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METHODOLOGY AND PROCEDURES FOR COMPILATION OF HISTORICAL EARTHQUAKE DATA

REPORT OF A CONSULTANTS MEETING
ON THE METHODOLOGY AND PROCEDURES
FOR COMPILATION OF HISTORICAL EARTHQUAKE DATA
ORGANIZED BY THE
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FOREWORD

This report was prepared subsequent to the recommendations of the project initiation meeting in Vienna, November 25-29, 1985, under the IAEA Interregional project INT/9/066 Seismic Data for Nuclear Power Plant Siting. The aim of the project is to co-ordinate national efforts of Member States in the Mediterranean region in the compilation and processing of historical earthquake data in the siting of nuclear facilities.

A Consultants Meeting to prepare the first draft took place at the Imperial College, London, March 18-21, 1986. This draft was sent out to all participating Member States for review and comments. A final review of the document was made during the annual Co-ordination Meeting of the project in Vienna, December 1-5, 1986.

The main objective of the document is to assist the participating Member States, especially those who are initiating an NPP siting programme, in their effort to compile and process historical earthquake data and to provide a uniform interregional framework for this task. Although the document is directed mainly to the Mediterranean countries using illustrative examples from this region, the basic procedures and methods herein described may be applicable to other parts of the world such as Southeast Asia, Himalayan belt, Latin America, etc.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

The assessment of seismic hazard for the siting of NPP's constitute one of the major safety considerations in high seismicity zones such as the Mediterranean. This assessment generally depends on the reliability of the eventual estimation of the earthquake potential of the area in question. The IAEA Safety Guide 50-SG-S1 outlines a methodology using the seismotectonic approach.

To achieve all this, however, more information about earthquakes and more field evidence of recent tectonics is needed. Especially we need a significantly more extensive sample of seismicity, particularly of the larger events, covering much more than the period of the few decades of modern seismology, which is minutely brief on the time-scale involved in tectonic processes. Obviously the large earthquakes which are informative events are far less numerous than small earthquakes, and as such are not easily counted unless the period of observation is sufficiently long. It is very possible, therefore, that the present distribution of seismicity in continental areas may not accurately reflect the distribution and pattern over a longer period of time and the present erratic pattern of seismicity may be due to scanty sampling of events devoid of any significant signal.

Studies of long-term seismicity in any region of the world have to incorporate and process information acquired from numerous and widely differing types of investigation. A long historical perspective is desirable, as well as familiarity both with the region itself and with the effects of earthquakes that have occurred there. In addition to macroseismic information, instrumental data covering 20th century events should ideally be of adequate high quality.

Only when these data are assembled can one begin to perceive their long-term significance. Analysis may be performed to elucidate the vulnerability of certain areas, and evaluation of the distribution and time variation of the level of seismic activity over a long period of time can also lead to a greater understanding of the tectonic processes in the region and of the underlying laws that may control the rate of activity. For the Eastern Mediterranean region long-term observations may cover a period of about 20 centuries, for the Middle East 15 centuries, for North Africa about 7 to 10 centuries and for southern Europe about 10 centuries.

The extent to which such a programme of research can be fulfilled satisfactorily depends on several factors. First among these is availability of information. Clearly if little documentary macroseismic material is available for study, it will not take long to be collected and processed. This is not normally the case for seismic regions in and around the Mediterranean area, which has a long and well documented history. Secondly, one must consider the accessibility of this information, i.e. whether it may be retrieved relatively easily from printed sources, histories, newspapers and scientific publications, or whether it has to be accumulated slowly and painstakingly from unpublished sources, archives and foreign libraries. Thirdly, experience of earthquake effects in the region suggests the desirability of being able to visit areas of past or recent earthquakes and to study local tectonics as well as man-made structures, identified from recent or historical accounts of events.

Implied by these three points, and ultimately determining the success of such a programme of research, lies in the question of the time and money available for the project to be carried out. The time allowed and number of people directly involved clearly determine, or are determined by, the cost. Equally, the number of people involved influences the speed at which the work is done: superficially, the more people are concerned, the more quickly information is retrieved and processed. In practice, this is generally not always the case. Administrative problems, duplication of effort, deficiencies of collaboration and conflicting attitudes to the progress of the study all too often lead to a reduction in efficiency and productivity. It is particularly desirable that long-term, moderate funding should be available for as long as it is reasonably necessary to achieve a level of comprehensiveness that is considered to be adequate. If done too quickly, without the full particpation of the public services responsible for the collection of seismic information and with unreasonably constraining dead-lines, results from the research may be rapidly invalidated by the discovery of new data after the completion of a hasty study. Ideally, the study should be performed by a small number of specialists in close contact with each other, drawing on the help of other specialists and public services, without unduly strict time restraint. Some elucidation of the procedure involved highlights these pre-requisites.

2. SOURCES OF INFORMATION

A region with a well-documented history may be capable of furnishing a considerable amount of information about earthquakes that have occurred in the past 10 to 20 centuries, defined here as the period before the advent of modern seismology. General chronicles, dynastic histories and archaeological findings may contain evidence of early events, and local histories in particular may describe the effects of earthquakes on monuments, local housing and the development of the area. These indications are generally restricted to well populated areas, particularly those in which a large urban centre is situated, and especially if the town has a long history of political and economic importance, as a trading centre, local administrative capital or political metropolis of the whole country. Information for such areas, and also for those less densely settled, may be provided by travellers passing through the country, or settling for a while in a town or area where they were interested to record local events.

Information about one country may be preserved not only by foreign visitors, but by diplomats on duty there, and other representatives of foreign powers. Data found in foreign libraries and official archives may thus supplement indigenous information preserved in histories, private correspondence, or early and recent newspapers.

All these sources of information have to be identified and studied, to extend and correct any data listed in current earthquake catalogues, most of which are based on second or third-hand information. The data they supply must be subjected to rigorous critical examination, not only to establish accurate dating and location of events in order to avoid duplication, but also in terms of the completeness of the sample. To this end, the characteristics of various historical records should be assessed, to see when and where the documents were being written, which areas were more important and which of more remote concern, which were populous and thus likely to suffer particularly from a large event; also to see which areas were frequently visited by travellers and which were not, along with the routes they took. How these factors influence the distribution of reported seismicity of the region must also be examined so that allowances can be made for areas about which little information is available. These negative and positive factors can then be taken into account when an assessment is made of the level of seismic activity throughout the country over a long period of time. Second hand information should be avoided as much as possible.

The main categories of source material which should prove of value for the study of historical seismicity are set out below, and discussed briefly.

(1) Existing earthquake catalogues

Earthquake catalogues are, of course, a useful starting point as they summarize the present state of knowledge on the subject. They are, however, seldom accurate in detail, and list duplicated or non-existent events. Neither are they complete, nor is the measure of their incompleteness indicated.

(2) Unpublished information

(a) Manuscript histories or other historical documents that may contain references to earthquakes or their effects. The most useful of these are general chronicles, local and regional histories, city or dynastic histories, and biographies, especailly where the material is arranged on a chronological basis. These histories may be supplemented by unpublished private diaries and correspondence or official archive material.

(b) Public records and official archives. Official correspondence between governments with their representative abroad as well as internal reports on home affairs are both potentially useful sources of macroseismic information, particularly when reports are sent on a regular and systematic basis. In addition, private collections of unpublished papers and diaries, correspondence, travel memoirs, etc. - may be found in some public archive repositories.

(c) Archaeological evidence. Much of this evidence of earthquake activity in the past has already been published, but there has been little attempt to collate it, or to determine its validity. Unpublished archaeological evidence of earthquake damage remains on site waiting to be investigated, which implies that archaeologists can provide valuable co-operation and assistance in the future.

(3) Published information

Numerous relevant published materials exist for the study of many aspects of history and historical geography, these will not only document the occurrence of historical earthquakes, but allow some examination of the context in which they occurred. It would be expected that anyone undertaking documentary research on earthquakes in this region would be familiar with the main primary and secondary sources of historical information and would therefore be capable of following these through as the research progressed. Some of the more obvious bibliographical aids are noted below.

(a) Primary historical sources. These are original historical documents that have contemporary or near-contemporary reports of events, including earthquakes.

i) Chronicles; the most valuable sources for the period up to around the sixteenth century A.D.

ii) Travel literature; chronicles are supplemented by travellers' accounts of the various countries of the region; these may yield not only first-hand descriptions of individual earthquakes, but also information on the state of the country, its population and its major buildings. Travel literature often provides independent evidence of earthquake effects, and equally important, may also help to identify positively certain periods or locations where earthquakes did not occur.

iii) Archaeological evidence, including architecture and inscriptions; not only ancient sites, but also surviving historical monuments may yield direct or indirect evidence of earthquake activity. The architectural history of mosques, churches or other public edifices may contain episodes of rebuilding or repair following earthquakes, which may also be recorded in inscriptions.

iv) Literature related to other natural phenomena, such as astronomical events, floods, storms, epidemics, etc. It is not unusual to find reference to earthquakes in such literature. Moreover some of these (e.g. floods, epidemics) may have a causal relationship to earthquakes.

(b) Secondary sources. Modern European, Middle Eastern or North African works that cover aspects of the history and geography of the region may contain references to earthquakes, and also elucidate the setting in which they occurred. Such works include historical studies, gazetteers, population studies and accounts of trade routes and communications.

(c) Newspapers: The press, the function of which is to report on a wide range of contemporary events, is an indispensable source of information for the last 150-450 years or so, particularly since earthquakes have always attracted attention and interest.

