NEW DEVELOPMENTS IN MACROSEISMIC INVESTIGATION

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ABSTRACT

In the last fifteen years, in Europe and throughout the world, a significant amount of resources has been devoted to improve the seismic catalogues, mostly for what macroseismic data are concerned. This has led both to the retrieval of a huge amount of data, and to a general reconsideration of their current use.

The catalogue records are the final output of very complicated research, decisions and synthesis, often performed, in a very rough way, by seismologists with some historical understanding. These steps are now accomplished by multidisciplinary teams including professional historians, providing data far more reliable than before, as some of the cases presented here demonstrate. The availability of such amount of data has raised the question whether catalogues can still be considered representative of the set of data used to produce them.

The answer is most likely "no": for instance, the habit of representing the whole earthquake by its "centre of mass" (t_o, lat, lon, h_o, I_o, and so on) is revealing unsatisfactory, as the use of epicentres and attenuation laws is becoming unable to approximate even the starting intensity points. From another point of view, however, it seems possible to develop new ways to exploit macroseismic data, according to the purpose for which they are needed.

A short overview of the project "Review of Historical Earthquakes in Europe", sponsored by the Commission of the European Communities, is presented as Appendix.

INTRODUCTION

Macroseismic data are commonly considered less reliable - by nature - than instrumental ones. At the same time they are widely used, as there is no alternative to them for considering the seismicity of more or less wide time-windows. This is one of the reasons why, during the last fifteen years, in many European countries considerable efforts have been devoted to improve the macroseismic data set. The improvement rate has often been estimated by the increase in number of earthquakes listed by the catalogues, sometimes resulting in the expansion of the "completeness" time interval. But the investigations have also improved the amount and the quality of the data related to many earthquakes.

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This paper takes the reliability of macroseismic data as the leading thread through some case studies in Italy and Europe which, however, don't pretend to give an exhaustive overview of all investigation carried out. Some more results can be found in the Proceedings of some Conferences, listed at the end of the paper.

The background of the investigation presented here can therefore be very different from other parts of the world with respect to history, sources, urban settlements and, mostly, to the time-windows for which earthquake records (archeological and documentary evidences and so on) can be found. However, most methodological aspects can apply in every situation.

MACROSEISMIC OBSERVATIONS

Macroseismic data generally don't carry accuracy estimates, or reliability assessments. To appreciate any improvement in this field, it is first necessary to understand how the data commonly used are formed, and then find a way to assess the reliability of the process.

The most popular format by which macroseismic data are used is the isoseismal map and the catalogue record (Fig. 1).

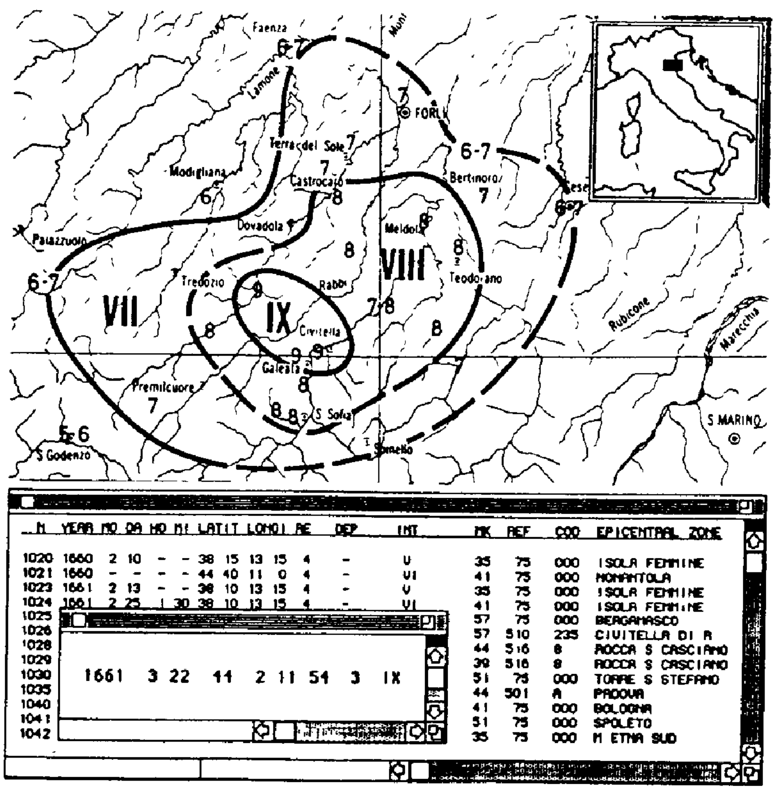

Fig 1 - 1661, Romagna (Northern Italy) earthquake.
upper: isoseismal map with intensity points (from Ferrari et al. (b), 1985)
lower: catalogue record derived from the isoseismal map

Both are not "observations", but the result of elaborations on some "primary" data, performed by someone having the classical earthquake model - focus and seismic field - in mind.

Macroseismic observations, or "primary data", are the historical records, or the macroseismic questionnaires. Processing them is not different, in principle, from the way instrumental data are processed (Fig. 2). In practice, the catalogue records are the output of a process which can be sub-divided into the following steps:

