Intensity assignments from historical earthquake data: issues of certainty and quality

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Abstract
The use of macroseismic data in assessing parameters for historical earthquakes for use in seismic hazard assessment has thrown more attention on the way in which these data are treated. The processes involved in selecting which macroseismic data from a historical earthquake survive to the present day can be modelled as a series of filters, most of which are outside the control of the seismologist/historian, and which cause distortion in the resulting picture of the earthquake. The ways in which the data become distorted should be taken into account when interpreting the data as intensity values. One can usefully discriminate between the certainty of an intensity assignment (how well the data fits the scale) and the quality of an intensity assignment (how well one can trust that the value is a true reflection of what really happened). The expression of uncertainty is usually in the form of ranged intensity values; the expression of quality requires an extra symbol or rating of some sort. A system is presented for three types of quality problems: reliability of intensity assessment, locational certainty or uncertainty, and veracity of the original data. Each of these is treated as a binary variable, giving a final quality code ranging from 0 (best) to 7 (worst). This single integer quality code preserves three types of information which can then be expanded as required by computer programs designed to handle macroseismic data.

Key words *macroseismics – intensity – historical earthquakes – certainty – quality rating*

1. Introduction

The use of historical earthquake data for extending back earthquake catalogues, to improve on seismic hazard studies, is now well established in most parts of the world. As a result, much more attention is being paid to macroseismic methods than was the case twenty years ago. This is true in the general sense (*e.g.*, Cecić, 1992; Grünthal, 1993) and especially true as regards the use of macroseismic methods for historical earthquake data (*e.g.*, Musson, 1991; Levret, 1992). There are a number of ways in which this question can be examined, as for instance the following questions:

1) How does the special character of historical textual material affect the processes of assigning intensity?

2) What are the techniques that should be adopted in converting historical textual material to numerical intensity values?

3) How does one handle incompatibility problems between historical data and the intensity scale being used?

4) How should one qualify intensity assignments to reflect the quality of the supporting data?

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In this paper, attention will be directed chiefly to questions 3 and 4, but some discussion of question 1 is inevitable as it strongly influences what solutions are realistic in practice. As for question 2, this touches partly on the work of the professional historian, and partly on the general question of how macroseismic data are converted into numerical intensity values. This is a process which has often been mysterious in the past, but which is elaborated (with some reference to historical data) in Grünthal (1993).

Questions 3 and 4 can both be viewed in terms of putting some sort of error bars or uncertainty estimates on intensity figures. It is well understood that expression of the epicentral parameters of an earthquake should be accompanied with a measure of the uncertainty in these parameters. An epicentral position determined ± 30 km will be treated differently in subsequent analyses to one determined ± 5 km. The same is true with regard to intensity values, although this is less frequently done. In this paper the causes of, and some methods for the expression of, uncertainty in intensity values, will be reviewed. The discussion will focus chiefly on historical earthquakes, although the same considerations (to a lesser extent) may still be applicable to modern macroseismic data.

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2. The transmission of historical earthquake data

To understand the problems involved in dealing with macroseismic data from historical earthquakes, it is important to understand the processes that are at work in shaping the data sets that modern seismologists have to work with. In particular, it is necessary to consider what relation the data available today bear to the original phenomenon (the earthquake). The general progression from data to earthquake catalogue entry is discussed by Stucchi and Albini (1991), and an overview of historical earthquake research can be found in Eisinger *et al.* (1992) among other papers. A model specifically of the survival and retrieval of data can be given following Musson *et al.* (1988). Between the actual earthquake and the modern observer come a series of what can be thought of as filters, which progressively distort the observer's view (fig. 1). These filters can be divided into two groups: *filters of transmission* and *filters of reception*. The first group con-