(4) Libraries and collections of documentary material

Libraries, archives and selected bibliographies. It should be stressed that relatively little use has been made of the archival collections throughout the Middle East, so that relevant information regarding their contents is difficult to find. However, it is certain that their potential value as repositories of macroseismic data may in some cases be very high. The majority of the libraries are a priority for research, containing original and unpublished material as well as useful printed or secondary works. Most of the libraries in both Europe and the Middle East are useful for the study of the whole area rather than exclusive to a single country. European libraries, containing large quantities of material on Islamic and Arabic studies are numerous, either in schools of oriental languages or forming part of larger collections in public libraries and national archives. They are generally well organized with full catalogues of their holdings, making identification of their contents and of specific works quite straightforward. Lists of these institutions may be derived from The World of Learning (the most recent edition is for 1981/82). The most important archives are those of countries which by virtue of long trading contact, close geographical proximity or colonial or imperial involvement, have maintained a long-standing presence or interest in the Arab countries of the Mediterranean region and S.W. Asia-namely, Turkey, the United Kingdom, France, Spain and Italy.

3. EVALUATION OF MACROSEISMIC OBSERVATION

3.1 SCOPE OF FIELD STUDIES

The site of a damaging or destructive earthquake constitutes a full-scale laboratory model from which significant discoveries can be made by keen observers, be they seismologists, geologists, engineers, archaeologists, historians or sociologists. As our knowledge of the complexity of earthquakes has increased, we have become more aware of the limitations nature has imposed on our capacity to understand, in purely theoretical terms, the effects of these events, the behaviour of a community and of the ground itself, or the performance of man-made structures.

Collection of data is best achieved by field study of earthquakes, which not only offers a unique opportunity to develop an intimate knowledge of the actual situation created by an earthquake disaster, but also promotes an understanding of the real problems that it creates. For instance, it is only in this way that ground deformations or faulting associated with earthquakes can be discovered and studied. Also, the resistance of local methods of construction and century-old building techniques, as well as the efficacy of new methods, can only be gauged after an earthquake.

The social and economic repercussions of the event can also be studied at first hand, so that the picture obtained is not distorted by non-scientific considerations, such as those of local politics, which may otherwise obscure the evidence.

Field studies of earthquakes which occurred before the advent of modern seismology are even more important. The historical sources discussed in the previous chapter describe the occurrence of a multitude of destructive earthquakes in the past whose effects were partly or totally unknown. These accounts prove useful in guiding field studies to sites of early events, some of them associated with faulting representative of very recent tectonic activity. These indications of past activity are essential for an accurate assessment of local earthquake risk.

The size (magnitude) of historical earthquakes can be assessed from the degree of damage caused in the epicentral area of the event (epicentral Intensity), the extent of the area over which the shock was felt (radius of perceptibility), and from other factors which can then be calibrated against macroseismic information of similar twentieth-century earthquakes. Much of the effort, therefore, should be concentrated on identification in the field of the meizoseismal area of all significant events, both historical and modern, for which literary or instrumental data exist and on uniform assessment of their epicentral Intensities.

3.2 LOCAL SOURCE MATERIAL

Information may usually be collected from local educated elders or people who because of their trade were familiar with local history. Quite often this leads to others in the region who possess additional information and occassionally family records. In many instances two or three independently- interviewed individuals may give basically the same details, thus confirming the reliability of the information. Without family records, oral information may seldom go back for more than three generations.

3.3 THE EFFECT OF EARTHQUAKES ON LOCAL HOUSES

A general observation about a typical house in the Eastern Mediterranean is that its inherent strength is very low and extremely variable, and its vulnerability to earthquakes extremely high.

The degree of damage or destruction observed in the field after earthquakes is proportional to the size of the housing unit or village affected. It was found that the larger the unit or settlement, the heavier the apparent damage. This is understandable when one considers how housing units and villages are built and expanded, i.e. simply by joining new adobe or rubble stone masonry elements to the existing ones. As a single detached house develops into a cluster of houses, and as the size and age of the group increases, it becomes increasingly probable that weaknesses and flaws will be present.

This produces weak units, and the resistance of a cluster, be it a single large house or a settlement, tends to become that of its weakest unit. In many instances it was found that the collapse of a unit affected others attached to it, the damage spreading out for a considerable distance from the original failure.

3.4 ASSESSMENT OF INTENSITY

In many parts of the Mediterranean the maximum Intensity in any destructive earthquake appears to be effectively the same; that is, at Intensity VIII on the Modified Mercalli (MM) scale, all adobe or other poorly built masonry houses are destroyed. Higher Intensity earthquakes can only be assessed from the behaviour of timber-frame or other types of construction with greater inherent resistance. In field studies, wherever adobe or other poorly built masonry is found in the epicentral area, it may be totally destroyed, while timber-framed houses may suffer comparatively less. The fact that in practice only one of these types of construction is normally available for observation in any one area may make it practically impossible to assess epicentral Intensities greater than VIII (MM). The degree of damage to a single adobe or other poorly built masonry house is generally an indication of the weakness of the structure rather than of the strength of ground shaking, making it very difficult to assign Intensity as the mode rather than the mean value observed at a particular site with relatively few dwellings.

Thus, conventional Intensity scales may be too subjective and often misleading, especially when they were designed to describe conditions in other parts of the world. A comparison of epicentral Intensities assessed independently by different investigators of the same event show unacceptable differences, from one to three grades.This also shows how sensitive the method is to the experience of the investigator and the means and time at his disposal.

In contrast with other parts of the world, the ease with which earthqauke damage in rural areas seems to have been made good suggests both a tendency to exaggerate Intensities of old and recent events, and also that local materials permit not only easy destruction but quick reconstruction. Additional evidence, such as whether or not a site was abandoned because of loss of its water supply, decimation of its labour force, or decline of its commerce, is necessary for an assessment of Intensity of historical earthquakes. Details of destruction of public buildings, mosques and minarets, as well as the number of casualites, all contribute to a better understanding of the effects of the event. Survival of information about earthquake damage over a very long period, a millennium or so, though not in itself conclusive, can also be supposed to suggest comparatively high Intensity effects.

Natural exaggeration in the sources, historical and modern, is not difficult to detect. The authenticity of the source, the style of its narrative, internal evidence in the account and experience gained from processing local information, all combine to permit a realistic assessment of the gravity of the situation. For instance, statements such as that after a destructive earthquake everyone was staying on the roofs of their houses, or that they took refuge in mosques, suggest that the shock was not in fact all that desructive. There are also cases when European travellers exaggerate damage unintentionally, mistaking the many delapidated old ruins for signs of recent destruction. Comparison between local and foreign versions of an event when possible, is also revealing.

In contrast, statements referring to fatalities among leading citizens mentioned by name, remission of taxes, famine or emigration and poems written after an earthquake all suggest a destructive event of high Intensity. Destruction of post stages, water cisterns and the disruption of communications also imply the occurrence of serious events.

Casualty figures are rather difficult to check and are anyway not necessarily indicative of the magnitude or the Intensity of an earthquake. In the past, because of the emphasis on effects in major centres, reported figures depended to a large extent on population distribution and density; even today, with fuller coverage of events, the same bias is maintained, although this may reflect the genuine situation: quite often the largest number of people killed were in towns or villages outside the meizoseismal region, within which semiabandoned settlements were totally destroyed but with little or no loss of life.

The present survival of historical buildings is not necessarily an indication that early earthquakes to which they were exposed were of low Intensity. Most of the buildings that are still standing have in fact, during their lifetime, been subjected to a number of destructive shocks and have survived through a process of natural selection. They are a very small fraction of the total number of structures that existed in early times and they represent a sample of buildings of the best final design and construction, achieved through the ages by experience, trial and error techniques, or by chance. Furthermore, frequent references occur in the sources to extensive restorations after earthquakes (or for other reasons), and even if the opportunity was rarely taken to introduce changes in design and construction to ensure a more resistant structure, these restorations, sometimes very numerous, prolonged the life of the buildings. Thus the mere existence of early monuments should not necessarily be taken on its own to mean that their sites have been free from high Intensity shaking in the past.

Similarly, the existence of tall, solitary free-standing structures such as a minaret, tower or belfry, made of brickwork, does not necessarily indicate an absence of damaging earthquakes. These special structures are far more flexible and better built than ordinary dwellings and their response to an earthquake is quite different. A near-by, strong earthquake, which may cause houses to collapse, may affect a minaret less, by merely whipping off its top. On the other hand, a large distant shock, not damaging to buildings, will overturn some minarets and damage the tops of others, but this is not an indication of high Intensity shaking. These effects are determined not simply by the distance of the minaret from the epicentre, but by a variety of factors, such as the resilience, flexibility, height and aspect ratio of the individual structures.

Without details of these characteristics of minarets that no longer exist, early statements of damage are not a reliable measure of the Intensity of shaking experienced by the structures affected, nor are these sufficiently numerous to allow any valid conclusions. Although the survival of towers, minarets and belfries over the centuries is not surprising, their disappearance nevertheless suggests the occurrence of large shocks somewhere in the immediate or distant vicinity. The same applies to the evidence of free-standing columns. Columns consisting of rigid cylindrical sections of stone can fail, not in bending as brick minarets do, but by rocking on their base and joints, a process that for homologous columns makes the highest the most stable. But because this type of structure has little reserve strength and totally lacks the benefit of being structurally redundant, the Intensity of early events can be assessed only from their observed effects on a large number of such structures.

Secondary effects, such as landslides, rockfalls and soil failures, are of limited value in assessing Intensity, however, they should always be evaluated. The destruction of a village perched on a slope, caused by sliding of the ground on which it stands, and damage to houses from rockfalls or other ground deformations can, and often may occur without the assistance of an earthquake. It is difficult to determine how strong or light a shock would be necessary to produce these secondary effects: earthquakes, like heavy rainfalls, may act as the last straw to trigger landslides prematurely, particularly where mountain faces crumble rapidly without assistance from earthquake shocks.