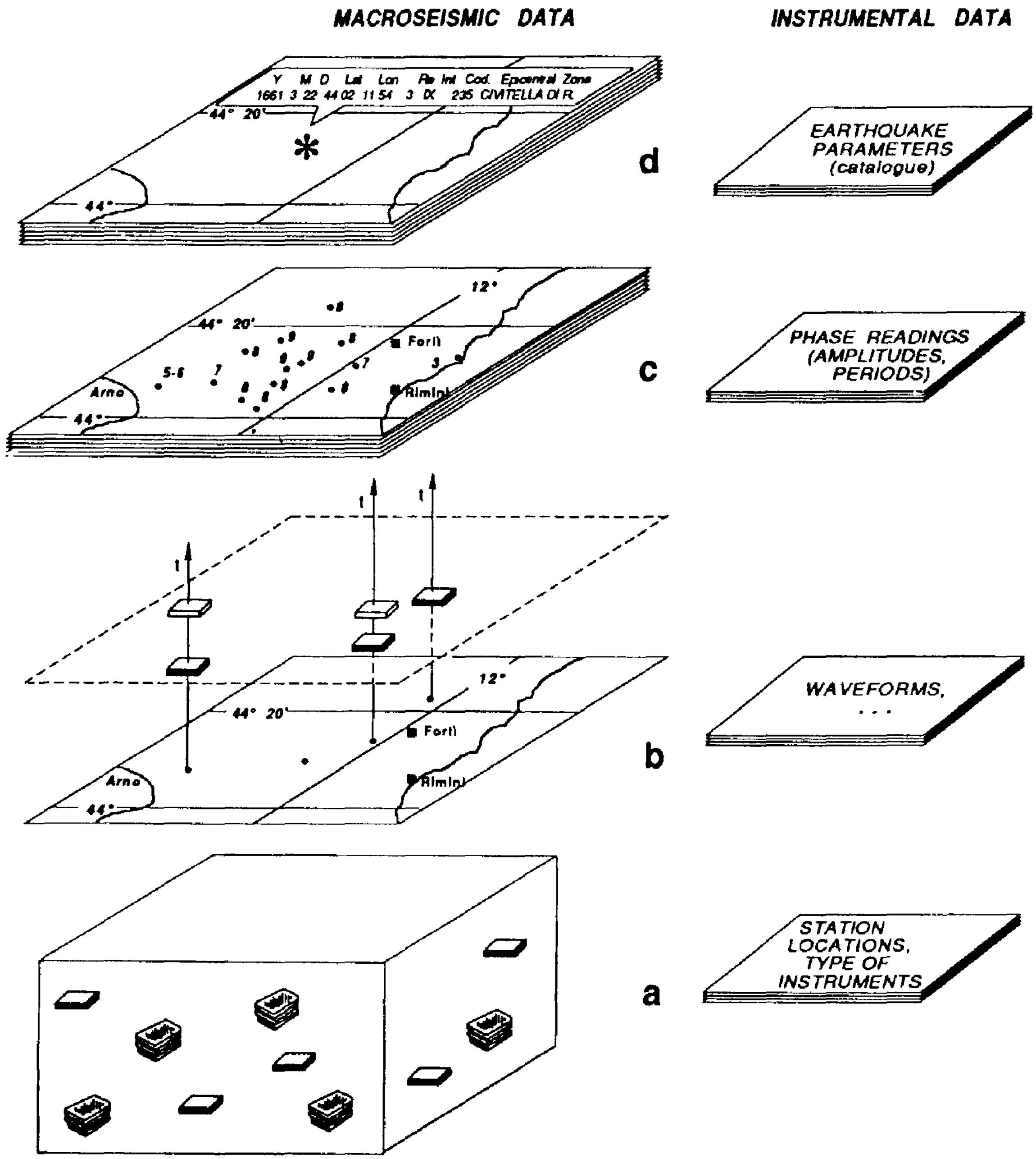

Fig. 2 - Scheme of the procedures of macroseismic processing, compared to instrumental (from Stucchi et al., 1990; Postpischl et al., 1991).

a) historical sources are investigated: records on earthquakes are extracted and referred to a time-space reference system;
b) someone decides that some records belong to the same event and "builds up" an earthquake: t_0 is assigned;
c) records are interpreted in term of macroseismic intensity: an intensity map is produced;
d) isoseismals are drawn through the intensity points and the focal parameters (lat, lon, h_0, I_0 and so on) are computed, according to some rules.

An "earthquake", therefore, is always the result of the critical assemblage of some historical records, at least one. As historians know, every investigator working on the first part of the process (a, b) may be seen as dealing with a sort of puzzle, where:

-the pieces are hidden somewhere;
-nobody knows how many they are;
-they will not fill up the board;
-some of them might be contradictory;
-some more problems can arise.

Moreover, he may be dealing with several puzzles/earthquakes at the same time, having all pieces mixed up. The risk of putting one piece on the wrong board is frequent, due to timing inaccuracy of the sources and different chronological styles. In the same way, the risk of putting a piece at the wrong place on the board is also very high.

The second part (c, d) is more familiar to seismologists and needs no further remarks.

Reliability factors

Following the scheme of Fig. 2, the factors which affect the reliability of the macroseismic data can be summarized as follows:

1) the set of sources which have been investigated. This is probably the most critical point and also the less referenced in the papers;
2) the time-space interpretation of each record, and the assemblage of some of them to build up an earthquake;
3) the intensity assessment. Beside the well known problems arising from the use of macroseismic scales, the availability of background information, such as number and typology of buildings, can be very important;
4) the number and distribution of the intensity points;
5) the way isoseismals are drawn;
6) the way focal parameters are determined.

Unfortunately, it is not evident how to evaluate the reliability of each step, and how they affect each other.

The existing data set

If someone wants to assess the reliability of the existing catalogues or isoseismal maps, in most cases there is no way to do it. Actually, often he will not find the primary observations, nor, even, the intensity points. They have simply disappeared, as the fall-out of a process which will remain unknown.

Someone can therefore decide to "improve" the existing catalogues, simply by operating on them, modifying parameters or adding new records. This practice, however, has led in the past to make the data set even worse, as errors, duplications, etc. have propagated uncritically.

Someone else can decide to go the opposite way, starting from the iceberg top (the catalogue record) and going down to the original records and sources. This is an amazing experience through data, assumptions and criteria that somebody has handled before you, leaving only, and not always, slim evidences: therefore, many investigators (and most historians among them) prefer, in principle, searching their own way through the sources. The result is that new studies of the same event appear, leading to new catalogue records. But, if in principle we are able to say which study is better, we are not yet able to say "why", and "how much", in a way that other investigators can understand, if not agree.

There is little hope to express the quality of the process in terms of numbers. However, it seems clear that the first need is to preserve the trace of all the steps through which the data have been formed, as they contain the elements which can be used for any reliability assessment.

IMPROVING THE DATA SET

In the following pages some examples will show how the data set can be improved, assuming the reliability factors listed before as reference.

Improving the use of the available historical records: the "analysis through the catalogues"

This approach has been adopted as a preliminary and low-cost procedure for improving the data set related to the most important earthquakes in Italy. It consists of retrieving the original records used by the most common "classical" earthquake inventories, such as [6, 23, 24, 29], and reconsidering them critically. This procedure is considered preliminary and low-cost, as it requires investigating only sources which have already been used, and not searching for new ones, what may be expensive and time-consuming.

The results are, nevertheless, encouraging to a surprising degree, as, for instance, the investigation of the 1389, Central Italy earthquake shows.In this case, retrieving the sources used by other earthquake inventories [24, 29] than the one [6] from which the Italian catalogue [30] has been derived, has allowed to plot five more intensity points, what can be considered a good result for this historical period (Fig. 3, 4).

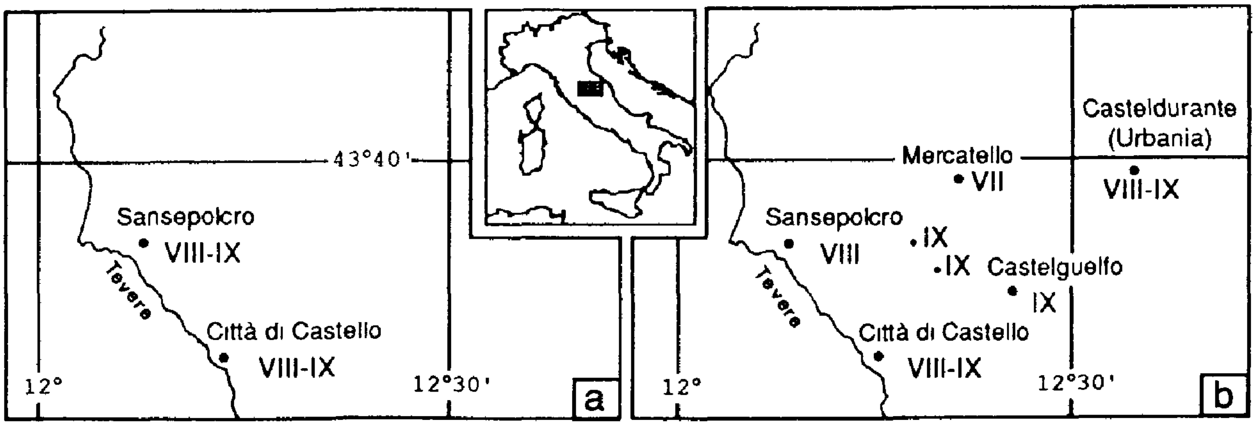

Fig. 3 - Investigation of the 1389 earthquake in Central Italy (from Castelli et al., 1990).
a) intensity map obtained from Baratta [6], source of the Italian catalogue [30]
b) intensity map obtained from the earliest sources, according to Fig. 4

