Problems of reliability in earthquake parameters determination from historical records

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Abstract
Earthquake parameters determination from macroseismic data is a procedure, the reliability of whose results can be impaired by many problems related to quality, number and distribution of data. Such problems are common with ancient, sketchily documented events, but can affect even comparatively recent earthquakes. This paper presents some cases of Central Italy earthquakes, the determination of whose epicentral parameters involved problems of reliability. Not all problems can ever be completely solved. It is therefore necessary to devise ways for putting on record the uncertainty of the resulting parameters, so that future users can be aware of them.

Key words *Central Italy – historical seismology – earthquake parameters*

1. Introduction

Earthquake parameters determination from macroseismic data is a complex matter. The survey of current procedures by Cecić *et al.* (1996) points out that there are no standard methodologies. In fact different operators working on the same data set could assess different parameters from them. The quality of data can also influence the determination of parameters. Even seismic events with rich intensity data distributions can give problems in this sense, if some data points, carrying more weight than others in the assessment procedure, present some «internal» weaknesses. Obviously, things can be even more difficult as one goes deeper back in time: historical earthquake data tend to get fewer, historical testimonies (however reliable) sometimes offer only very few really useful data for reconstructing earthquake effects.

Central Italy is not an exception to these «rules». Generally speaking it is a propitious field for historical investigation, with many potential sources for the centuries from the Middle Ages onwards. However there are peculiarities (such as demographic trends, geographic features, ups and downs in the production and preservation of written sources, etc.) which can impair the informative potential of some parts of Central Italy, making them almost «silent» (at least in some periods) in terms of textual accounts of earthquake effects. This is at least one of the reasons why there are many central Italian earthquakes whose intensity data distributions (albeit based on data of good quality) show weaknesses which could affect the reliability of epicentral parameters.

This paper presents some cases taken from a set collected over ten years by the National

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Group for Protection against Earthquakes of Italy's National Council of Research during an investigation of major earthquakes which occurred in Central Italy from the year 1000 to present times. Most of them are related to ancient events (no later than the XV century). However, as historical seismology does not study only «very old» earthquakes and as reliability problems can be found to affect even comparatively recent, well attested events, one modern case has also been included.

2. Case histories of parameter determination

2.1. *A good data set: the earthquake of 3 October 1943, Southern Marches*

On 3 October 1943 a strong earthquake occurred in the Southern Marches. Considering that the area was then under military occupation, this event is very well documented. The study by Raccichini *et al.* (1985) lists 86 intensity data points (fig. 1). Most data were taken from a detailed official damage survey (ASAP, 1943-1949), compiled shortly after the event and allowing a good definition of the near-field. The worst damage is reported in San Venanzo, a hamlet belonging to the commune of Castignano. Raccichini *et al.* (1985) sum up the effects there as the collapse of *«most of the houses»* and assess IX degree MCS. The study stresses that *«the average intensity for the municipality of Castignano does not reach IX»* and that *«it is not possible to decide between the VIII and IX degree for the village of Castignano itself»*.

The San Venanzo IX degree is the only one in the 1943 intensity distribution, which includes sixteen data points of VIII. In this case, which is frequent enough, most operators would probably adopt determination «A» (fig. 1: epicentre between San Venanzo and Castignano) with an epicentral intensity of either