Many historical events are documented only by a very brief note or description which makes a proper assessment of intensity degree practically impossible. Under such circumstances it is advisable to indicate at least the probable intensity range together with the full quotation of the text. It may also be feasible to define and use simplified grading of losses similar to that introduced for historical events in Persia (Ambraseys and Melville, 1982), i.e.

i = 1 Total destruction of all man-made structures, including stage posts and water cisterns with a large number of people killed, including leading citizens; total loss of livestock

i = 2 All dwellings destroyed and many public buildings ruined, with numerous casualties and some loss of livestock.

i = 3 Many houses ruined and a few people killed.

i = 4 Few dwellings ruined, public buildings cracked, without fatalities.

i = 5 Shock widely felt, causing concern and in places panic.

3.5 MACROSEISMIC EPICENTRES

Data provided by historical sources and field studies are generally adequate to permit accurate locations of the meizoseismal region of earthquakes of the last two centuries. For events before about 1800, however, it is often difficult to ascertain the true epicentral region of a given event.

When several places or areas are mentioned, without any apparent indication of a meizoseismal region and no evidence of serious damage at any one location, the epicentral region can be estimated fairly closely by reckoning its position from the various places named. This technique was used to identify potential epicentral regions, not only of historal events but also of early twentieth-century earthquakes for study in the field, particularly in sparsely populated areas. The meizoseismal region of shocks felt in towns and villages round the borders of deserts or mountainous regions was often located successfully in this way, with an error of a few tens of kilometres.

In cases where only the name of a province or district is given as being affected, no precision is possible.

It is often the case, that only one place is named as affected, and then a great deal depends on the extent of detail available about the effects in that place and in its dependencies.

Internal evidence often suggests that destruction was not particularly severe and that outlying villages also suffered damage, indicating that the meizoseismal region should be sought some small distance from the town itself. Alternatively, mention of a town but with no details of serious damage may suggest either the occurrence of a local earthquake of small size, or that of a large event some distance away.

The problem of location is intimately connected with that of assessing the size of the earthquake. One measure of this magnitude is the radius of perceptibility (r') of the event, or the average epicentral distance at which the shock was felt. Our sources are generally adequate to permit an assessment of this parameter. Long-period effects, such as the collapse of free-standing high walls, or tops of minarets, the sloshing of water out of ponds and the swinging of curtains and screens in houses, all help assess the relative size of an event, and thus the location of the epicentre in relation to places where these effects are reported.

Each macroseismic epicentre may be graded according to the quality and quantity of the information from which it has been derived.

Grade (a), or good determination, implies the existence of good isoseismal maps or sufficient information describing the meizoseismal region to help define its limits. This may include evidence of faulting, or significant changes in the water supply and other factors deduced from written sources or field studies, or both. Such precision is rarely encountered in early historical documents.

Grade (b), or moderate accuracy is assigned to epicentral locations deduced from evidence of the locality or district where the Intensity was maximum, with indications of places or areas affected at lower Intensities, that help assess the limits of the meizoseismal region.

Lower grades, all denoting poor determination, are assigned according to the types of macroseismic data available:

Grade (c) is used for locations based only on the evidence of high Intensity shaking reported at one locality or town, and also for locations calculated only from lower Intensity isoseismals, from radii or perceptibility or from a combination of the two. Indirect evidence, such as abandonment of sites, may also help assess the location of the epicentral region.

Grade (d) implies that the shock was felt locally; it may indicate the approximate location of a small shock, or the occurrence of a large magnitude event some distance away, for which data are still incomplete. Grade (e) denotes a very approximate location of events that were probably large but for which we have insufficient details; such epicentral locations are generally not shown on figures and are of value only on a global scale. Similar locations but not based on reliable data are deemed to be associated with dubious events, which are not listed.

3.6 CALIBRATION OF MACROSEISMIC DATA

Once collected and assessed in the general terms outlined above, it is then necessary to calibrate or normalise the data with observations of recent earthquakes. This implies that adequate investigations of recent events have been, or will have to be made, and that field studies have concentrated on all relevant aspects of the earthquake, such as damage to housing of different types, epicentral intensities, radii of perceptibility and ground effects. Field studies may also bring to light information on earlier events in the same region, particularly important if it is a remote rural area that has not been prominent in documentary sources.

As macroseismic data for recent events is likely to be fuller than it is for earlier earthquakes, to achieve a uniform scale of assessment applicable to the whole period, it is necessary to simplify the existing Intensity Scales and the criteria used to quantify earthquake effects, concentrating on the salient features that emerge from both historical and modern descriptions. On this basis, with say, a 5-grade Intensity Scale, historical data can be classified consistently alongside modern data.

This stage being reached, one should be able to have assigned epicentral intensities and radii of perceptibility to historical and modern events on a uniform basis, making use of experience from the field study of recent earthquakes. For obvious reasons, this kind of work cannot be done by an arm-chair seismologist or engineer. The effort involved will have included thorough research in documentary sources, probably written in a wide variety of languages, some retrieved relatively easily and some with difficulty by reason of the inaccessibility, or the poor state of preservation or legibility of the relevant material. Secondary areas of study, such as archaeological work on sites, and on the architectural history of both major monuments and domestic dwellings, will have contributed some useful insights. Geographical and historical study of the country will have been carried out, particularly with regard to the distribution of population and the channels of communication, which have influenced the survival of data. In addition, thorough field studies will have been made of as many earthquakes as possible. It will be appreciated that these procedures take time and require a variety of skills.

3.7 ISOSEISMAL MAPS

It is highly recommended to plot on the map individual macro-seismic observations belonging to a particular event and to draw isoseismals separating observations of different macroseismic grades. The isoseismals should not observe invidividual deviating observations, on the other hand, they should not be too generalised. The averaging is done when mean radii of isoseismals r_n are determined. The r_n values are very significant in estimating depth of foci of shallow events and in compiling intensity-distance curves for further application in hazard assessment.

3.8 RETRIEVAL AND UNIFICATION OF INSTRUMENTAL DATA

Within the context of this document instrumental data is particularly required for the calibration of historical data as described in Section 3.6. It is with this objective that a short summary related to the retrieval and unification of instrumental data has been included. Eventually the cataloging and presentation of events substantiated by both instrumental and macroseismic information could have a common format which will be discussed in Chapter 4.

To achieve a similar homogeneity for instrumental data, it will be necessary to undertake a process of revising existing epicentral location estimates and magnitudes.

This may be done from existing recordings and station bulletins, or it may be necessary, for events which are important or not previously identified or processed, to resort to original records. As with macroseismic information, the value of instrumental data must be assessed and unified, in terms of accuracy. The relocation of early instrumental epicentres is unlikely to result in new positions which are much more reliable than the originals, but major improvements can be achieved when these locations had only been adopted. For events after about 1950 and for areas of limited geographical extent, macroseismic epicentres may be used as calibration locations in joint epicentre determinations (JED). One of the methods for improving or confirming instrumental epicentres of pre-1960 events is to attempt to find correlations with macroseismic data.The true source of the earthquake may not be in the centre of the felt area and the felt or meizoseismal region is dependent on population distribution. But at least the macroseismic epicentres will not be liable to the gross mislocations which are possible with instrumental relocations.

Also, it will be necessary to calculate magnitudes for all events of the instrumental period using a standard procedure, viz. M and m, as defined in the Manual of Seismological Observatory Practice, making use of amplitude period data from station bulletins or from decoupled seismograms. In cases where instrumental data are lacking or inadequate for the calculation of magnitude, it may be possible, for shallow depth earthquakes, to estimate magnitude from other parameters, particularly the epicentral intensity of the earthquake and its radius of perceptibility or radii of isoseismals. As these can generally be determined from macroseismic data, it is possible to assign magnitudes to historical events.

4. FORMAT OF THE SUMMARY SHEET

Basically, four categories of information should be summarised:

a) Earthquake parameters from existing homogeneous regional lists and catalogues e.g. that by V. Karnik and parameters revised or completed recently.
This information should be followed by the final list compiled by national experts from data mentioned in b, and c, and from revised parameters.

b) Instrumental data (periods and amplitudes of seismic waves) used for magnitude determination.

c) Macroseismic data, i.e. mean radii of isoseismals, list of localities affected by the earthquake, isoseismal map.

d) Information on degree of damage for different structural types, on casualties, injuries and economic loss.

The sheet should contain a full account of sources retrieved.

The summary sheet is attached to copies of all source information from archives, chronicles, reports, maps, etc. voluminous sources are deposited separately.

The list of localities including all names used in the past and geographical co-ordinates should be compiled.

a) <u>Format</u>

1	2	3	4	5	6	7	8	9	10
Ref.	Origin time	Epicentre co-ordinates	Depth of focus	M	m	I_0	r_5	r_3	Remarks

2. Time given to full hour, minute or second according to the estimated precision.

3. Geographical co-ordinates given to full degree and its fractions according to the estimated precision. Both instrumental and macroseismic epicentres should be given.

4. Focal depth in km or in category of depth: s - very shallow ($h < 5$ km) n - normal ($h = 5-60$ km), i-intermediate ($h = 61 - 300$ km), d - deep ($h >$ 300 km).

5. Magnitudes can be calculated using either trace amplitudes a(mm) according to the original Richter's procedure (M_L maximum amplitudes A of the true ground motion in main seismic phases P,S,L, or the ratio A/T where T is wave period). These magnitudes are designated by m_B, M_S or M_P, m_s, M_{LH} or M_{LZ} (see e.g. Bath 1981). In short distances magnitudes based on duration of seismic waves are useful. In the absence of instrumental data magnitudes can be estimated from empirical formulae linking magnitude, with Intensity I_i and corresponding average radius of the isoseismal I_i.