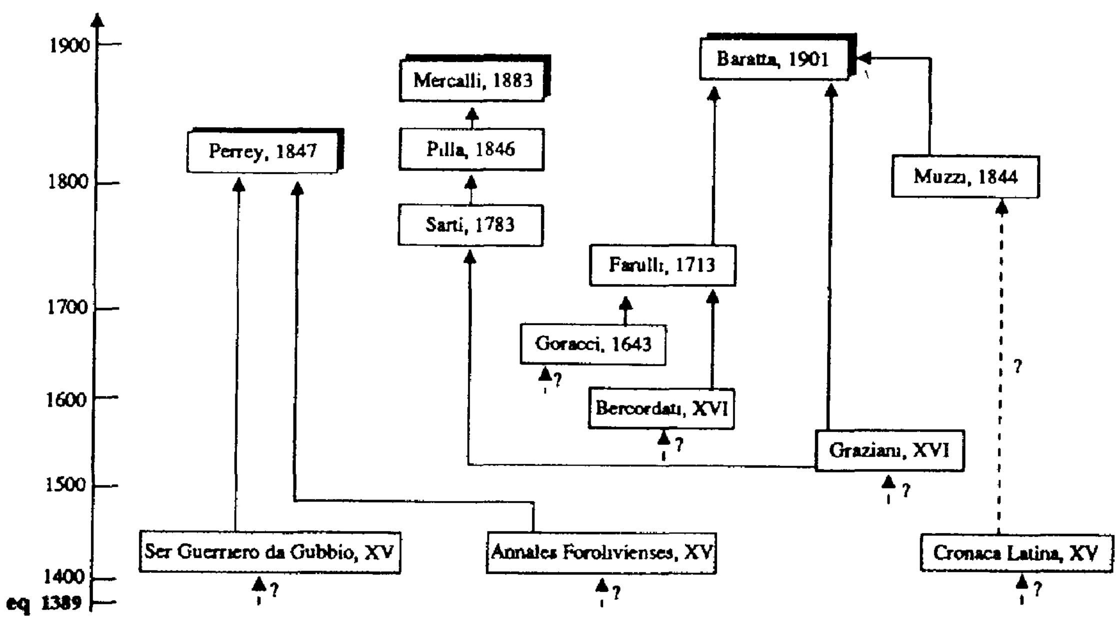

Fig. 4 - "Family tree" of the records used by the catalogues (shadowed). Earliest sources, used for the intensity map of Fig. 3b, are shaded; full lines indicate explicit links; dotted line indicates a presumed link.

Expanding the set of historical sources

Once the previous step has been done and the data are still regarded as insufficient, the next obvious step is to expand the source set. The most significant improvements in this field have come by the collaboration of professional historians. Some pioneer works, such as for instance some works by Ambraseys [4, 5], have shown that earthquakes of even tens of hundred years ago can be investigated to a satisfactory extent. Recently, E. Guidoboni has coordinated a thorough investigation of earthquakes and tsunamis of the Mediterranean area, which has produced a catalogue for that area before the year 1000 [22], including for instance the earthquake which destroyed the famous Colossus of Rodi around 227 B.C. (Fig. 5).

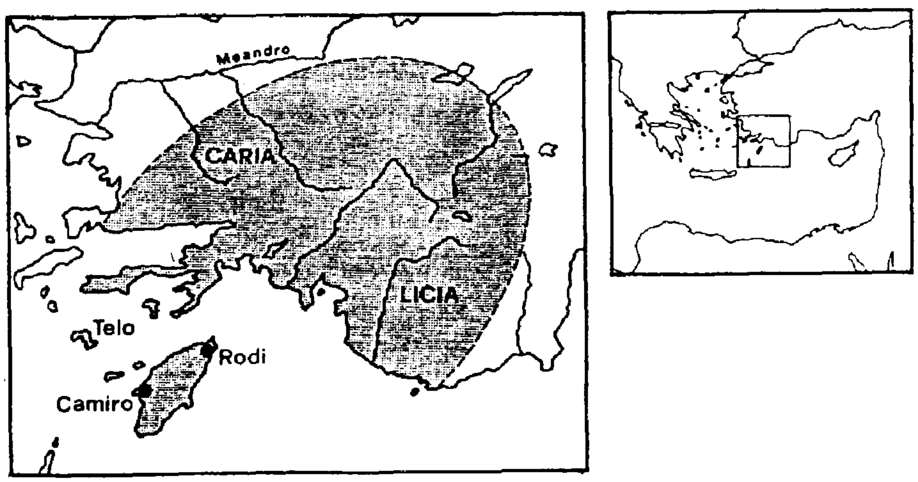

Fig. 5 - Areas damaged by an Eastern Mediterranean earthquake around 227 B.C.(from Guidoboni, 1989).

Sources useful for historical seismology may be everywhere, as many examples show and, mostly, a paper by J. Vogt [37] has summarized. To find sources is a matter of personal instinct, but also of methodology: for instance, good knowledge of state boundaries, urban settlements and political-admnistrative organization at the time and in the area where the earthquake is supposed to have occurred can provide useful information about the sites from where records can be expected, and where they may be today.

The next example evidences how the complicated situation of the state boundaries in a little region of the Northern Apennines (Italy), in the period 1815-1848, affected the distribution of the records of two earthquakes which occurred in 1834 and 1837 (Fig. 6).

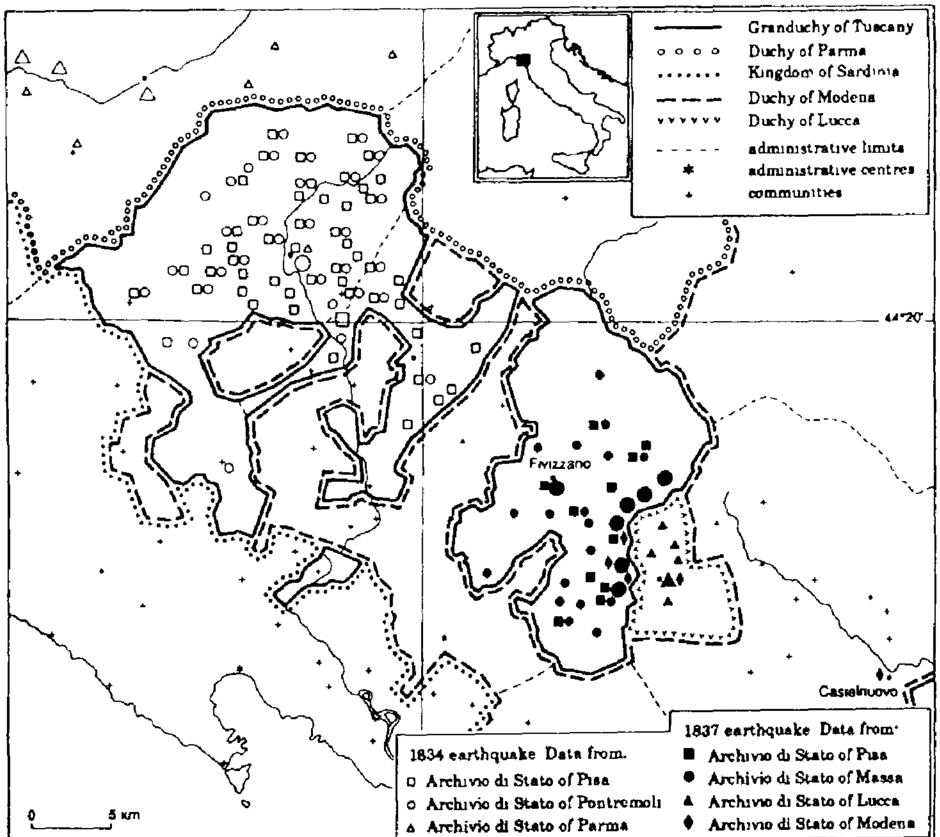

Fig. 6 - Space distribution of records on the 1834 and 1837 earthquakes The documents have been found in the main archives of the states sharing the area at that time, nearly no records have been found for the areas belonging to the Duchy of Modena (from Moroni et al , 1990)

Expanding the source set can be useful if appropriate criteria are adopted. An indiscriminate collection of any record of earthquakes is not useful, and may even be misleading, if the sources are not filtered according to some criticism. The most common catalogues assembled uncritically records coming from reliable as well as unreliable sources, often one derived by the other.