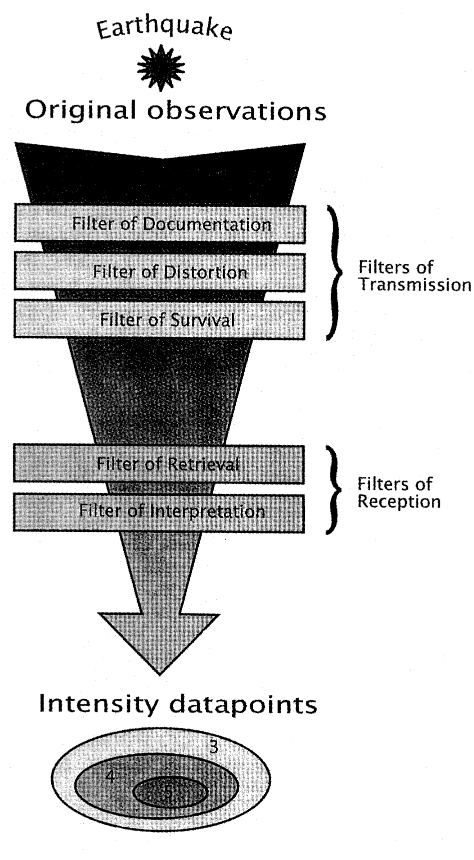

Fig. 1. Schema for the transmission of historical macroseismic data from the time of the earthquake to the present day.

cerns degradation of the available data through historical processes over which the seismologist has no control whatsoever. The second group concerns distortions that arise through the actions of the modern seismologist, and these can be reduced at least partly. The sequence can best be explained with a hypothetical example.

Consider an earthquake occurring in 1796, somewhere in Europe. Assume that it was observed by some 100000 persons. The experiences of all these people make up the complete observed phenomena of this earthquake. If one could possess 100000 testimonies of the earthquake then one would have an almost perfect data set, consisting of the whole population (using the word in its statistical sense) of effects. Needless to say, such a thing is impossible. For us to have any testimonies of the earthquake, they must be written down. Of the 100000 observers, how many will write down their experiences of the earthquake? Very few. This introduces the first filter: the *filter of documentation.* Relative to the total number of observations, only a few accounts will be transmitted, because most were never written down. Considering those reports that were written down, how accurate are they with regard to the original observation? They can be biased in one way or another, depending on the attitudes of the writer and the purposes for which he was writing. The loss of accurate data introduced by bias in the writer's account may be termed the *filter of distortion*; this is the second filter that operates. Suppose that of the 100000 observers of the earthquake, 200 make written records, of varying degrees of accuracy. How many of these are going to survive to the present day? A certain number will be thrown away, burnt or otherwise destroyed in the succeeding years. The third filter is therefore the *filter of survival.* Only a small proportion of the original records are likely to survive to the present day, and more data are lost in the process.

These three filters comprise the first group, the filters of transmission, which control what small percentage of the data that were available in 1796 are still surviving 200 years later.

Suppose that in 1996 a seismologist decides to study this earthquake. Of the 200 written records that existed in 1796, there are 50 still extant. The seismologist consults the major libraries and archives and finds 25. The rest of them are stored in obscure places, or buried in unsorted collections of material that have no calendars. The loss of the other 25 to the total data available represents the *filter of retrieval.*

Finally there is the *filter of interpretation* – when the seismologist sits down to assign intensities on the basis of the reports recovered, he may exercise an individual bias that affects his ultimate results. Some seismologists seem as a matter of principle always to assign the highest possible intensity to a given description; others always the lowest. The data can be further filtered by interpretation if the seismologist then provides an isoseismal map instead of a list of data points. This last filter is a special case as it can be avoided completely if the seismologist only takes the trouble to publish the written accounts of the earthquake along with his interpretation.

In statistical terms, the 100000 observations in this hypothetical case represent the total population. The 25 observations that the seismologist has collected are a sample. One can draw statistically valid conclusions about the nature of a population, based on a sample of observations, if, and only if, the sample is random. In the case of a modern earthquake, a seismologist can control the sampling procedure by adopting the same methods used to ensure random sampling as are followed in the social sciences (although this is rarely done in practice). In the case of a historical earthquake, the sampling process is outside the control of the seismologist and is done by the filters of documentation, survival and retrieval. Are these filters random in their effect? The answer to this question cannot be known precisely, but is probably that they are not. It can be argued that observations of higher-intensity effects are more likely to be documented than those of lower-intensity effects. (This is potentially still a problem with much present-day macroseismic data). And the survival of documents in one part of the felt area of the earthquake may be worse than in another depending on the passage of war.