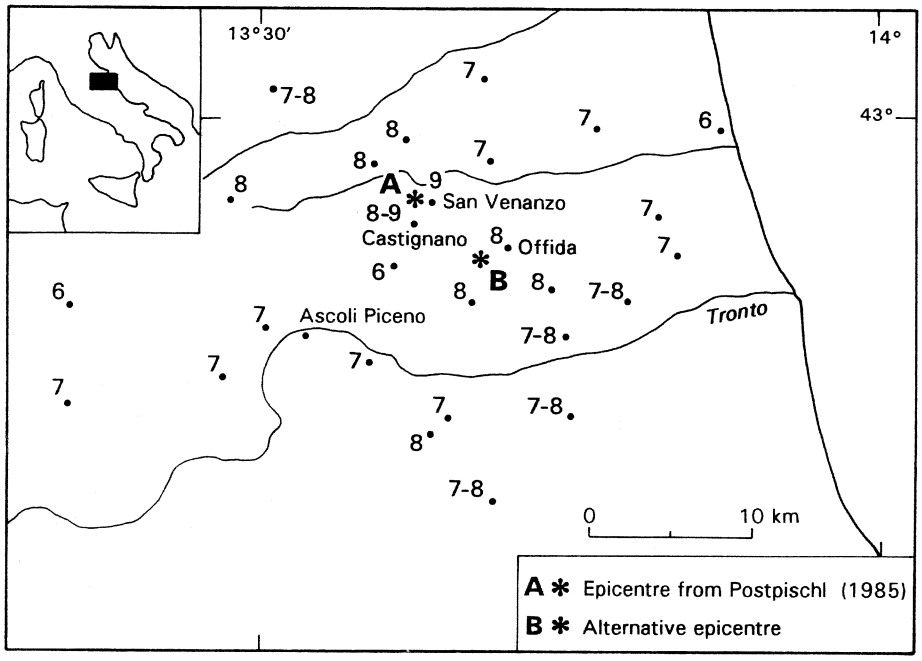

Fig. 1. Alternative epicentral parameters for the event of 3 October 1943 (main data points from Raccichini *et al.*, 1985).

VIII-IX or IX, according to the weight given to the point of IX.

When parameter determination hinges on a single data point, it is advisable to evaluate its reliability through an *ad-hoc* investigation, which can involve side-studies of some complexity. One case, described by Moroni (1994), required recourse to indirect sources (cadastral maps) in order to reduce the uncertainty about the maximum intensity assessed to one locality through official damage surveys.

Size seems to be the element which most likely could affect the weight to be given to the San Venanzo data point in the 1943 intensity data distribution. The problem of «*how large or small a place may have an intensity assigned*» is in fact discussed by the Guide to the use of the macroseismic scale annexed to the European Macroseismic Scale 1992 (Grünthal, 1993). The Guide concludes that «*the smallest place should be not smaller than a village*». After a search for contemporary documents *in situ* and interviewing local witnesses, it can be agreed that in 1943 the place-name «San Venanzo» designated about 15 houses – at least two of them fairly sizable farms – scattered round a country chapel. It is a tiny sample of buildings, if compared with nearby Castignano, the commune centre and namesake, that had nearly two hundred buildings. San Venanzo could barely reach the threshold established by Grünthal (1993) and therefore be a very «weak» data point.

This could influence the determination of parameters. Leaving out, or not giving special weight to the San Venanzo data point, most operators would probably adopt the determination «B» (fig. 1: barycentre of the degree VIII data points) with an epicentral intensity of VIII. Other solutions are also on record: for instance the Italian seismic catalogue by Postpischl (1985), which is based in this case on Racchini *et al.* (1985), proposes an «A» location with an epicentral intensity of VIII.

This case shows that, even for a recent, fairly well known earthquake, a single data point can cause the parameters to vary, albeit slightly (about 10 km and one intensity degree are involved), according to the weight it is given. This is a warning with respect to the reliability of parameters derived from less promising data sets.

2.2. *A poor and contradictory data set: the earthquake(s) of August 1414, Western Tuscany*

Table I shows the events located in Tuscany in August 1414 and August 1413 by Postpischl (1985), based in this case on Baratta (1901). Figure 2 maps the data distributions reconstructed from the information collected by Baratta, according to the dates proposed by Postpischl (1985). Baratta does not give an exact date for the Sansepolcro-Arezzo information: it would seem that it was related by default to the event of August 7 by the Postpischl catalogue compilers.

The information collected by Baratta comes from a mixed set of sources. Some are coeval or quote known coeval sources. These can be evaluated and crosschecked (Istorie ..., XV century; Buoninsegni, XV century; Ammirato, XVI century; Ghirardacci, XVI century; Bonito, 1691; Soldani, 1798; Pilla, 1846). Others are neither coeval nor do they quote older sources (Farulli, 1713; Farulli, 1717): it can therefore be difficult to check their statements.

Table I. Parameters of the Tuscan events of 1413-1414 (Postpischl, 1985).