To optimize time and money, a strong interaction between historians and seismologists is recommended, even before the investigation begins. Seismologists should make clear the localities/areas for which they would like to have records, according to their priorities. This point may guide historians to give priority, in their turn, to investigate some sources rather than others.

Sources can contribute to historical seismology in many ways. For instance, investigators usually consider only the sources which report earthquakes (positive sources), and neglect the others ("silent" sources), which are seldom referenced, though they can solve many problems, when used carefully. As an example, the catalogue [30] lists a damaging event in 1414 - same area as Fig. 3 - following only some records about Sansepolcro and Arezzo from a chronicler, Farulli, who wrote three centuries later and is generally considered not very reliable, also because he doesn't quote his sources. A recent investigation [10] has shown that no contemporary sources report earthquake evidences at Città di Castello, Sansepolcro and Arezzo (Fig. 7).

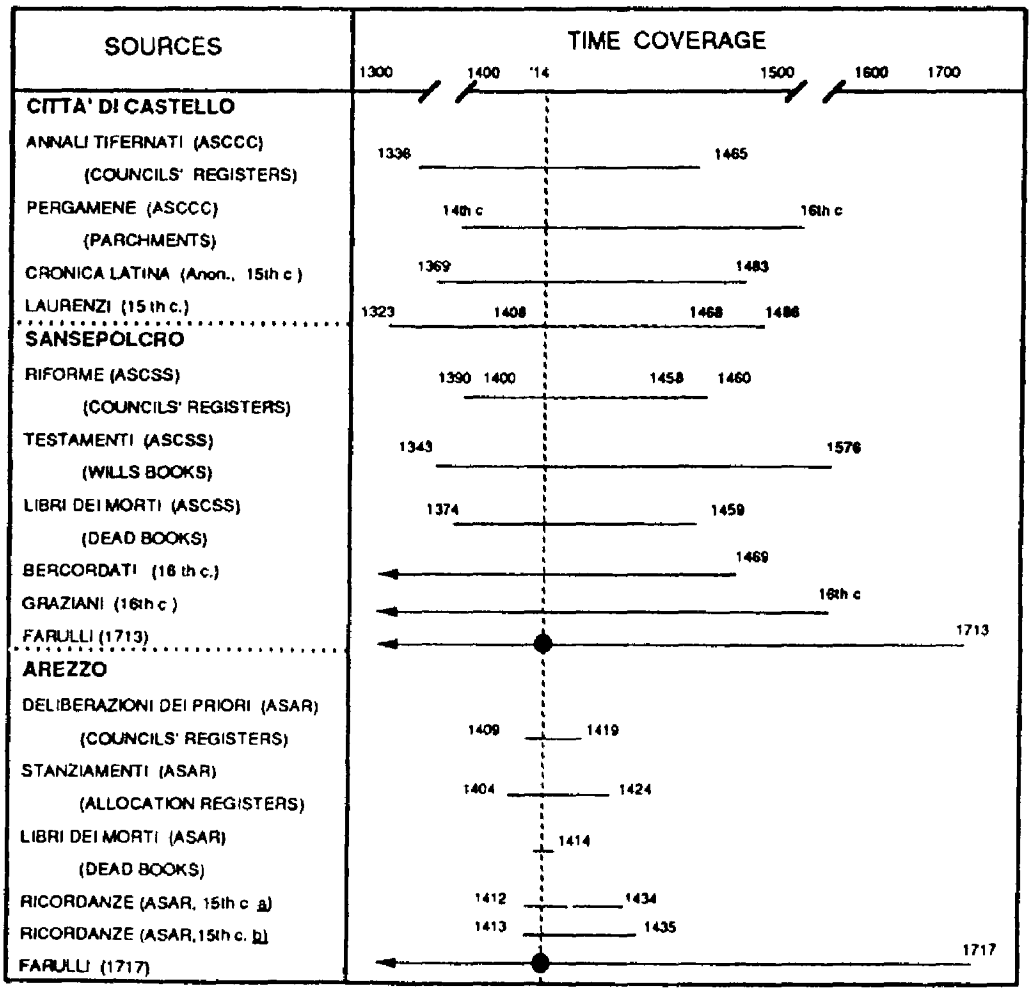

Fig. 7 - Time-plot of the sources investigated for the 1414 earthquake, evidencing the time-period spanned. Dots indicate that the earthquake is reported (from Castelli et al., 1989).

Most of the sources plotted in Fig. 7 are very reliable; some of them are very sensitive to earthquakes and other calamities, as the example of Fig. 8 shows. These evidences have therefore led to the conclusion that no damaging earthquakes took place in that area in 1414 [10].

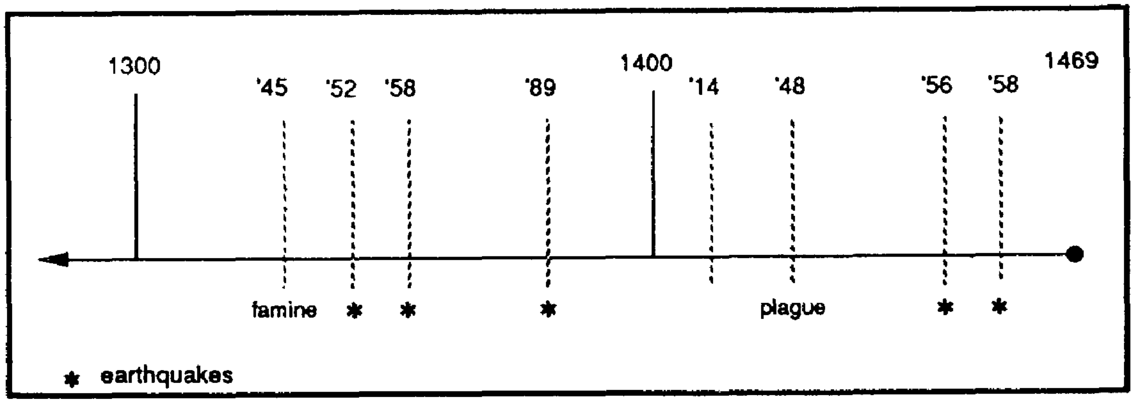

Fig. 8 - Main facts at Sansepolcro, as recorded by the "Cronaca di Sansepolcro all'anno 1469" by F. Bercordati, 16th cent. (from Castelli et al , 1989).

Improving the "building up" of the earthquakes

Improving the time-space association of the records and their assemblage to form an earthquake is a problem which requires careful interpretation and rigourous cross-checking of data. Earthquake records have often been associated by careless or unaware investigators to wrong localities, as demonstrated for instance by J. Vogt [38] and P. Alexandre [3]. Consequently, many earthquakes have been built up uncritically, by summing pieces which didn't belong to the same event; some others resulted in extremely large isoseismals, as the example of Fig. 9 shows.

