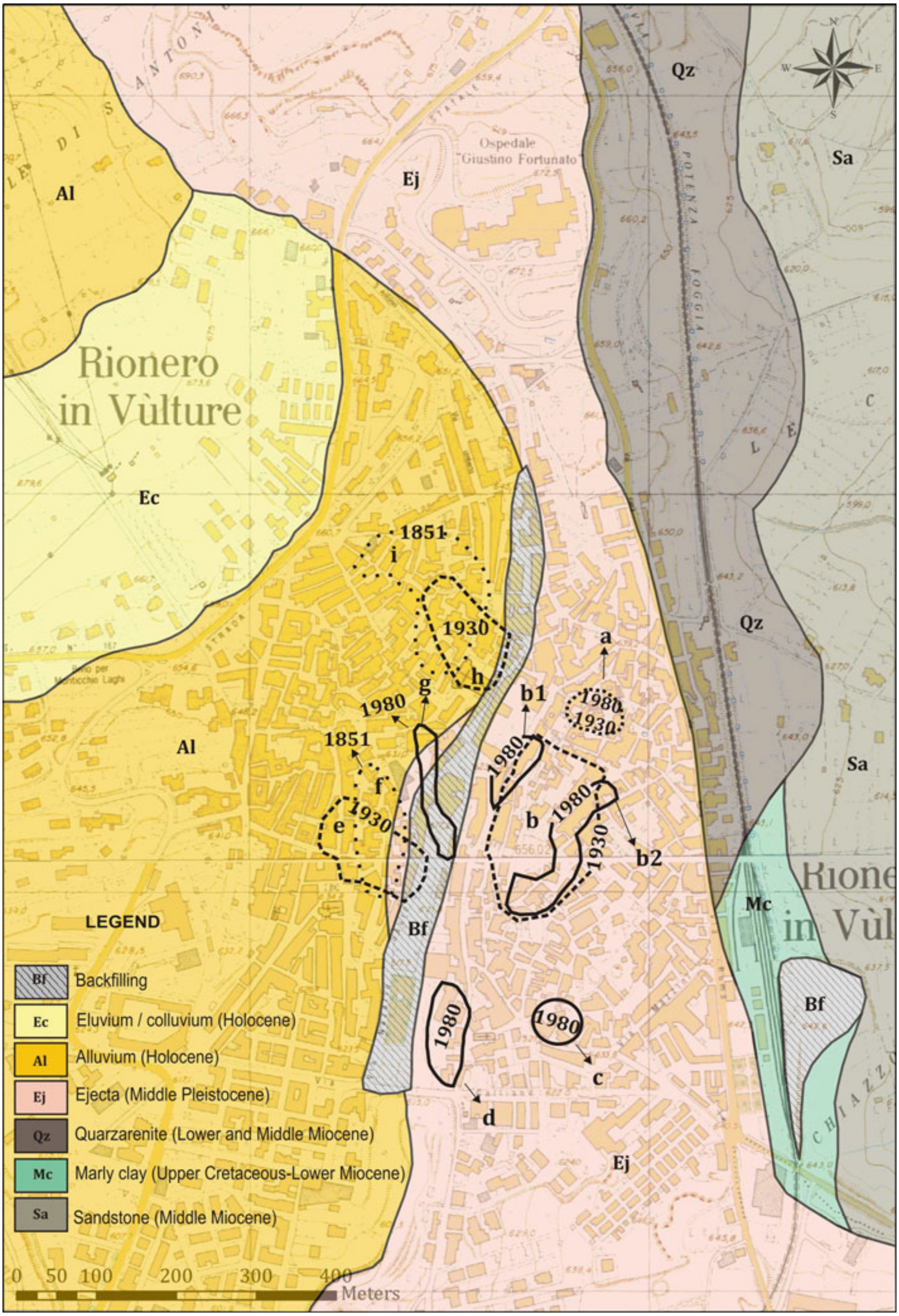


Fig. 12 Rionero historical centre: the neighbourhoods most affected by the 1851, 1930, and 1980 earthquakes superimposed on the lithological map. Sectors 1, 2, 3, and 4 were the quarters hit most hardly by the historical events