No.	Year	Month	Day	Hour	Epicentral area	I_0	Lat.	Long.
366	1413	08	08	–	Siena	70	43 20	11 20
367	1414	08	03	21	Cascina	70	43 40	10 30
368	1414	08	07	13	Sansepolcro	90	43 30	12 10
369	1414	08	07	18	Sansepolcro	80	43 30	12 10

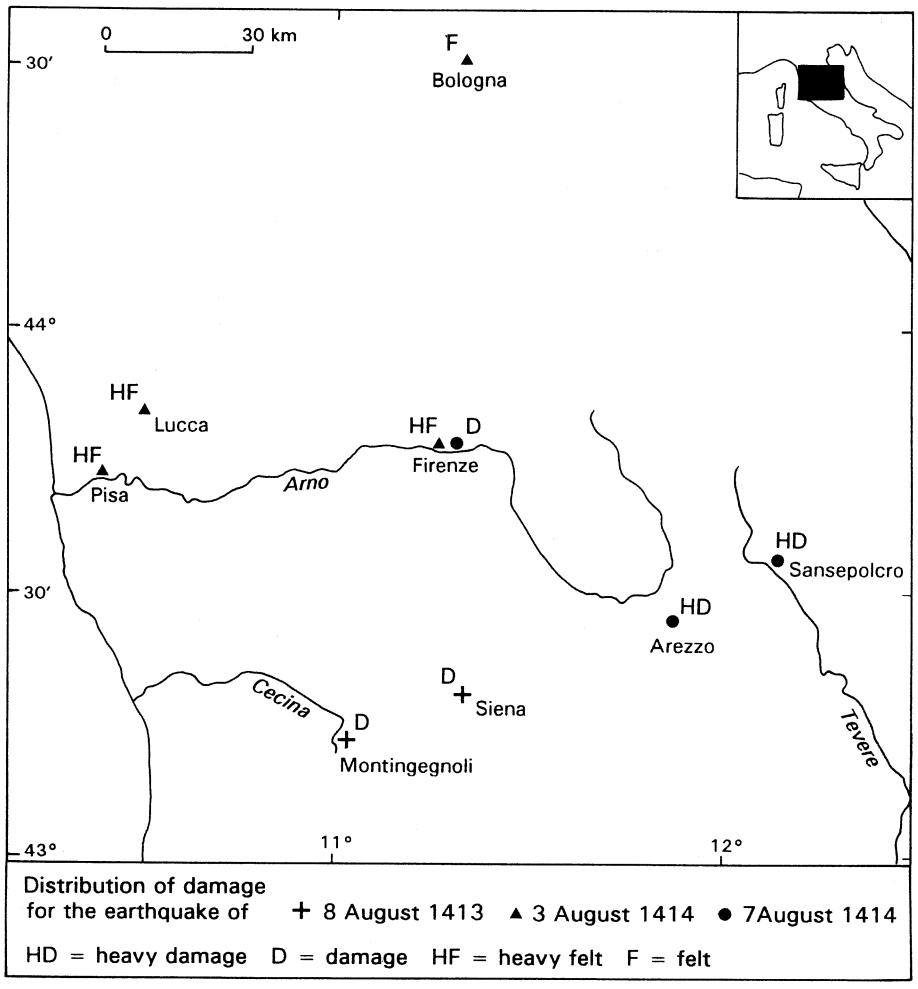

Fig. 2. The events of 1413-1414: distribution of effects from the initial data set (Baratta, 1901).

An investigation was started in order to reconstruct a more homogeneous set of data (Castelli *et al.*, 1989). The information on Siena and Montingegnoli (related by Baratta to an event of «August 1413») was found to be in fact related to August 1414. Data on more places affected by the 1414 events were retrieved from Soldani (1798), a source quoted by Baratta, which had however overlooked them. No contemporary evidence was found to support the information – supplied by Farulli (1713, 1717) – on a damaging earthquake in Arezzo and Sansepolcro. Archive evidence indirectly suggests that, in August 1414, life was going on normally in Arezzo (the Sansepolcro archives show a gap for that year). There is no record of such an earthquake in Arezzo or Sansepolcro either in contemporary chronicles written in Florence and Siena (Buoninsegni, XV century; Corazza, XV century; Montauri, XV century) or by Arezzo and Sansepolcro chronicles older than those by Farulli (Bercor-

dati, XVI century; Burali, 1638; Goracci, 1643). Coupled with the knowledge that Farulli was judged to be a very inaccurate historian, both by old and modern critics (Mittarelli and Costadoni, 1764; Pasqui, 1899-1937), this led to discarding the Arezzo-Sansepolcro data.

A valuable result of the investigation was the retrieval of data on seismic effects in the area south-west of Siena (where Montingegnoli, Radicondoli and Belforte are placed). This area was marginal and underpopulated, much poorer in written local sources and much less likely to fall under the scrutiny of outside observers than the highly urbanised areas of Central and Northern Tuscany. Possibly the 1414 data are the oldest record of seismicity in this zone, well known, in later times, for thermal and volcanic phenomena.