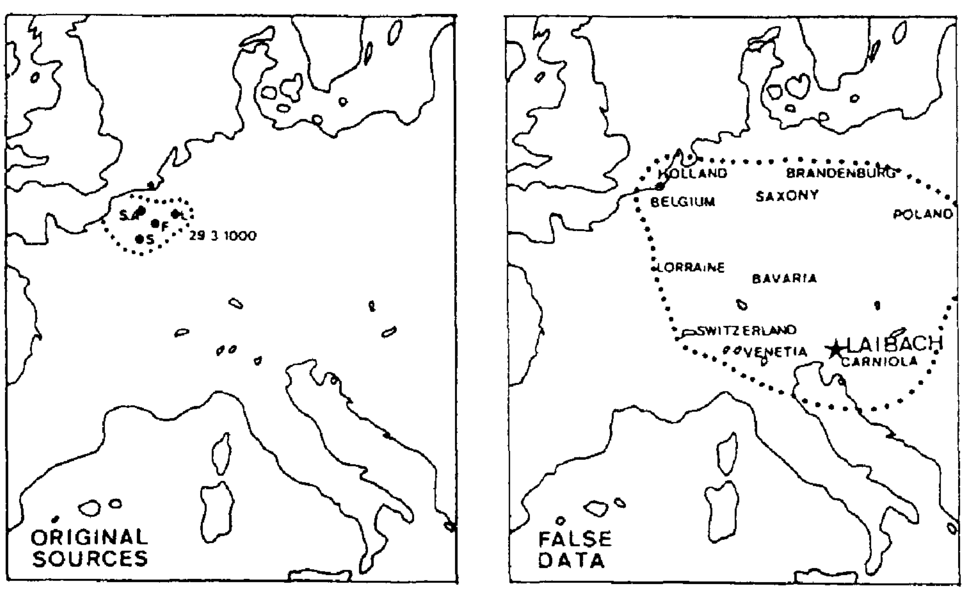

Fig. 9 - Investigation of the 1000 earthquake (from Alexandre, 1991). Extension of the earthquake according to: a) original sources; b) catalogues, most of which locate the epicentre in Slovenja.

The same holds for timing problems, as pointed out by several works such as [14, 38], and many others: the uncritical use of calendars and time-systems has resulted in countless duplications and misinterpretations of earthquakes.

Avoiding many mistakes would require to process all the records through a "historical-geographical information system", that is a database containing the historical evolution of name, population, calendar, time-system, etc. for every locality (Fig. 10). As this doesn't seem a goal for tomorrow, a careful handling of these problems is highly recommended.

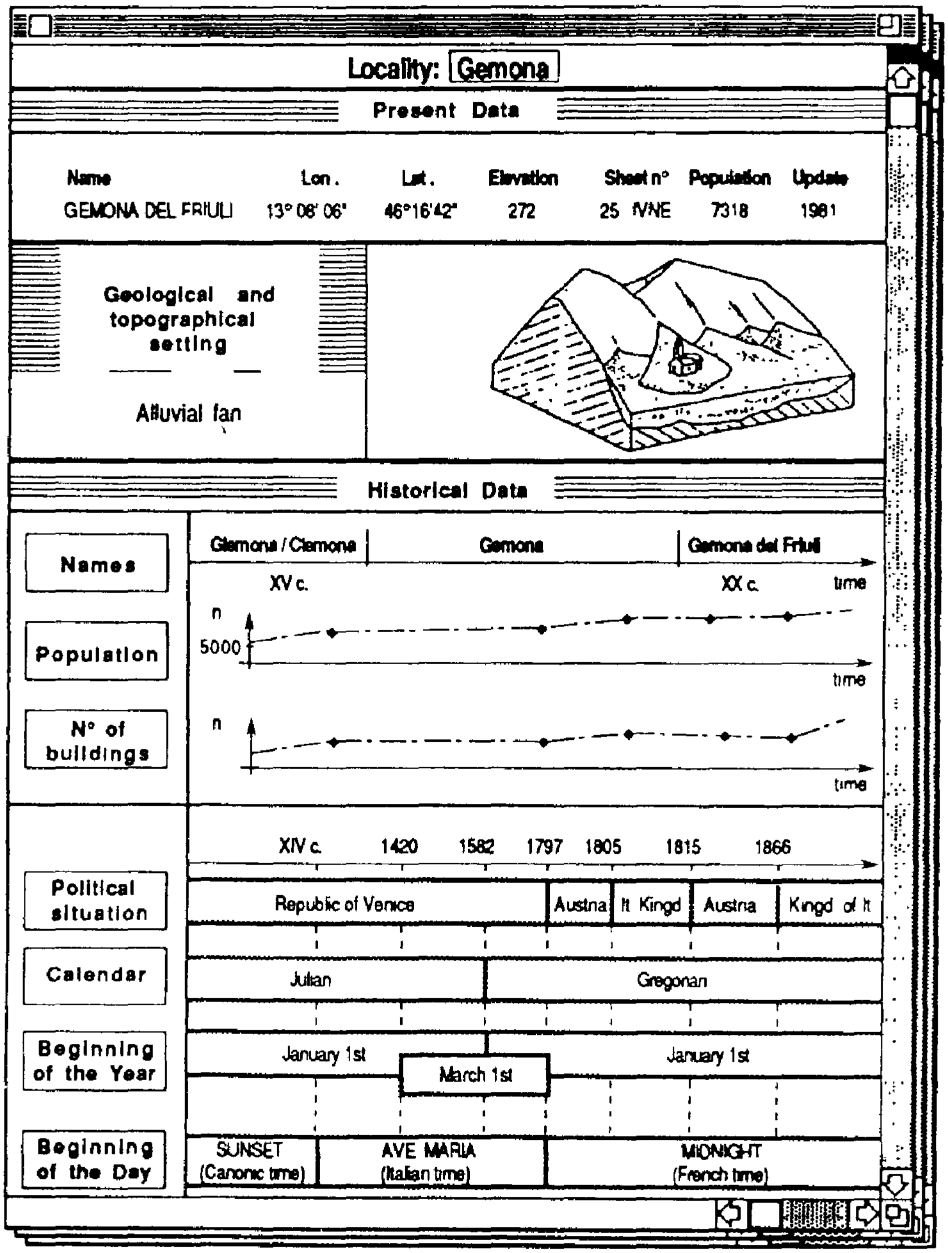

Fig. 10 - An example of output of a "historical-geographical information system" for the locality of Gemona, Friuli, North-Eastern Italy (from Postpischl et al., 1991).

Improving the intensity estimates

More and better records can help improving the intensity estimates: but, to make proper use of them, some points have to be considered. First of all, sources are to be investigated thoroughly. The effects of an earthquake, in the archive files, are not always found in the period immediately following the earthquake (Fig. 11): moreover, descriptions can be contradictory even inside the same source, and are to be weighted carefully [35].

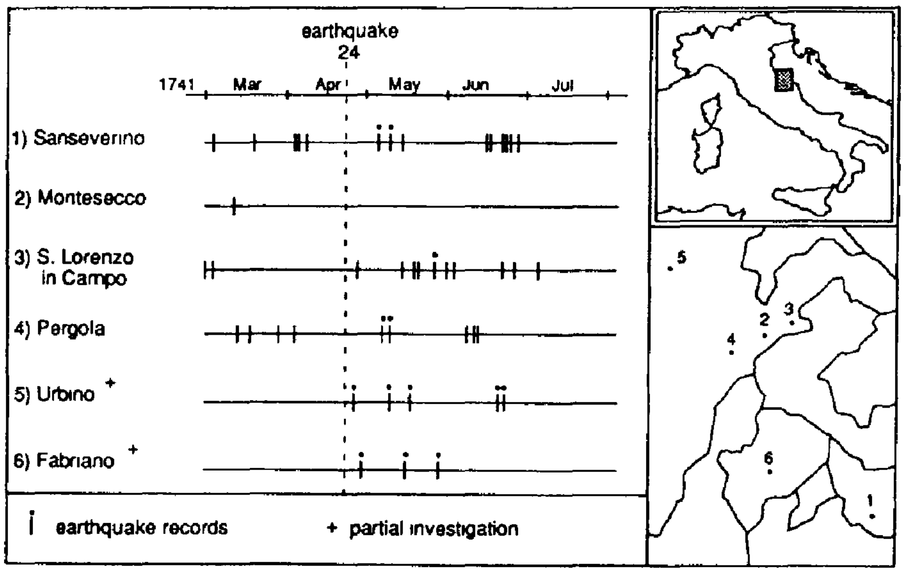

Fig. 11 - Sequence of the council meetings, before and after the 1741. Fabriano (Central Italy) earthquake. of some towns included in the damaged area (from Stucchi et al., 1991).