Simplified formulae of the type $M=f(I_o)$ are permissable only if a small variation in focal depths can be assumed. In any case, the reliability of these formulae should be ascertained before they are used.

The principal requirement for all procedures is that all formulae are consistent, i.e. they are calibrated by the same type of magnitude, preferably by the standard one based on surface waves with T = 20 s.

When combining determinations from several stations, station corrections should be introduced to reduce the scatter.

Surface wave amplitudes are not convenient for the determination of magnitudes of shocks deeper than normal except, when depth corrections are introduced, for these shocks body wave amplitudes are used.

6. Body wave magnitudes based on PZ, PH, SH, etc. amplitudes; distinction should be made between the original Gutenberg type body wave magnitudes and magnitudes based on short period PV, PZ waves T= 1s I. Body-wave magnitudes are recommended for events deeper than normal.

7. Intensity in the epicentre, given only if the epicentre is on the continent, for off-shore events the largest observed intensity Imax is given in Remarks. If possible MSK-64 scale should be applied.

8.9. Mean radii of isoseismals of intensities 5^o and 3^o respectively.

10. Any relevant additional information : landslides, tsunamis, observed faulting type, length, other source parameters determined instrumentally, e.g. size of the focus, fault plane solution, seismic moment, stress drop, etc.

Notes: i) Information under 2,3, and 4 should be marked by "n" if determined macroseismically during the 20th century.

ii) Magnitudes should be followed by the number of stations used for the calculation of the mean value; if available the standard error of the mean should also be added.

iii) If only a brief text describes the event it should be reproduced from the original source if it does not permit to evaluate the event in terms of parameters.

iv) Uncertain or doubtful information should be marked by a question mark or commented in Remarks.

(b) Amplitude Data Format

Station	Distance	Phase	T_N	A_N	T_E	A_E	T_z	A_z	$M/_m$

(c) Macroseismic Information

The information on radii of isoseismals published by different authors should be given together with the values finally adopted. The final isoseismal map with all points of observation plotted should be attached. It is recommended to attach also the list of shaken localities with their co-ordinates and assessed intensities.

(d) Information on Losses

i) Number of houses totally destroyed, i.e. completely collapsed

ii) " " " heavily damaged, i.e. beyond repair

iii) " " " damaged, i.e. repairable

iv) Number of people killed

v) " " injured

vi) Total number of houses exposed

vii) Total number of people exposed

viii) Total financial loss in units used in that time.

(e) References

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Appendix I

EXAMPLE OF WORKSHEET: EARTHQUAKE DATA FILE, IMPERIAL COLLEGE OF SCIENCE DATA BANK

Saros-Marmara (Name of event)								1912 Aug 9 (NS Date of event)		
	Origin Time (GMT)	Epicentre	Depth	M_s (no.st.)	m (no.st.)			Intensity	Main Source
(1) KAR:	012900	40.50 - 27.00	n	7.3(20)	6.8(4)	r5=500		X	GR
(2) SHB&K:	0129--	40.60 - 27.23m	16	7.3(20)	7.0	r5=460	r3=	X	(RF)
....	......	.. ..	..	... ..	...	.. ...	.. ..		...

(1): Main secondary source of information
(2): Main secondary source of information with revised data.

(3) F:	012905	40.75 - 27.20m•(4)	21	7.4(23)(5)	6.9(0.3)(5)	r5=270	r3.5=440	X	TS

(3): Final determination based on primary sources
(4): Relocated or re-determined epicentre

Determination of magnitudes M and m from teleseismic amplitude-period data.

Station	TN (Phase)	(Period)	AN (Amplitude)	TE	AE	TZ	AZ	D°• (Distance)	M/m
UPP:	PH	5"	8	-	-	-	-	20.2°	6.45
	L	12"	400	12"	375	-	-		7.13
...	.	..	...	.	...	.	...	....	....

(6) L = 50+ N/RL
(7) R = 400 cm
(8) Ra= 200 cm
(9) h = 21 km
(10) bn= 3.24
a/n= 3.2×10^{-3}

(6): Measured length of fault-break associated with event(N:normal; T:thrust; RL/LL: right-lateral/left-lateral strike slip)
(7): Maximum observed slip (8): Average observed slip
(9): macroseismically determined depth of nucleation
(10): computed absorption coefficient.
(5): recomputed magnitudes, standard deviation and number of stations used.

Determination of magnitude M from Milne amplitudes.

Station	A(mm)	D°	M
Shide	40.0	22.1°	7.46
...	....	....	....

(11): Isoseismal radii from published isoseismal maps.
(12): Recomputed isoseismal radii in terms of (MSK) i.e. values used to determine (9) & (10)

M = 7.29(0.37)29

(5) M= 7.38(0.3)23 m = 6.9(0.3)5

Isoseismal radii (11)

	Macov.	Sieb.	(12) F
r11=	-		-
r10=	22	9	-
r9 =	41	15	25
r8 =	76	33	60
r7 =	132	105	100
r6 =	208	-	175
r5 =	-	-	270
r4 =	-	-	-
r3 =	-	-	440+
r2 =	-	-	-

Do	=	Number of houses totally destroyed	12,687
D1	=	" heavily damaged	12,293
D2	=	" damaged	15,002
K	=	Number of people killed	2,836
I	=	" injured	7,353
D	=	Total number of houses exposed	200,000
P	=	Total number of people exposed	650,000

References (sources retrieved, analysed and studied)

Mihailovic(1927)P   P= primary sources

Mihailovic(1933)

Macovei(1912)P

Watzov(1914)P

....

Pinar & Lahn(1952)

Press Reports P   P= Newspapers consulted

Appendix II

THE 1627 EARTHQUAKE IN NORTHERN CAPITANATA (SOUTHERN ITALY)

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ENEA,
Rome, Italy

1. Introduction

In the field of research into past earthquakes, undertaken in relation to likely nuclear sites in Molise and Apulia, a study has been made of the one that took place in the Capitanata on 30th July, 1627.

The same research is also to be set in the context of the Work Grouup on the "Earthquake Catalogue" of the CNR "Progetto Finalizzato Geodinamica", that envisages, among other things, a re-examination of the most important earthquakes in Italy's past, based on original sources.

The earthquake had a maximum intensity of XI degrees on the MCS scale (inclusive of several shocks). It caused the deaths of thousands of people, caused fissures in the ground, variations in the regimen of underground waters, and a severe tsunami along the coasts of Apulia and Molise. The macroseismic activity closely connected with the earthquake lasted for a good three years, with a total of 1,700 shocks. The importance of the phenomenon is clear from these general data; so is the importance it assumes in relation to the safey of nuclear sites in the adjacent areas.

In the present paper dotts (...) replace all the original informations that have not been reported because they are written in old italian language and their translation could change their meaning and therefore the evaluation of intensity. Original data can be found in the italian version of the paper, published in the monography edited by "Commissione mista ENEA/ENEL per lo studio dei problemi sismici connessi con la realizzazione degli impianti nucleari" and printed in occasion of the Udine Congress of Progetto Finalizzato Geodinamica of CNR in 1981.

2. Bibliographical Sources

There is a fairly large bibliography about the earthquake, both contemporary and of a later date. The contemporary literature is formed of reports, letters and accounts written in the days just after the event, or a few years later, at most; the later literature, on the other hand, consists of some seismological works, generally written at the end of last century, and many historical works about towns or villages involved in the seism. The event is described more or less fully by all the Italian seismic catalogues, particularly those of M. BONITO (1691), E. CAPOCCI (1861), G. MERCALLI (1883), and M. BARATTA (1901).

It has been possible to obtain practically all the known contemporary literature, except for two documents, possibly transcriptions into French of reports written in Italian, referred to in bibliographies and probably to be found in Paris or Lyons.

The tracing of a 1930 publication that quotes the whole of Antonio LUCCHINO's manuscript (1630) was essential for research into the earthquake; he was living at San Severo at the time, and was therefore an eye-witness. This manuscript had already been published by M. BARATTA (1894), but only in part and it was attributed to Giulio LUCCHINI.

From research undertaken by N.CHECCHIA, who edited the manuscript for publication it was shown that Giulio, Antonio LUCCHINI's brother, could not have been the author, since he had died in 1608, before the earthquake took place. The manuscript, also published in the histories written by V. GERVASO (1871), M. FRACCACRETA (1828) and N. PITTA (1921), has proved to be by far the most important work on the earthquake. It consists of a very exact and detailed chronicle of the event, with news of the seismic period, the effects of the earthquake on the ground and on the underground waters, and the topographical siting and names of various places that either no longer exist or have changed their names.

Among the contemporary writers, besides A.

LUCCHINO there are other eye-witnesses, who were living in villages situated outside the area of the epicentre

These include G J. CERQUA, F. DEL VASTO and G DI NAPOLI at Lucera, F. SECINARA at Chieti, and an ANONYMOUS writer at Naples (Naples, 1627) All the others wrote their reports based on indirect information

It is interesting to note that on the occasion of the earthquake in question, the first exaples of seismic maps were probably published; they describe damage according to a macroseismic scale, of four degrees, that they include as a key. The first one (Fig 1) is by M. GREUTER (1627), the second (Fig. 2), attached to G.V. DE POARDI's report (1627) indicates "MARINARI H F " (where "F" stands for "fecit") as its author, with "BRICCIO G. del" ("del" standing for "delineavit") as artist-engraver. The first one, unlike the second, has a fairly exact topographical basis, or at least, one very like the real one. Some authors attribute the map in Fig. 2 to G.V. DE POARDI, author of the report to which it is attached; on the contrary, however, it is obvious that the author is actually H MARINARI: not only because he signed the map, but also because of the remarkable disparity between the map and G V. DE POARDI's account.