As a working hypothesis, all data on major effects were related to August 7. Florentine sources (Buoninsegni, XV century; Corazza, XV century; Rinuccini, XV century) record that shocks were felt from the first days of August onwards, but according to the more accurate ones (Corazza, XV century; Buoninsegni, XV century) a damaging event occurred on the 7 August. A Pisan source (Manuscript note, XV century) reports a «*huge earthquake*» in

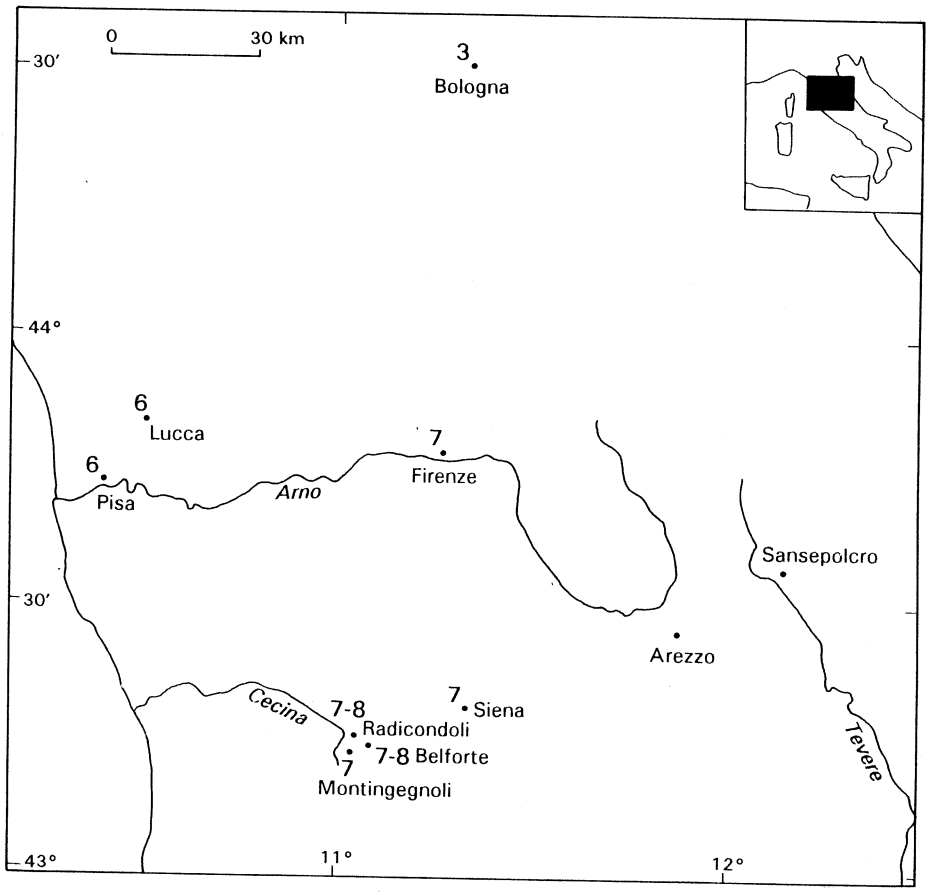

Fig. 3. The event of 7 August 1414: intensity data distribution from the present data set (Monachesi and Castelli, 1993).

Pisa, Lucca and Florence on August 3 (almost at the same hour given by Florentines for August 7). This source, which makes no mystery about the Lucca and Florence information being hearsay, could have confused the dates of different events: in fact the Florentine diarist Cambi (XV century) seems to hint that the shocks started on August 3.

The intensity data distribution derived from this data set (fig. 3) shows a cluster of intensity VII and VII-VIII data points in the Montingegnoli-Siena area and some VII and VI data points placed northwards, in the Arno valley. Between these two areas there is a «blank zone». The term «blank» relates here to the lack of data, not to a complete lack of settlements, though in the XV century this area was, on the whole, much more sparsely populated than the Arno valley.