The point of all this is to demonstrate that even historical macroseismic data sets that appear to be reasonably good can really have quite considerable uncertainties attached to them. The extent of these uncertainties is better appreciated if one has an understanding of the processes operating that make the data more «noisy», as outlined above. It is important, therefore, not to overestimate the accuracy of intensity assignments, but to give realistic measures of the reliability of intensity values.

In order to do this, the following proposal is offered: that one can make a distinction between the *certainty* and the *quality* of an intensity assignment. These two terms are defined as follows. Certainty is an estimate of the numerical error in an intensity assignment, similar to the estimated error in any other numerical parameter. Quality is an estimate of the value of an intensity assignment in terms of the extent to which one can have faith that it is an accurate reflection of what actually happened at that place during the earthquake in question.

These two concepts will now be discussed separately.

3. Certainty and scale resolution

The concept of certainty in intensity assignment is actually a very familiar one, although perhaps not always consciously thought about. It occurs every time that a seismologist is unable to assign a single intensity value to a set of observations. If the data suggest intensity 6, but are also compatible with intensity 7, and the seismologist cannot be sure about a single value, he assigns a range of possible values, in this case 6-7, meaning «either 6 or 7». This range is the degree of certainty (or the lack of it), and a case that can be written as 6 is more certain than a case that requires to be written 6-7, which is still more certain than one for which the best assignment is 6-8.

One must guard against the tendency, sometimes encountered, to treat 6-7 as an intermediate grade between 6 and 7 (and so on with 7-8, 8-9, etc.). Such a practice is akin to implying that the intensity scale has 23 degrees instead of twelve; such resolution is hardly practical, as is discussed further below. On occasion one even sees isoseismals for 6-7 and 7-8, which are surely lines with no real meaning.

There are two typical cases in which uncertainty is a problem. One is when the data are very lacking in detail, and therefore highly ambiguous with regard to the different degrees of the intensity scale. This is very commonly the case with historical data. The other case is when the data are perfectly detailed, but do not easily fit any degree of the scale, either because the data are inconsistent (perhaps because the same description includes buildings on different soil types) or because there is difficulty in assessing the strength (vulnerability) of the buildings that have been damaged. Worked examples of this type for some historical Italian cases are presented by Monachesi and Moroni (1995), showing that even when one has precise information on the number of houses that were damaged in a town, assessments of intensity can easily range over two degrees of the intensity scale according to whether one makes more conservative or less conservative assumptions.

It should be noted that the degree of certainty in an intensity assessment is not just a function of the goodness of the data, but also of the intensity scale. One can think of it as how well the data and the scale fit. In an extreme case, using an intensity scale of the sort envisaged by Ballore (1916) in which there are only two degrees: 1 = not felt, 2 = felt; there would never be any uncertainty at all. The more finely divided the intensity scale is, the greater the likelihood of uncertainty in the resulting assignments. Certainty is thus linked to scale resolution as well as to the data.

The reason that most modern intensity scales have stayed with twelve degrees since this number was proposed by Cancani (Davison, 1921) is that practice has proved that this is the highest number than can be reliably and repeatedly discriminated in field investigations of earthquakes. However, intensity scales have generally been designed with modern earthquakes in mind, not historical ones, and it may be the case that there is some convenience to be gained by using a simpler scale, in which certainty is more easily obtained. An example is given by Musson (1991), of a scale that runs as shown in table I.

There is no problem in using an individual scale as long as it is applied consistently, in which case it can be used for all the purposes that a «standard» scale is used for. The only difficulty occurs when it is necessary to make comparisons with some other study. An example of a unique scale being used for a major study of historical earthquakes is found in Ambraseys and Melville (1982) where an original five-degree scale is applied to data for historical Persian earthquakes. A more recent case is the four-degree scale used by Gutdeutsch and Lenhardt (1996) for studying the 1348 Friuli («Villach») earthquake.