Fig. 3 shows another map (by M BARATTA, 1897), which shows only the area most affected by tremors however, but includes a series of drawings referring tto amazing events that happened on that occasion. Speaking of the seismic maps of Figs. 1 and 2, R. ALMAGIA' (1915), when comparing them, points out the differences between them, without however giving the actual wording of the key

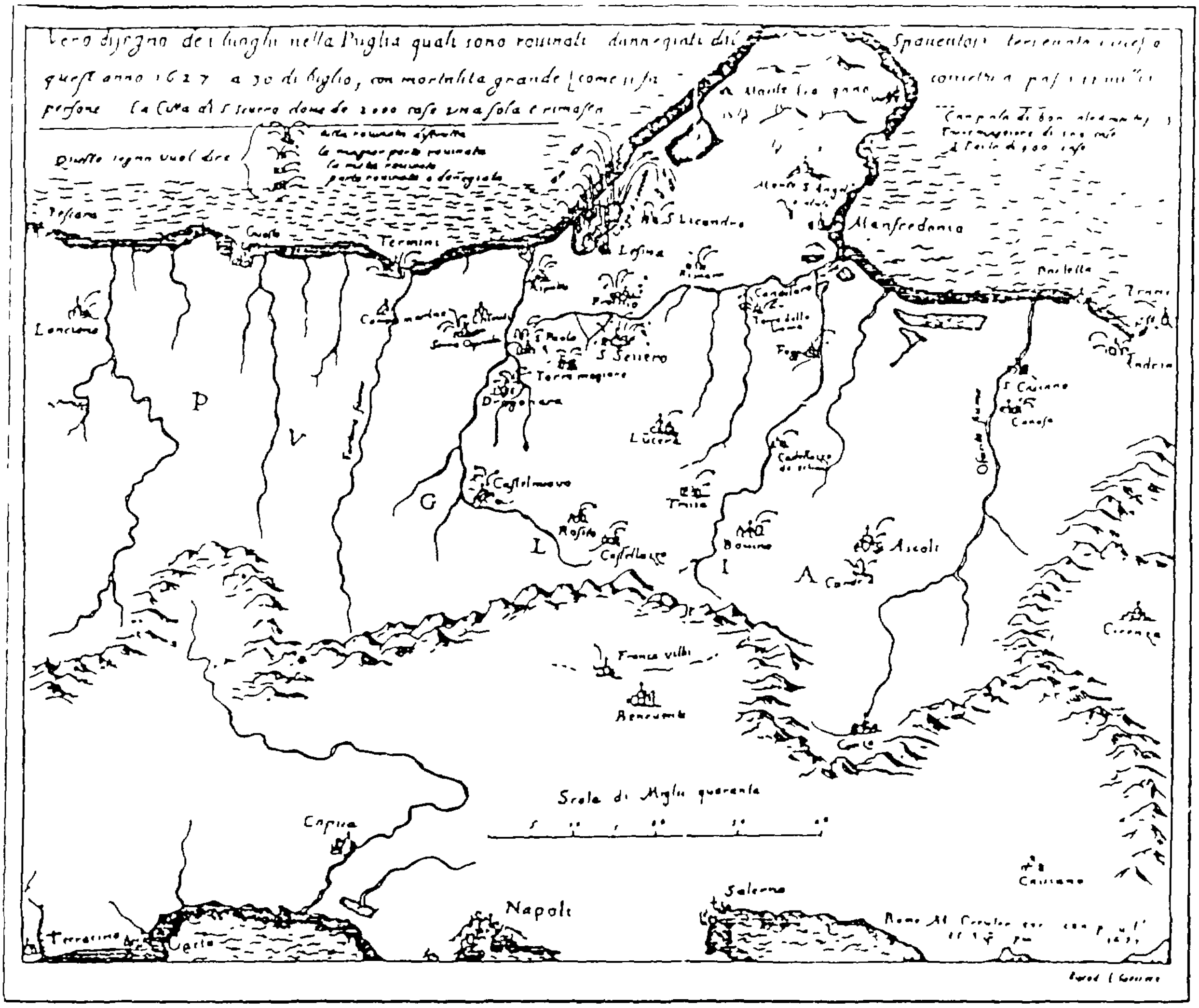

FIG 1

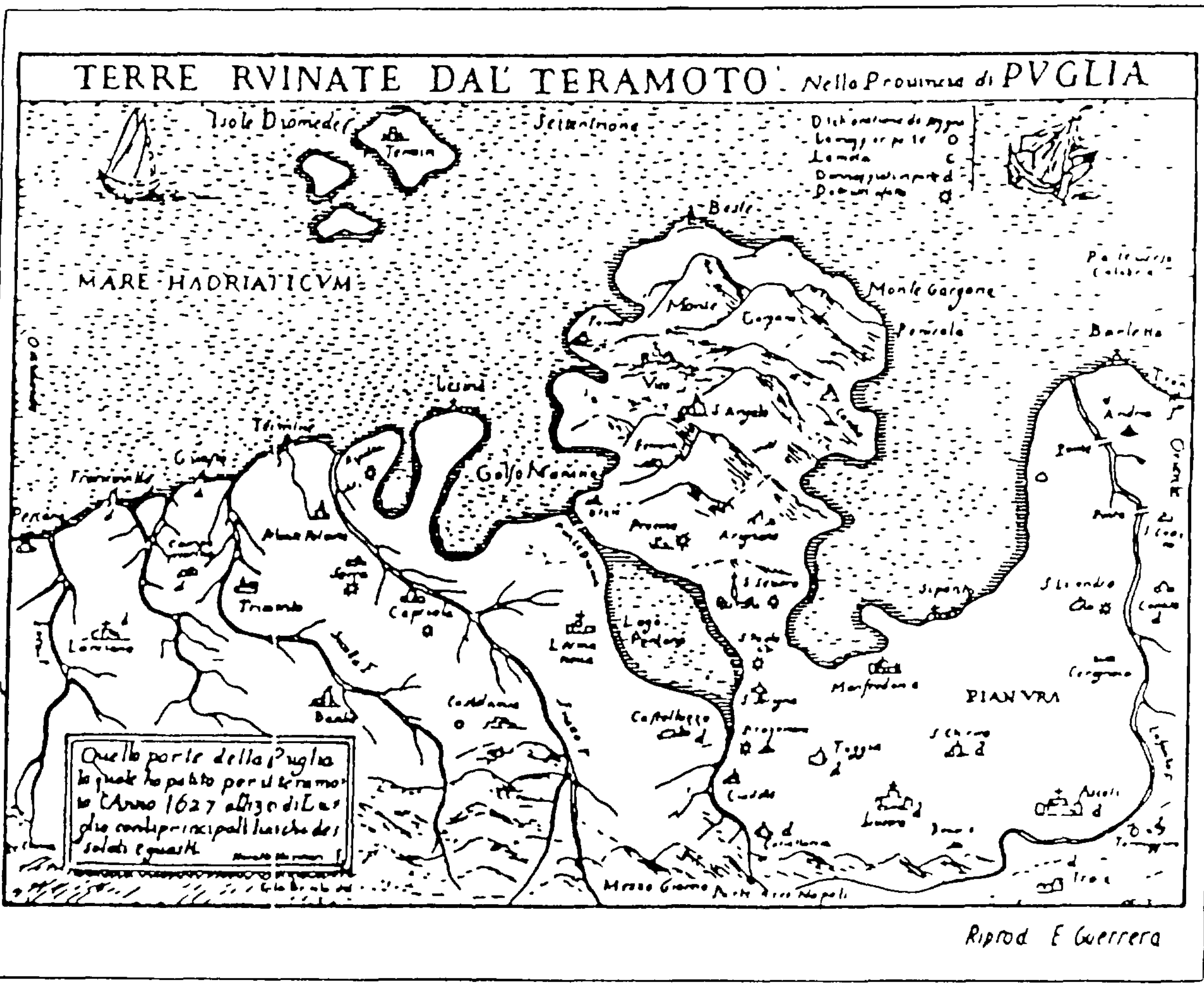

FIG 2

3. Collection of Macroseismic Information

All the informations used for reconstructing the seismic activity connected with the earthquake, the preparation of the isoseismal maps and the map of the natural collateral effects are listed.
The informations provided by contemporary writers have always been drawn upon, but those offered by later writers has only been used when they are appropriate. The passages taken from works and transcribed word for word from the originals have always been published in inverted commas and proceded by the author's name, with the date of publication. In this way, it was intended to offer the reader a chance to examine the original source directly, and make and individual choice, if necessary.
This system is useful since it concentrates the information about each place drawn from many different authors; however, it has an inconvenience in that it does not let the reader know the general context of the publication from which it has been taken.