The distribution of fig. 3 could justify either an epicentral location in the Montingegnoli-Siena area with I_0 = VII/VIII or one in the «blank zone», with a higher epicentral intensity. To evaluate the various possibilities, the 1414 intensity data distribution was compared with those available for some major earthquakes on record in Western Tuscany (fig. 4). The aim was not to find a better documented

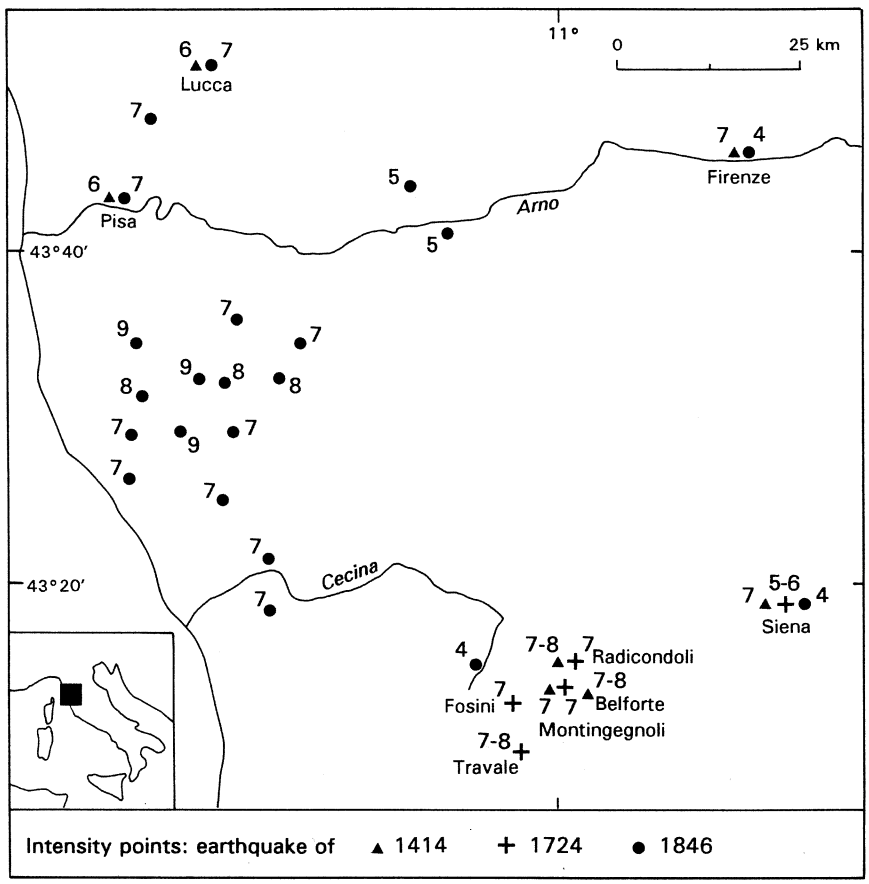

Fig. 4. A comparison between intensity data distributions: 1414, Western Tuscany; 1724, Travale; 1846, Orciano Pisano.

«twin» for the 1414 event (in order to adopt its epicentral parameters) but to evaluate the consistency between the effects reported in 1414 and in better documented cases.

No definite conclusions were reached. The intensity distribution of the 1724 earthquake fits the 1414 pattern in the Montingegnoli area. The 1846 earthquake (located on the outskirts of the 1414 «blank zone», with higher intensity values than the 1414 event) is coherent with the effects attributed to Pisa and Lucca in 1414, but reaches the Montingegnoli area with effects no greater than IV. The problem of comparatively high intensity data points placed far from the higher intensity area remains unsolved. Possibly this feature could be partly removed by connecting the Pisa and Lucca information to a separate event which occurred on August 3. However, this solution would not apply to Florence, where the event of August 7 seems well attested.

In order to determine parameters a choice had to be made: it was decided that the 1414 epicentre should be «dictated» by the four VII and VII-VIII data points in the Montingegnoli-Siena area, and the epicentral intensity was assessed as VII-VIII. This is, however, a subjective choice, made in the awareness that a very different alternative could also be reasonably proposed. The alternative solution would involve a variation of some 40 km in location and more than one degree in epicentral intensity.

2.3. *A very poor data set: the April 1458 event in the upper Valtiberina*

The April 1458 event (fig. 5a) was part – as «case C» – of a set of cases which were distributed as «homework» to the participants in the first meeting of the ESC Working Group «Macroseismology» for a survey of the current practice of epicentre determination from macroseismic data (Cecić *et al.*, 1996). Most people solved case C by putting the epicentre between the two higher intensity points (usually nearer the point of IX) with an epicentral intensity of IX. However, the data set is so poor that it could be compatible with other solutions.