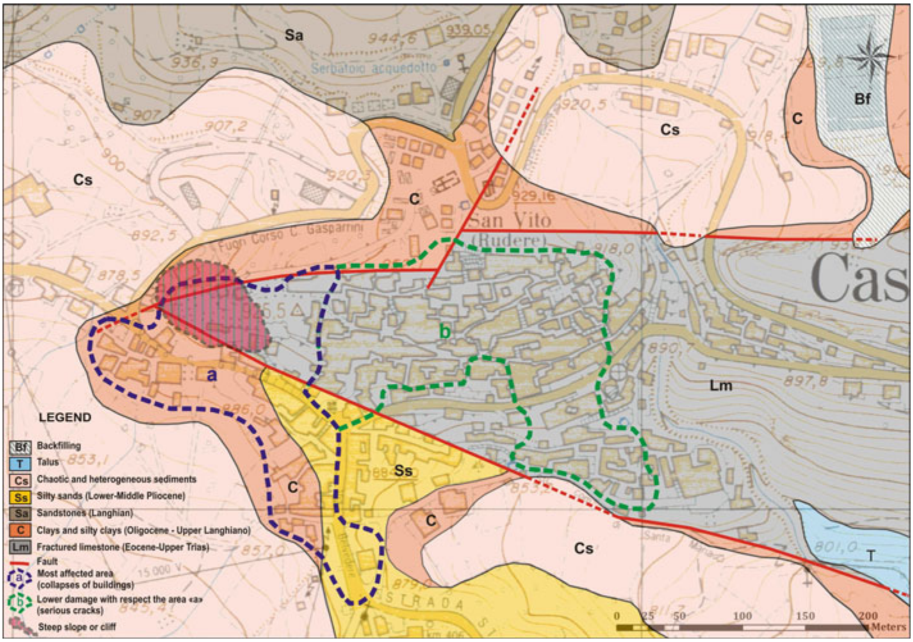


Fig. 13 Castelgrande historical centre: areas ruined by the 1980 earthquake drawn on the geological map. A good agreement exist between these two thematic layers: the greatest damage occurred on soils of poor geotechnical properties or shaped into very steep slope

resonance frequency of the sedimentary cover (Parisi et al. 2010). On the one hand, results reveal moderate peaks of resonance in the central-eastern quarters most affected by the 1930 and/or 1980 earthquakes (sectors a, b–b2, g, Fig. 12). On the other hand, the western area does not reveals clear peaks.

The resonances observed in the eastern area fall within the frequency of engineering interest (1–10 Hz) and, therefore, this can explain the increase of damage caused by the 1930 and 1980 earthquakes.

Another significant factor that increased the seismic effects produced by the 1930 event were, similarly to what said for Melfi, the failures under seismic shaking of the vault grottoes on which the buildings are founded (Gizzi and Masini 2006).

Analyzing the consequences of the 1980 earthquake in Castelgrande, it is clear that the damage map reflects the contrasting geological features of the site (Fig. 13).

The western area of the municipality lies on clays of poor geotechnical properties. Moreover, a strip of buildings is sited on a stiff. These features may increase the shaking levels at the site as it seems to be confirmed by the greatest damage recorded in this portion of the village (area ≪a≫, Fig. 13). Opposite statements can be made for the central-eastern portion of the downtown, characterized by the outcrop of the limestone bedrock. Buildings founded on this part suffered minor consequences compared with those on the western area of the village.

The role played by the geology in influencing the level of damage can also be inferred considering the village of Muro Lucano. This site was ruined by at least two strong earthquakes, the 1694 and 1980 ones, that hit with the heaviest effects the same quarters sited on a strip of little cemented sands and breccias or a steep slope (Fig. 14).