3.1 Seismic Activity between 1621 and 1630

All known shocks have been indicated in chronological order, as well as all the informations that can contribute to knowledge of the macroseismic activity in the area where the earthquake occurred in the years between 1621 and 1630. Before and after these years, tremors had not been recorded for long periods of time
The date (day, month and year), time, epicentre co-ordinates and intensity according to the MCS scale are given for each shock. The time is the local time, changed into the present-day system from the "Italian stile" one then in use In that


TERRA RUINATE DAL TERREMOTO NELLA
PROVINCIA DI PUGLIA
Die zerfallne erd durch den Erdbidem in der
landschafft Puglia
Settentrione
Isole Diomede
MARE HADRIATICUM
Monte Gargano
Barletta
Trani
PIANURA
Mezza Giorno
Manfredonia
Foggia
Tosciano
Lago

FIG 3

system, the first hour began when the Ave Maria was rung, which was itself normally timed half an hour after sunset, but sometimes a quarter of an hour after or even at the same time as the sun set Considering the imprecision of the timekeeping at that period, it has not been considered useful to change the local time into the time-zone hour, on the other hand, the time may be considered as referring to the meridian of Termoli, or Central Europe, passing practically through the epicentre of the earthquake
The seismic activity closely connected with the earthquake very probably began in October, 1626, however, the shocks felt at San Severo in 1621 are included in the list Mention is also made of the 1625 earthquake at Termoli and Regione Frentana, reported by many authors, although it very probably never happened

6 8. 1621, 2am, San Severo (41.68 15 38) VI degree

( )

It is very likely that during 'a half quarter of an hour several shocks were felt.

6 8. 1621, after 2am, San Severo (41.68 15 38), VI-VII degree.

( )

30.7 1625, Termoli and the Frentana area, VIII-IX degree.

The earthquake, recorded in almost all the Italian catalogues, very probably never happened, since the writers who mention it, all of them late ones in any case, have fallen into clumsy errors

D ROMANELLI (1806) and A MAGLIANO (1895) mention L PIGNORIA (1629) in their accounts, but he does not refer to earthquakes taking place in 1625, but in 1627,

A PERRELLA (1889) writes about it without giving bibliographical references, and ignoring the 1627 earthquake, thus evidently mistaking it for this one,

- M BARATTA (1901) includes it in the catalogue, refering A PERRELLA (1889), and thus, refering M BARATTA (1901), almost all the most recent catalogues mention it

From the above, we can easily see the mistake in the date between 1625 and 1627, made by the authors mentioned above The information given by the writers themselves follows

( )

Period from October, 1626 to 29th July, 1627

( )

The above reports of shocks noticed at San Severo and Ariano Irpino should refer to local earthquakes, not the same one, considering the notable distance there is between the two places and the probable low intensity of the shocks themselves In this period, light shocks are also noted at Naples by E Capocci, and the same argument is valid, with more reason

30.7.1627, 12am, San Paolo di Civitate (41.78 15.30), X-XI degree

All the contemporary writers agree about the date of this shock, except for some minor differences in the time, very probably due to inexact measuring in their way of calculating the time, using the "Italian style" method, which was not uniform The great majority of authors give the time as "16" Italian time, corresponding to 12am according to the present system
This is certainly the strongest shock of the whole seismic period It severely damaged San Paolo di Civitate, San Severo, Serracapriola, Torremaggiore, Apricena and Lesina LUCCHINO, who was in the country at San Severo at the time, near the "delle Grazie" church, saw clouds of dust rising from the village shortly afterwards, a sure sign of severe damage
The epicentre is to be taken somewhere in the middle of the above-mentioned villages, which were the most severely damaged in the whole seismic period
Amongs the descriptions of contemporary authors, only eye-witness accounts have been used, in particular that of A LUCCHINO, th only one who was actually in the epicentral area

( )

30.7.1627, 0.15am. San Severo (41.78 15.30), IX degree

Only LUCCHINO mentions this shock for San Severo, however it is very likely that it was felt in all the other villages included in the area of the epicentre of the prevous shock, Similarly, the epicentre may also be considered as coinciding with the one before

( )

Other earthquakes on 30th July, 1627

Many other shocks were noted on 30th July, in the short interval between the two earthquakes mentioned above and also after them, as may be deduced from the following descriptions

( )

Period from 31st July - 7th August, 1627

( )

The shocks also continued during the next few days. Considering the period between 31st July and 6pm on 7th August, we have the following descriptions

7.8.1627, 6pm, Serracapriola (41.78 15.30), X degree

There is almost complete agreement among contemporary writers about the date and time of this shock, with the sole exception of CERQUA, who times it at 23 instead of 22. Among the later writers however, there are differences of up to two days in the date.
The earthquake damaged Serracapriola and Apricena again, also causing deaths. The epicentre, calculated as a point between the two villages, coincides with that of the first shock

( )

8.8.1627, 1am, North Capitanata (41.78 15.30), V degree

( )

24.8.1627, North Capitanata (41.78 15.30), VII-VIII degree

( )

8th 27th August 1627

There were many further shocks during this period as the following reports show

( )

6.9.1627, 5pm, San Severo (41.68 15.38), IX degree

This is the last disastrous earthquake of the seismic period, the epicentre, judging from the effects felt in San Severo and Lucera, has probably moved south, compared to the previous ones

( )

Except for LUCCHINO, no contemporary writer makes any reference to the prolungation of the seismic period after the event of 6th September. Only CAPOCCI, among later writers, while referring to Naples says that "17 tremors were felt here March to November", many of which are probably to be linked to the earthquake in Capitanata.
The information passed on to us by LUCCHINO follows, including that contained in the summary he makes towards the end of his account

7th September, 1627 - Spring 1628

( )

12.7.1628, 3am, San Severo (41.68 15.38), VII degree

( )

Final Summary

( )

3.2. Effects of the earthquake on people and structures

All the information used to assest the intensity, the compilation of the quotated plane and the drawing of the isoseismal map is reported, village by village. The maximus intensity assested (XI degree MCS) is comulative of the shocks that took place during the whole seismic period. This value is, in a certain sense, confirmed in the volume "Apulia" of the T.C.I. "Guide to Italy": it shows that there are no monuments or buildings in any of the villages comprising the area of the epicentre earlier than 1627, except for some "remains", the bottom part of some bell-towers, the lower part of church facades, rebuilt parts of castles, etc.
Accumuli, Scanno and Isernia are included among the villages affected by the earthquake, despite the fact that we do not know exactly whether they were damaged by the shock on 30th July or by another one in the same month.
There are contrasting opinions about this by the writers concerned (see A. CAPELLO and M. BARATTA)
The number of human victims varies in the contemporary accounts from a minimum of 4,000 to a maximum of 17,000 dead, however, it is possible to obtain a figure surely close to the real one from the account written by A. LUCCHINO. This gives 900 victims for Apricena, 150 for Lesina, 350 for San Paolo di Civitate, 800 for San Severo, 2,000 for Serra

Locality	Number of "fuochi"	Number of inabitants	Number of victims	Victims percentile
Apricena	400	2000	900	45%
Lesina	—	—	150	—
S Paolo d Civ	200	1000	350	35%
San Severo	1000	5000	800	16%
Serracapriola	1000	5500	2000	36%
Torremaggiore	400	2000	300	15%

Capriola and 300 for Torremaggiore; adding these figures together, we reach a total of 4,500 victims, without counting, the author warns, the "number of strangers" that was "large" in San Severo, for example

However, we are not informed whether the writer means by "strangers" travellers passing through, or more probably, people living outside the town In any case, considering the above, and the fact that LUCCHINO does not give the number of victims for villages struck by a shock of the X or IX degree, which must certainly have had casualties, it may be affirmed that the total number is more than 4,500 victims, but much less than 17,000

Using G. DI NAPOLI's account (1627), that gives the number of fires (equivalent to families, that may be judged as consisting of an average of about 5 persons) for several damaged villages, and the number of victims given by LUCCHINO, very meaningful evaluations of the percentage of victims may be arrived at, as can be seen from the following table.

Lists of villages having the same type of damage, usually noted generically, may be found in the writings of the authors consulted; since it has been noted that the villages included in the same list have suffered damage of quite different types, this kind of information is always preceded by the phrase "included among the villages".

In the following alphabetic list of damaged villages, any ancient or dialect names found while examining the sources have been put in brackets

(...)

3.3 Effects of the earthquake on the surface and on underground waters

There is a good deal of information and descriptions of the earthquake's effects on the environment available

When the data have been traced, they are given in Fig 5, and shown in the key of the figure itself, as typology of effects. When they are not identifiable, however, they have been only noted in the list, under the heading "in the affected area generally".

As one may see from the figure, the effects of the earthquake are chiefly to be found in the area within the isoseismal of the IX-X degree, particularly close to San Paolo di Civitate and along the lower course of the river Fortore However, events took place even at a great distance from the epicentre, but these were generally alterations in the regimen of the underground waters and landslides.

As far as the events occurring near Troia are concerned, one may put forward the hypothesis that a large cone of sand was formed, owing liquefaction penomena ("sand fountains").

It is only at San Severo that there is any news of events occurring before the earthquake, all the other information refers to phenomena taking place afeter the earthquake itself

Bofore the Earthquake

(...)

During the Earthquake

In the Affected Area generally

(...)