The 1458 event occurred in the upper valley of the Tiber (alta Valtiberina). From the historical viewpoint its sources are of high quality, including first-hand reports written a few days after the event (ASMI, 1458a, 1458b; Cronaca A, XV century). These reports are partial, focusing on effects in Città di Castello and Sansepolcro, the leading towns of the area and also the highest intensity points assessed in 1458. It is known that the event damaged some unnamed hamlets and walled villages placed in the countryside of Città di Castello («*in pagis et castris multa damna fecit*», Cerboni, XV century). This information cannot be translated into intensity data points; it exists, however, suggesting that the near-field could include the lower slopes of the Apennines that, in the XV century, were the territory ruled by Città di Castello.

This hypothesis is substantiated by a comparison between the 1458 intensity distribution and that of the 1389 event (fig. 5b). This earthquake caused the heaviest effects in the Apennine hamlets of Baciuccheto and Pietragialla, ruled by Città di Castello, which «*collapsed*» («*caddero*», Laurenzi and Laurenzi, XV century), while the nearby village of Castelguelfo was «*destroyed and ruined*» («*destructum et ruinatum*», ASCCC, 1389): in all three cases an intensity IX MCS can be assessed.

The effects recorded in Città di Castello and Sansepolcro in 1389 are comparable to those of 1458. A reasonable alternative location of the 1458 event could therefore be proposed, about a dozen km eastwards from those chosen by most «case C» solutions, while the epicentral intensity could be assessed as IX-X.

2.4. *Some cases of events known through single data points*

Seismic events for which only one data point is available are tricky cases. The commonest way to determine parameters (epicentre located in the affected locality with $I_0 = I$) is probably only one of the possible solutions. Some way to evaluate the maximum credible distance from the «presumed epicentre», assessed this way, to the real epicentre should be devised, but this can be difficult.

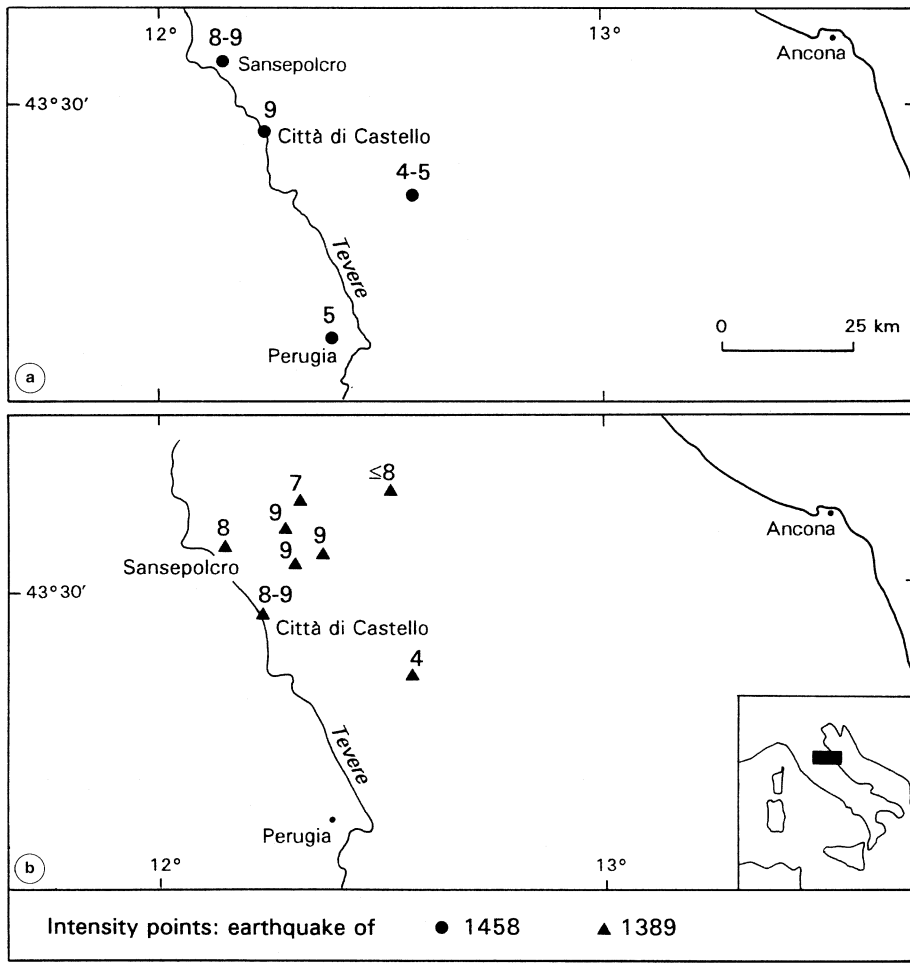

Fig. 5a,b. A comparison between intensity data distributions: a) 1458, Città di Castello («case C»); b) 1389, Bocca Serriola.