Next, terms are to be interpreted critically, in the light of the historical context where they have been produced. Some words have changed their meaning, or use, in such a way that the uncritical reading of them could be very misleading. For instance, the term "terrae motus" has literally meant "ground motion", up to a few centuries ago; therefore not necessarily "earthquake", but also "landslide" and so on. Again, the result is that many false earthquakes have been introduced in the catalogues by careless compilers: some examples can be found in [1]. The same holds for the Italian and French terms "crollato" and "croulè", which today can be easily understood as "collapsed", while for medieval times they should be read "shaken".

Further, intensity is the output of processing two pieces of information: what happened, and to what object. While the first is supplied by the records, the second generally is not, or not clearly enough. A record like "40 houses collapsed" can lead to different interpretation if the existing houses were 40, 100, 400 or more; or if they were clustered in a town, or the figures refer to both locality and country; if the houses were made by adobe or masonry, or part of both.

Similar considerations also apply for damage to single, monumental buildings (churches, castles, towns, etc.). In many cases this is the only information available from historical records, but, as such buildings escape any typology class of the intensity scales, a careful reconsideration of all intensity figures based on this kind of data seems highly necessary.

Another point arises in connection with the intensity scales, their use being necessarily subjective, as even some attempts to standardize it by means of statistical approach or expert systems [7, 18, 31] demonstrate. The Working Group "Macroseismic Scale" of the European Seismological Commission is preparing an up-dated version of the MSK-81 intensity scale [21]. But the most important problem to be solved is probably related to the meaning, or use, of the intensity itself, which always oscillates between a simple, hierarchical estimate of effects and something which would like to be a measure of the ground shaking. The increasing use of damage to very special structures (bridges, highways, lifelines), which are not included in the most popular scales, for assessing intensity, is a clear evidence of the second issue, which is probably not coherent with the original meaning of the intensity scales.

The final point to be considered is that some historical records provide very detailed descriptions of damage, sometimes to every single building of a locality, which seismologists and engineers have seldom exploited to their full extent. Forcing such descriptions into the very poor and rough classes by which the intensity scales are defined, can result in the loss of important data. Some attempts to avoid it, using historical damage distribution for microzonation studies [13, 17], or even for assessing the liquefaction potential [9], have provided good results.

Improving the intensity maps

One main result of many historical investigations is that the total number of intensity points of a given earthquake generally increases. The total number, however, is not by itself an index of the quality of the intensity maps. Depending on what the map is used for, a regular azimuthal and radial density of the points, or a concentration in a part of the field, can be preferable.

Some users may like also that each intensity point shows a reliability estimate - which would depend, in principle, on the operations described before. An estimate of Δs_i (location reliability) could be useful, though sometimes this kind of estimate is rather difficult to be expressed on a map. An estimate of Δt_i (timing reliability) is not useful on a map, as all the intensity points on it have been assigned to the same earthquake, and, therefore, same time (the set of Δt_i can on the contrary play a role for assessing the overall Δt_0 of the earthquake).

With respect to ΔI_i, it is important to remember that I is defined only by integers and that the steps of the scales are defined by percentage intervals which are contiguous (for instance: ≤ 10 : 20. 50; ≥ 60). Every attempt to assess any ΔI, therefore, should lead only to figures like 7-8, or 6-8, or even wider classes, such as 5-9. It also should be pointed out that a figure like 7-8 doesn't mean 7.5 in the compiler's mind, but simply an uncertainty between 7 and 8 which cannot be further solved. The use of 7.5 for some computation is one possible choice; a conservative choice, on the contrary, should prefer 8, maybe with a lower probability than a full 8, while other choices are also possible.

Another way for improving an intensity map can consist of indicating also the localities for which we have no data (see a partial example in Fig. 6). This would allow to weight the available data with respect to their potential background, for instance warning the user that a blank area may mean that no records have been found, but, also, simply that there is a mountain range or a desert.

IMPROVING THE USE OF DATA

Intensity points versus isoseismals ?

The intensity map is the most genuine description of an earthquake in macroseismic terms. Drawing isoseismals through the intensity points has always been performed because of two main reasons:

- seismologists have always interpreted the intensity points as rough "measures" of a "macroseismic field";

- user need a tool for predicting intensities at the sites where no data are available.

But how to draw the isoseismals has always been controversial, and any estimate of the fit of the isoseismals to the intensity points will result in many cases extremely poor. Moreover, a recent, interesting experiment to which several investigators have taken part [8] has evidenced how isoseismals are influenced by coastal shape, density of localities, etc., further than by the availability of data and by the personal judgement of the investigator.

A careful reconsideration of what isoseismals represent is therefore needed. This will also improve understanding the relationship between experimental and synthetic isoseismals, which are commonly computed from instrumental parameters [12, 28].

By another side, the availability of thousands of intensity points has stimulated some alternatives which are currently tested in order to use the intensity data set directly, without drawing isoseismals [19, 27]. In these studies, intensity points are used for evaluating the seismic hazard by means of the "true" seismic history at the site, or, even, to determine attenuation laws.

Catalogues or databank ?

Focal parameters are derived from intensity or isoseismal maps according to some rules. By these procedures, most of the information on the earthquake is concentrated into its "centre of mass" which will represent, from then on, the whole earthquake. This option was considered obvious when the intensity points didn't exceed a few units for each earthquake; today, with some tens, or a few hundreds of points, finding a centre of mass has become more difficult.

Moreover, the centres of mass are commonly used for hazard evaluations in combination with intensity attenuation laws derived by some sets of experimental isoseismals. What happens is that even the fit of the most up-dated attenuation laws - such as the one proposed by Grandori et al. [20] - to the intensity points is becoming lower. A declining use of isoseismals and attenuation laws, together with the availability of a macroseismic data bank, will probably lower in the future the interest for having centres of mass.

However, if someone needs catalogue records, a data bank will provide greater flexibility than a catalogue. As it can store, for instance, all the studies concerning one event, this can help overcoming the problem of standard catalogues, which has always required heavy discussions on the cataloguing procedures, and forced selections of the "best" study; or, even worse, has caused the mixing up of several catalogues. From each study more than one catalogue record can be extracted, according to different rules or formats, depending on the use for which they are needed. As an example, Fig. 12 shows an intensity map which represents a critical situation, as far as the weight to be assigned to the only intensity IX point is concerned. Below. some of the catalogue records available for this event from the Italian data set are listed; the format of the record has been proposed in order to evidence also the parameters describing the intensity map.