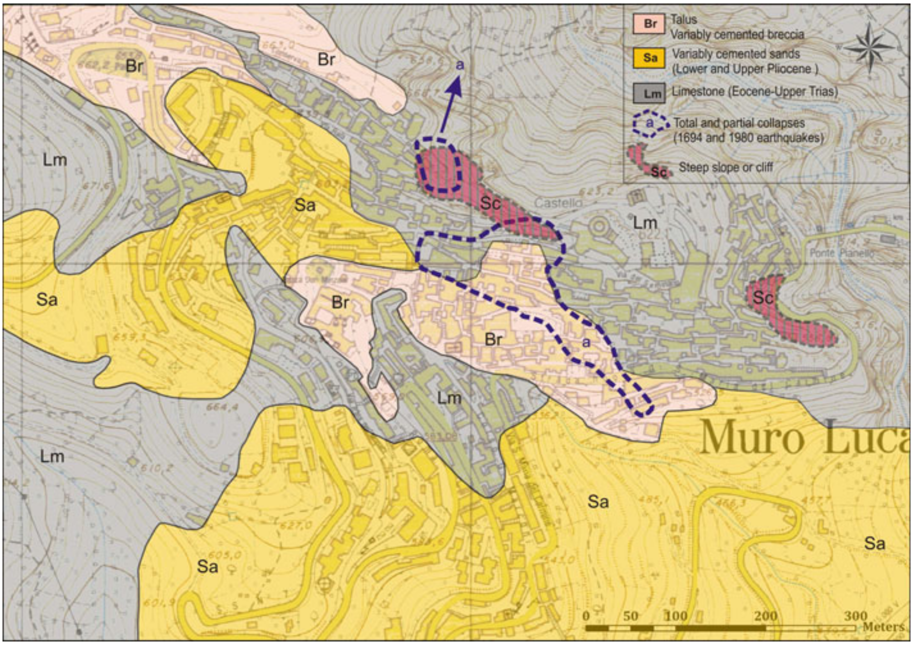


Fig. 14 Muro Lucano historical centre: effects of the 1694 and 1980 earthquakes correlated with the lithological map of the area. The quarters with the greatest consequences are located on soils made-up of un-cemented sands and breccias

Taken as a whole, the examples examined here emphasize the role of the macroseismic data in contributing to identify the area with damage enhancement where further studies could help to separate the role of building vulnerability and seismic amplification.

5 Conclusion

The knowledge of the 1980 Irpinia–Basilicata earthquake prior this study did not allow us to get a complete picture of the macroseismic data. This assertion is sound for the macroseismic field and damage patterns at urban scale. In particular, the intensity data points referred to the southern area of the macroseismic field are few if compared with the total number of locations potentially involved. Moreover, the analysis of the distribution of the effects in the urban conglomeration is lacking for the most of the towns.

With this in mind, the authors carried out an in-depth and systematic analysis of the damage suffered by the municipalities of Basilicata, an area heavily damaged by the 1980 earthquake. The investigation was carried out by considering only unpublished documents, mainly direct-technical sources.

This research supplies two main outputs: the assessment or re-assessment of the MCS macroseismic site intensity for about 80 municipalities and about 80 damage maps. It is the first time that a large earthquake has been the subject of such extensive retrospective inquiries from a macroseismic point of view, with special attention to the analysis of effects at urban scale.

The advances deriving from the knowledge of data intensity will be of help in several seismological fields such as the seismotectonic analysis and evaluation of seismic hazard.

Studies on effects at urban scale led to a significant improvement in the knowledge of the geological-geophysical features of the site so as to undertake actions useful to mitigate the seismic risk. This significant number of cartographic elaborations will converge in the ≪*Atlas of Seismic Effects of Italian Earthquakes*≫, a project aimed at collecting all published and unpublished thematic maps concerning the effects of past earthquakes on the urban contexts to supply a practical tool for those who work in the field of risk mitigation.

Acknowledgments The authors are grateful to Professor Marco Mucciarelli of the Università degli Studi della Basilicata for the critical revision of the text that allowed to improve the original version of the manuscript. Moreover, the authors would like to thank two Anonymous reviewers and the Editor in Chief for their helpful suggestions.

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