2.4.1. 11 July 1293, Pistoia (Tuscany)

On 11 July 1293 an earthquake caused many houses to collapse in Pistoia (fig. 6). An intensity VIII can be assessed from this information, which is reliable, coming as it does from three independent contemporary chronicles (Chronicon Parmense, XIV century; Cronaca senese, XIV century; Tolomeo da Lucca XIII-XIV century). The near field cannot be defined more precisely as the chronicles do not describe what occurred outside Pistoia. This does not mean that nothing happened there, but simply that, in the eyes of a medieval, non local chronicler, Pistoia was more newsworthy than its hinterland. In fact Pistoia was the only city in a radius of some thirty km, in a countryside partly occupied by marshy, underpopulated plains, partly dotted with country villages (Herlihy, 1972).

Not to assess epicentral parameters from the single 1293 data point would lead to «forget» a

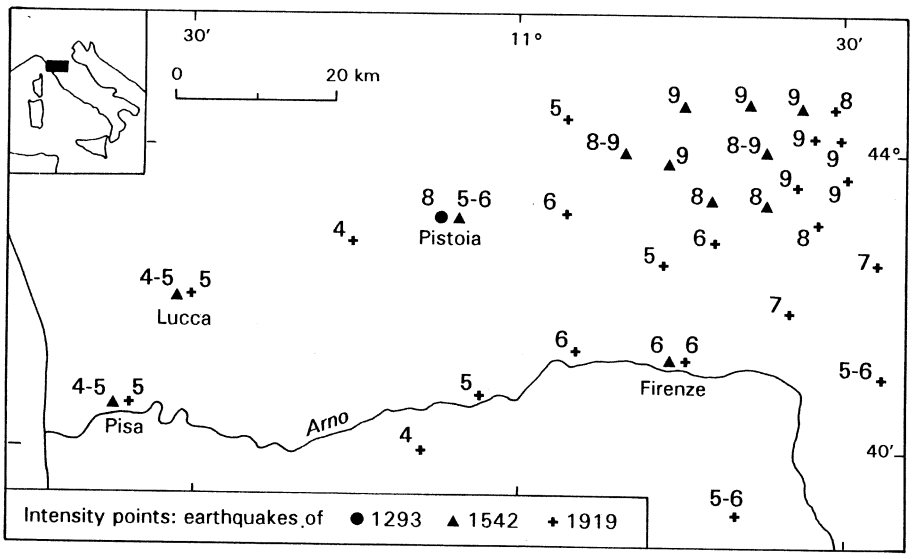

Fig. 6. A comparison between intensity data distributions: 1293, Pistoia; 1542, Scarperia; 1919, Mugello.

strong earthquake in the Pistoiese area, and one of the stronger earthquake effects on record for Pistoia from the year 1000 onwards. On the other hand an epicentral location of the event «in» Pistoia could be judged not very reliable. It would be hard, however, to evaluate what the maximum credible distance could be to an alternative epicentral location. A comparison with the intensity distributions of better documented events, originated in the Mugello area, north of Florence which is known for its seismic activity, does not supply decisive data (fig. 6).

Between the end of XIII and the first half of XIV centuries quite a few chroniclers were at work in big towns placed 40/100 km far from Pistoia (Florence, Lucca, Pisa, Bologna). None records the occurrence in his home town of an earthquake which could be identified with the event recorded in Pistoia, a hint that the 1293 near field could be somewhat restricted. In this light, a reasonable alternative to a location of the event «in» Pistoia could be a location somewhere not farther than 10/15 km from the city itself, maybe in the nearby Apenninic area, whose seismic characteristics are well attested from latter-time activity.