3.4 The tsunami

The tsunami, according to the information gathered, took place along the stretch of coast level with Lake Lesina, Manfredonia, and the mouth of the Sangro river (Fig 5)

The same information seems rather to exaggerate the phenomenon; for this reason, it is difficult to evaluate the exact scale. Descriptions like "the sea drew back into its bed for three miles" seem exaggerated, frankly, also considering the shallow sea bed at that point. It is also difficult to interpret the reference to Manfredonia, where "it arrived up to the middle of the walls", without

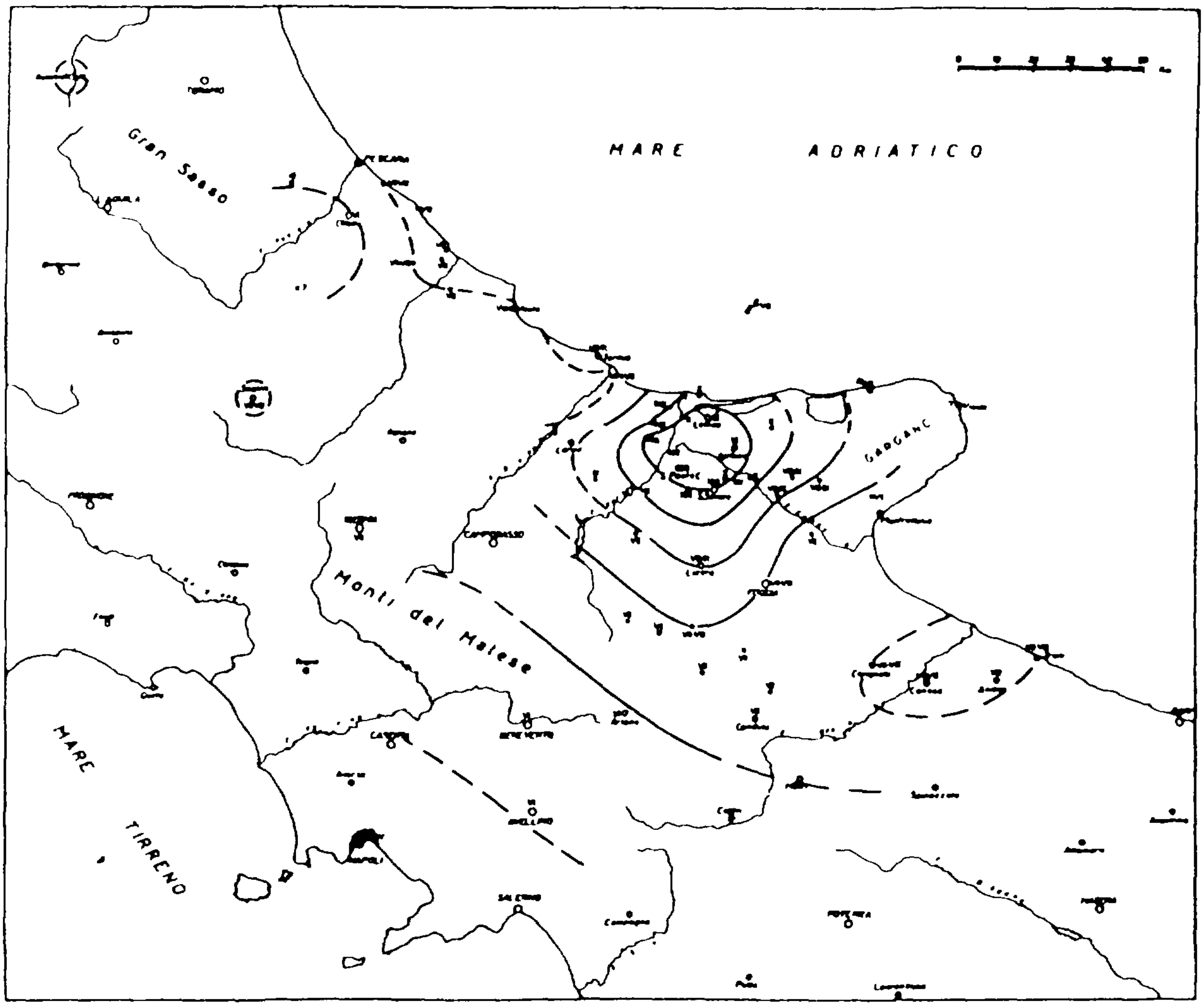

FIG 4 Isoseismal map of the July-September 1627 earthquake

QUOTATED PLANE OF THE 1627 EARTHQUAKE

Locality	Lat	Long	I (MCS)	Locality	Lat	Long	I (MCS)
Accumoli	42 69	13 25	VIII	Ortona	42 35	14 40	VII VIII
Andria	42 22	16 29	VIII	Paglieta	42 17	14 50	VII VIII
Apricena	41 78	15 45	XI	Rignano Garganico	41 67	15 59	VIII IX
Ariano Irpino	41 15	15 09	VI	Ripalta	41 86	15 28	X
Ascoli Satriano	41 20	15 57	VII	Roseto Valfortore	41 37	15 10	VII
Avellino	40 55	14 47	VI	San Giovanni in Venere	42 25	14 46	VIII
Benevento	41 13	14 77	VI	San Giovanni Rotondo	41 71	15 73	IX
Bovino	41 25	15 34	VII	San Marco in Lamis	41 71	15 64	IX
Campomarino	41 96	15 04	VII	Sannicandro Garganico	41 83	15 57	X
Candela	41 44	15 52	VII	San Paolo di Civitate	41 74	15 26	XI
Canosa di Puglia	41 22	16 07	VII VIII	San Severo	41 68	15 38	X XI
Castelluccio de' Sauri	41 30	15 48	VII	Santa Croce di Magliano	41 71	14 59	IX
Castelluccio Valmaggiore	41 34	15 21	VII	Sant'Agata	41 88	15 24	IX X
Castelnuovo della Daunia	41 58	15 13	VIII IX	Scafieta	41 67	15 90	VIII
Cerignola	41 27	15 90	VII	Scanno	41 90	13 88	VII VIII
Chieti	42 35	14 17	VI	Serracapriola	41 80	15 16	XI
Chieuti	41 85	15 17	IX	Taverna di Civitate	41 78	15 24	XI
Dragonara	41 69	15 15	X	Termoli	42 00	15 00	VIII IX
Foggia	41 46	15 55	VII VIII	Torre dei Giunchi	41 71	15 42	X
Fossacesia	42 24	14 48	VIII	Torre di Brancia	41 71	15 50	X
Francavilla a Mare	42 41	14 29	VII	Torre di Zecchini	41 71	15 46	X
Isernia	41 59	14 23	VII	Torre Fortore	41 91	15 33	X
Lanciano	42 23	14 39	VII VIII	Torremaggiore	41 69	15 38	X XI
Lesina	41 86	15 35	XI	Trani	41 28	16 42	VII VIII
Loreto Aprutino	42 43	13 58	VII	Tremiti (isole)	42 12	15 50	VIII
Lucera	41 50	15 34	VIII IX	Troia	41 36	15 31	VII VIII
Masseria San Chirico	41 58	15 70	VII	Vasto	42 11	14 70	VII
Masseria Negri	?	?	X	Vieste	41 88	16 17	?
Napoli	40 85	14 27	V				

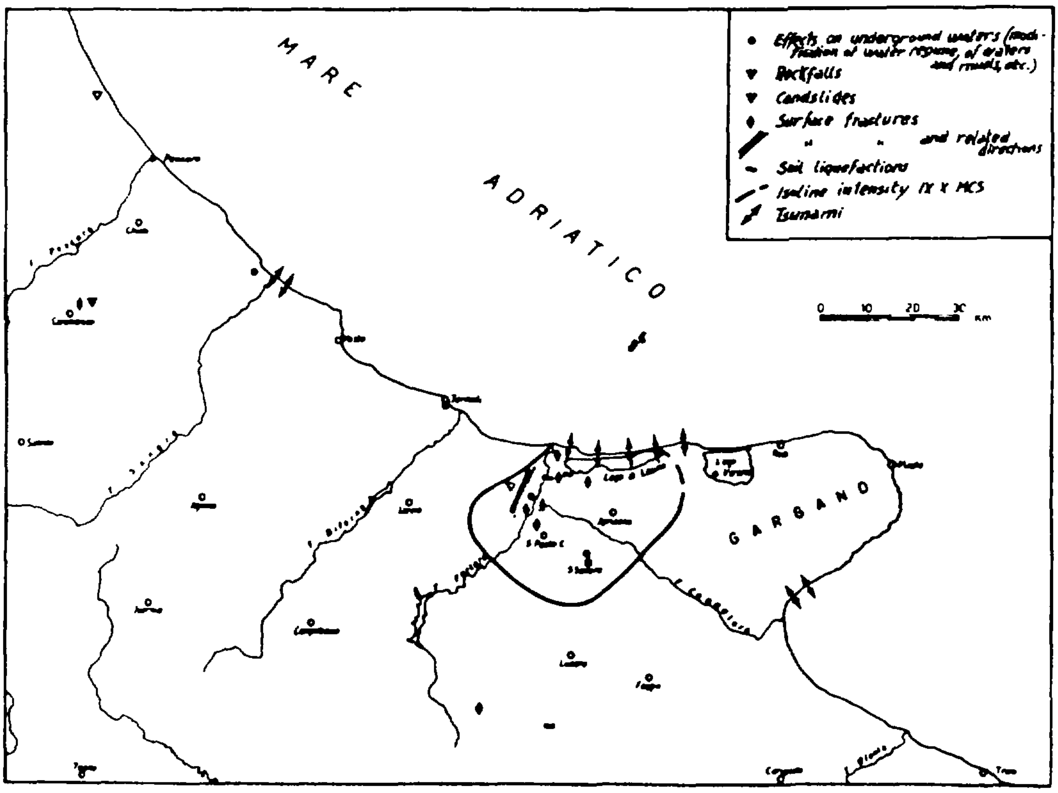

FIG. 5. Effect of the earthquake on the ground and on the undergruound water.

specifying which walls. It must be remembered that Manfredonia is not mentioned by any authors as being one of the towns damaged or suffering casualties.
There is no news of damage or victims in the other coastal areas either, due to the tsunami; it is very likely however that Lesina at least suffered certain effects.

(...)