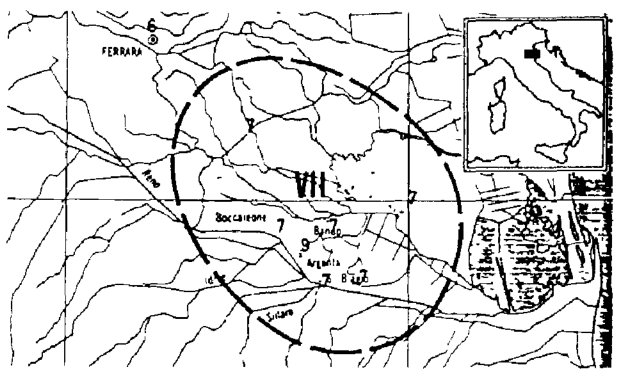

Fig 12 - Intensity map for the 1624 Argenta (Northern Italy) earthquake (from Ferrari et al. (a), 1985)

N	TIME	INTENSITY MAP PARAMETERS							FOCAL PARAMETERS				
		Imax area	Imax	Imin	Pt	PS	Q	Author	Lat	Lon	Re	Io	Cod
905z	19/03/1624	Argenta							44 35	11 50	4	10	000
905aa	18/03/1624	Argenta	9	4	11	10		Ferrari et al , 1985	44 40	11 55	3	7	510
905ab	18/03/1624	Argenta	9	4	11	10		Ferrari et al , 1985	44 37	11 50	3	9	888

where

Imax = maximum observed intensity
Imin = minimum observed intensity
Pt = total number of intensity points
PS = number of intensity points with I ≥ V
Q = quality factor (to be defined)

Author = compiler of the intensity map
Re = location reliability (defined by the procedures adopted by Cod)
Cod = rule according to which the focal parameters have been derived

The origin of the three records is

- one (905z) comes from the ENEL (1988) file (Cod 000) - intensity map not available,
- two (905aa, 905ab) are derived from Ferrari et al [15] - intensity map available (Fig 12) according to different rules, referred in the catalogues named 510 and 888

Every catalogue record derived from it can be unsatisfactory for some investigators: actually, while the epicentral locations do not differ very much, the epicentral intensities range from 7 to 10 (7 and 9 from the same data set !). In such situation - which is not uncommon - it is probably better not to make an "official" selection and leave it to the user.

CONCLUSIONS

Macroseismic investigation has been so far considered as a second-class branch of seismology. This is most likely due to the fact that seismologists and engineers have, often unsuccessfully, tried using macroseismic data in the same way physical quantities are used, for instance forcing them into equations derived from other seismological representations; but this has turned out very difficult, and sometimes inconsistent.

Processing the historical data can be performed according to scientific criteria or not, depending on the investigator, not on the nature of data. It requires also ad hoc expertise, computer facilities and software. Macroseismic data have not yet been exploited deeply: the large amount today available can be very helpful to seismologists and engineers, provided that the data are used according to their nature.

Appendix - The CEC Project "Review of Historical Seismicity in Europe" (RHISE)

In 1989 the CEC has funded a three-years project concerning historical earthquakes in Europe, to which seven institutions of Italy (coordinator), Portugal, Spain, Greece, France, Belgium, United Kingdom take part. The goal of the project is to investigate the historical seismicity on an international basis, stimulating the collaboration among European institutions and producing a set of homogeneous data according to common methodologies [34].

To accomplish this goal, it has been decided to study transfrontier earthquakes in some areas and time-windows, where at least one important earthquake took place (Fig. 13).

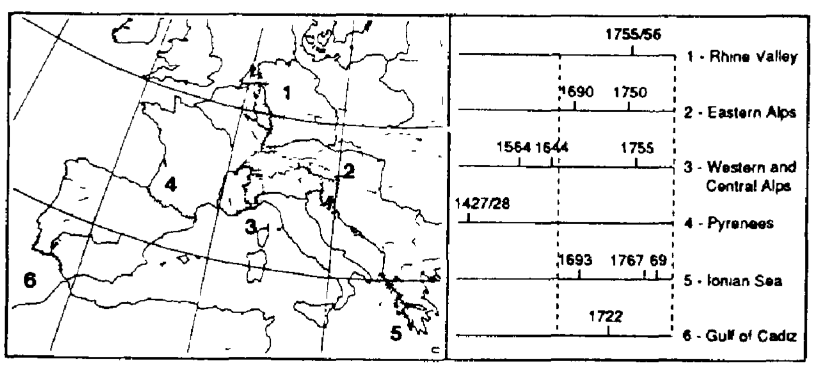

Fig 13 - Sub-areas and main earthquakes investigated by the CEC Project "RHISE". The main time-window includes the first half of the 18th century

The studies concerning the sub-areas start from the critical review of the catalogues and their sources, and proceed investigating other sources. The partners investigating the same area collaborate deciding the research strategy, exchanging data and discussing the results.

An interesting case is represented by the earthquake of 1564 in the Maritime Alps, for which contemporary sources report heavy damage in some villages north of Nice, and only a few evidences for the far-field area. Fig. 14 shows the results of the investigation of some sources for Cuneo and Savona, where the earthquake should have been strongly felt, or even damaging [25].

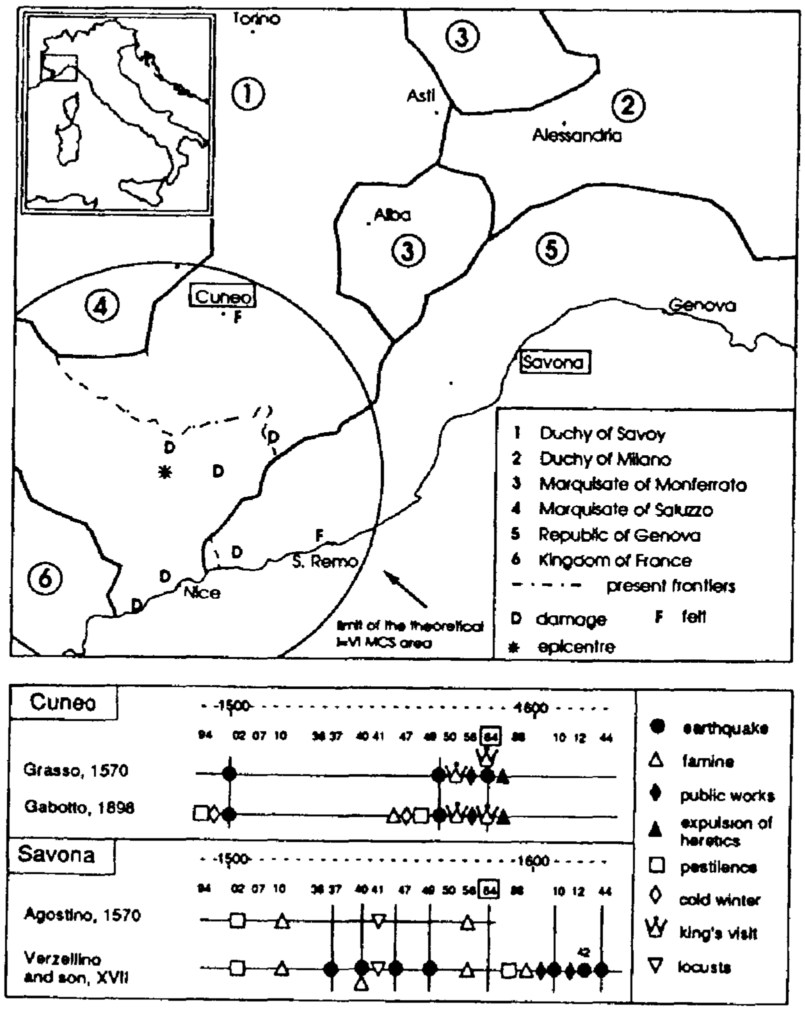

Fig. 14 - Investigation of the 1564, Maritime Alps earthquake (from Moroni and Grillo, 1990, modified).