2.4.2. 2 February 1477, Foligno (Umbria)

In 1477 a notary employed by the Foligno municipality recorded in the council's minutes that on February 2 «*an earthquake left no building undamaged in town, to the extent that some of the oldest and weakest collapsed*» (ASFOL, 1477). The soundness of the source is out of the question, not so much because of its official origin, but because the notary would have gained nothing at all from recording a fictive or exaggerated description.

From this testimony an intensity VII-VIII MCS can be assessed for Foligno. The epicentre could be located «in» Foligno, but an intensity of VII-VIII recorded at this place could also be compatible with the intensity distributions of two other earthquakes (fig. 7). These events, which occurred in 1791 and 1832, are both well documented by official damage surveys and other contemporary reports. Assuming that the 1477 earthquake was generated in the area of these events, it can be concluded that to locate the epicentre in Foligno with I_0 = VII-VIII could involve an «error» of about 10 km and maybe one degree of intensity.

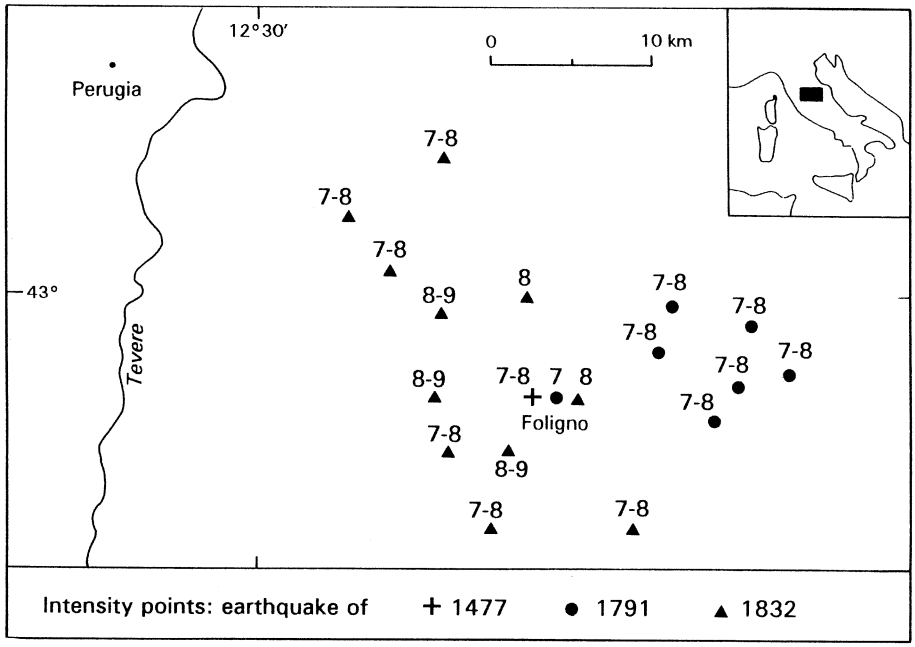

Fig. 7. A comparison between data distributions: 1477, Foligno; 1791, Scopoli; 1832, Foligno.

3. Conclusions

Among the more usual ways of exploiting historico-seismological data there is the compilation of parametric earthquake catalogues. To this end an earthquake's location and size – meaning a couple of co-ordinates and an epicentral intensity value – must be derived from each intensity data distribution.

Although limited to Central Italy, the case histories presented here show that, often, more than one set of epicentral parameters could be derived from the same intensity data distribution. This does not depend solely on problems of a historical nature. Even in well documented, recent cases, like the 1943 event, epicentral parameters determination can be uncertain, if comparatively so (for 1943 the alternative solutions are no farther than 10 km and one intensity degree from one another). Generally speaking, the degree of uncertainty is closely related to the amount of available information, meaning not only the number of available intensity data points but also the quality and reliability of each of them.

Parametric earthquake catalogues describe each listed event through a single set of epicentral parameters. Therefore, they do not disclose the complex interpretive procedures that can be hidden behind each set of parameters, nor to understand why one set was chosen rather than any other.

However large the range of possible solutions, in the end the requirements of parametric earthquake catalogues will force us to choose one set of epicentral parameters, but the chances are that the choice will be a subjective one.

In order to keep this subjectivity under control, no choice should be made without having previously checked the various possible interpretations, with the help of additional information – such as the comparison with other (better documented) intensity distributions – useful to evidence its limits.

This paper does not presume to solve this situation but only to point out a problem and to stress that it is necessary to find ways to qualify earthquake parameters determination from macroseismic data, as is ordinarily done with earthquake parameters determination from instrumental ones.

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