4. Isoseismal Map

Since it has not been possible to identify the damage shock by shock, the isoseismal map (Fig. 4) shows the effects of the earthquake during the whole seismic period, particularly that of the shock of 30th July that took place at 12am (X-XI) and at 0.15pm (IX), on 7th August (X) and 6th September (IX).
Degrees of intensity attributed to the above shocks are uncertain, because of the lack of information available for each shock.
There are no indications that during the seismic period there were any perceptible movements of the epicentre, except for the shock on 6th September; on that occasion, the epicentre seems to have moved southwards.
The isoseismic curves of the epicentral area are rather rounded on the whole, with a slight movement discernible along the Apricena - Serracapriola axis. The roundish shape may be due to:
- effects of the 6th September shock, that affected San Severo and Lucera severely and produced a "swelling" in the isoseism towards the south;
- the high degree of intensity at Lesina (XI), very probably partly due to the tsunami, so that there is a "swelling" of the isoseism towards the north.
In conclusion, it seems that the main spread of the seismic waves in the epicentre is roughly E-W. This direction, also evident on the occasion of the shock of 7th August, coincided by and large with the high structural at Apricena, which is sunk, as the deep seismic sounding make clear, in a WNW-ESE direction, under the Plio-Quaternary sediments of the "Adriatic foredeeps".
The increases in intensity, uncertain as they are, that may be noted in the area of Canosa di Puglia, could be linked to the seismogenetic tectonic structure of the lower river valley of the Ofanto.

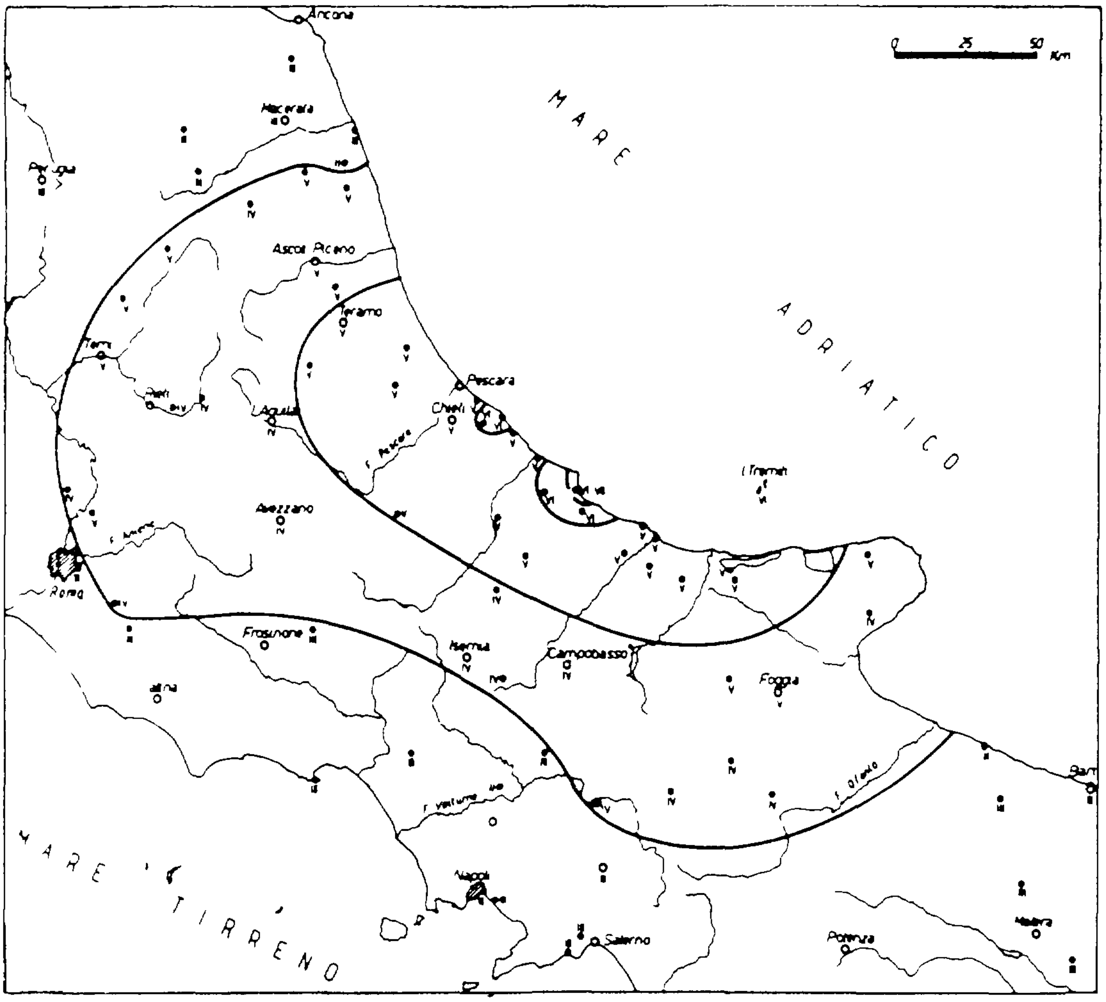

FIG 6 Isoseismal map of the 1895 Aug 9 earthquake

The distribution of intensity in the Abruzzi region is not very much defined, owing to the lack of information available, and the relatively high intensity found in areas a long way away from the epicentre, such as Accumoli, Scanno and, to a lesser extent, Isernia, may be due to shocks with a secondary epicentre along the Appennines and the local effects or even to other earthquakes occurring in 1627 This hypothesis, put forward by M BARATTA, cannot be proved with the information available at the moment

With regard to the relatively high intensity (VIII degree) noted along the Molise-Abruzzi coastline, one may assume that this is due to an earthquake having its epicentre in the sea, of the same type as that of 9 8 1985, whose isoseisms (Fig 6) have been traced on the basis of information provided by M BARATTA (1896)

It is interesting to note how the isoseism of the 1937 earthquake (Fig 7) also follows that of 1627 in various ways, it is evident that the two earthquakes have involved the same seismogenetic structures

In conclusion, it may be stated that the detailed historical research carried out has considerably improved our general knowledge of the earthquake that occurred on 30th July, 1627, both as regards the quantity and the quality of the data gathered

As a matter of fact, it is worth noting that epicentral co-ordinates and maximum intensity obtained in this work differ from those reported in previous national catalogues, both as regards numerical value and, above all, the reliability of the data themselves, particularly because of the considerable difference obtaining between one bibliographical source consulted and another A further difference also lies in the reconstruction of the seismic period, that is more extended and more reliable in this work than in previous ones

The following table shows the calculations carried out, the number of shocks occuring during the seismic period and the number of references used by previous writers

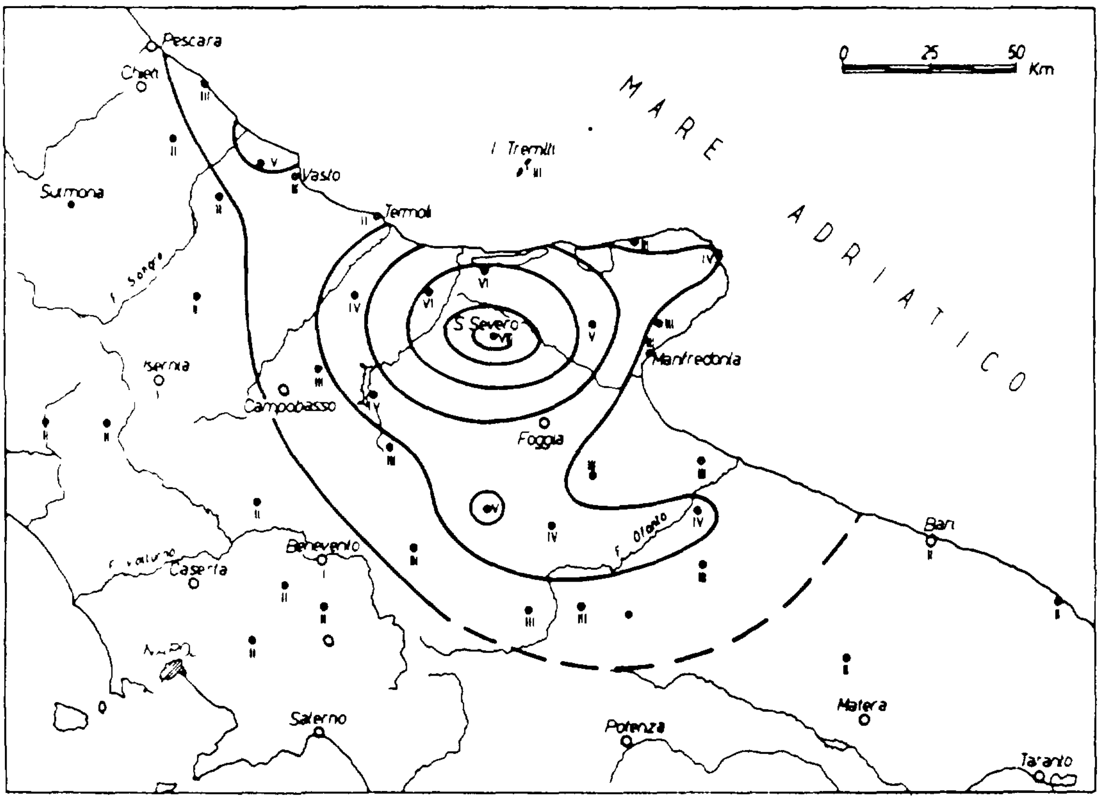

FIG 7 Isoseismal map of the 1937 July 17 earthquake.

Authors	Ep.coord.	I	n.shocks	n.ref.
Giorgetti - Iaccarino (1971)	41°42' - 15°19'	X	1	2
Carozzo - De Visentini - Giorgetti - Iaccarino (1973)	41°45' - 15°15'	X	4	3
ENEL (1978)	41°50' - 15°20'	IX	4	4
This work	41°47' - 15°18'	X-XI	9	89

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(+) not found

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