Another interesting aspect is the attempt of investigating important depositories of European interest, such as the Archives of Venice, Wien, Simancas, the Vatican Archive, and so on. As the investigation of each archive requires a basic knowledge of the archive itself, it has been thought that each archive will be investigated by one group, for the benefit of all partners.

The case of Venice has been particularly promising so far. The governors and the diplomatic and commercial representatives of the Republic of Venice can be seen as a network of observers and recorders, scattered in continental Europe and the Mediterranean basin (Fig. 15) [2]. Since 14th century to the fall of the Republic (1797), they produced a big amount of records, sometimes on earthquakes, contained in dispatches, letters and reports sent to the central magistracies. For instance, a sampling carried out inside the diplomatic correspondence has shown that evidences about the Lisbon earthquake of 1755, November 1, are mentioned by documents from London, Paris, Madrid, Torino, Wien, Napoli, while no records have been found from Lisbon, Cadiz, Algiers, Marseille. Information on the Valais (Switzerland) earthquake of 1755, December 9, was found in the documents from Paris and Torino.

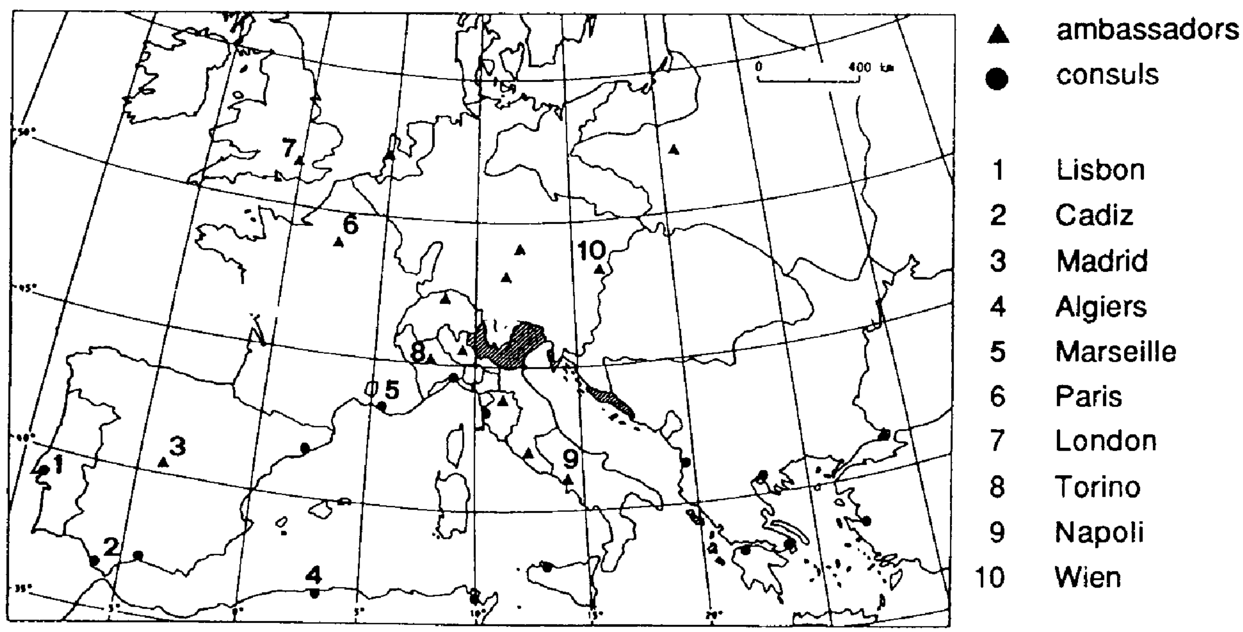

Fig. 15 - Representatives of the Republic of Venice (shaded) between 17th and 18th century, on a map showing the state boundaries in the second half of 18th century (from Albini and Daltri, 1990, modified).

On the other side, documents produced by the Venetian governors of the territories belonging to the Republic (Fig. 15) are rich in number and quality, and can provide great potential for some areas, such as the Ionian Islands (today Greece), where fire, war, and also earthquakes, destroyed most of the documents stored in the local archives.

For instance, the General Governor "da Mar", ruling over the Ionian Islands and resident in Corfù, annexed to his dispatches to the Senate in Venice copies of documents produced by the local authorities of Santa Maura (Leukada), Cephalonia, Zakynthos (Fig. 16), to support the requests of aid coming from the population. The continuity of such correspondence allows investigating in detail a series of damaging earthquakes which affected the Ionian Islands from July 22, 1766 to October 11, 1769 [2, 36].

As an example, Fig. 16 shows the time sequence of the dispatches concerning the Ionian Islands between July 1767 and April 1768. The July 22nd, 1767 earthquake caused damage especially in Cephalonia, the October 3rd one in Santa Maura (Leukada).

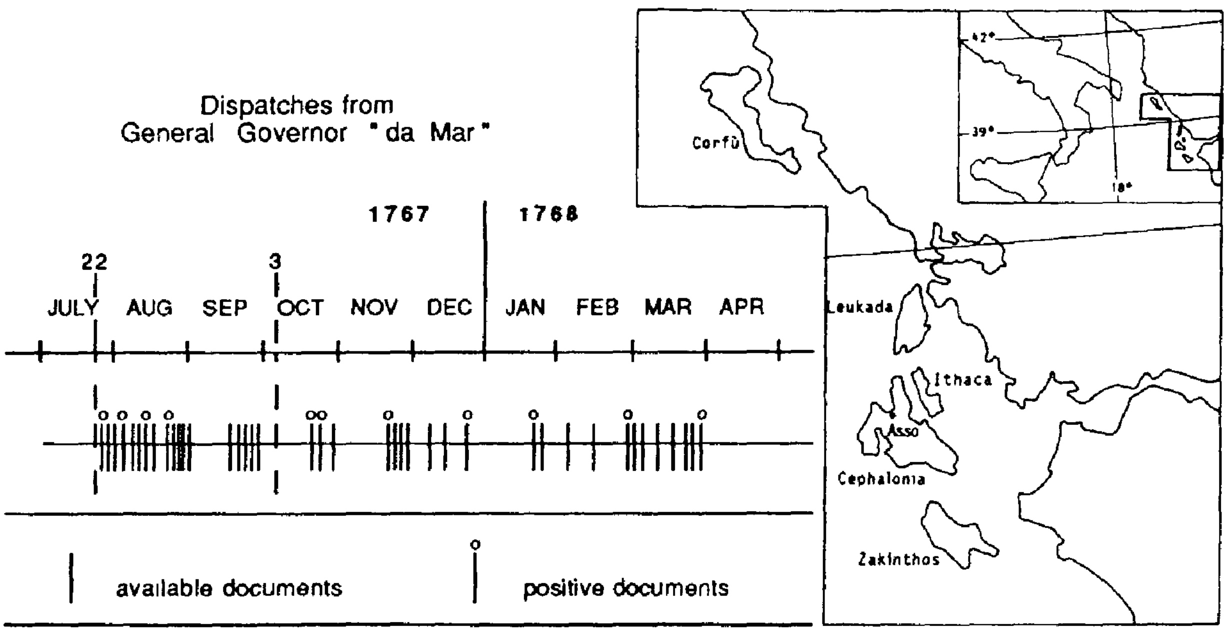

Fig. 16 - Time-sequence of Dispatches from the General Governor "da Mar" (Corfù) to the Senate in Venice, July 1767 - April 1768 (from Albini and Daltri, 1990).

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