Some authors have sought to side-step difficulties of uncertainty by using symbols or codes for «felt», «damage», «heavy damage» and so on, for example, the study by Alexandre and Vogt (1994) on earthquakes in NW Europe in the mid 18th century. To some extent, these are just another personalised scale, and one could as well use numerals instead of symbols. The exception is the case of tall structures like spires or minarets, which may be damaged or destroyed by long period effects of a large, distant earthquake (Ambraseys and Finkel, 1995). Such reports are certainly damage, but would not normally be considered for purposes of assessing intensity (Grünthal, 1993).

Table I. Example of a simplified intensity scale for historical earthquakes.

Degree	Character
1	Not felt
2	Weak
3	Generally observed
4	Strong to slightly damaging
5	Damaging
6	Destructive

4. Measures of quality

Although, as shown in the discussion above, seismologists are already well practised in assessing uncertainty, there is not as yet an established way to express the quality of the data, which, as defined here, is a matter of the reliability of the intensity value assigned over and above whether the data can be discretised down to one integer value or a range. Thus, while certainty is an issue of whether the macroseismic data fit the intensity scale being used, quality is an issue of whether the data fit what actually happened. The discussion of the historical «filters» illustrates why there may be problems in this respect, and some hypothetical examples will indicate typical cases. There are three aspects of any intensity data point in a historical earthquake study which may be less than satisfactory.

Firstly, are the data adequate to establish the intensity assignment beyond reasonable doubt? If a historical account gives a detailed, lengthy, and carefully-researched description of the effects of the earthquake at a certain place, one may be confident that the intensity value given is a good reflection of the strength of shaking at that place. But supposing the only data for a place is a sentence in a newspaper report which states «at X small objects were thrown from shelves»? This would appear to be intensity 5 when taken at face value, but the information is extremely lacking in detail. Perhaps only one or two objects fell, and other diagnostics, if one possessed them, would suggest an intensity of only 4. Alternatively (perhaps less likely) it might be that canned goods were thrown off supermarket shelves in large numbers and the intensity was really 6. One cannot really assign 4-5 or 4-6 as intensity values as there is no actual evidence for intensity 4 at all, yet the investigator may suspect that this may be a possible correct value. It would be more correct to write intensity 5 (assuming one assigns a value at all), as long as one can indicate in some way that this value should be treated with caution, and is not as useful a data point as one based on much better information.

This sort of problem can be equally present with negative information. A statement, «the earthquake was not felt in town X» may really mean «I didn't feel it and neither did the neighbour I spoke to».

Secondly, are the data adequately located? Consider the following made-up account: «Reports come from several of the mining villages up in the hills stating that the shock there was very alarming. Houses shook, dishes clattered and broke, cupboard doors flew open violently and a number of the villagers rushed out into the night, fearing their houses were about to collapse». This would seem to be intensity 5, but where? Some investigators might take a selection of villages in the area indicated and assign a value of 5 to each of them, but this is rather making up data. Alternatively, one could choose a spot representative of the area from which the report originates, and plot one intensity 5 at this arbitrary location. However, if this is done then some means must be adopted to warn the reader that this location is not precise.

Thirdly, are the data actually true and do they refer to the correct earthquake? It is not unknown for completely false statements about earthquake effects to be uncovered in historical research; usually these are transparent in their falsehood on account of the gross exaggeration and fantastic details employed. On other occasions, the seismologist may be uncertain whether to take a report at face value or not. For example, he may find a point of intensity 7 far from the epicentre, surrounded by other data points that are 4 or 3. This might be a true anomalous point. Alternatively, (and perhaps more likely) it might be a confusion with a different earthquake, or a different place with a similar name, or it might be a hoax. If the seismologist suspects one of these things but cannot prove it, he needs some means of conveying his distrust of this data point if he is not simply to leave it out.

For convenience, these three quality measures will be termed *reliability*, *locational certainty*, and *veracity*. A means of expressing them has previously been presented by Burton *et al.* (1984), in which unsatisfactory reliability and veracity are indicated by appending question marks after or before the intensity value, and locational uncertainty is indicated with the letter A (for approximate or arbitrary), giving values such as ?7, 5?A and so on. An advantage of this system is that it can be plotted on an intensity map; anyone seeing a data point ?7 on the map will treat it with due caution. The disadvantage is that it makes handling computer files of intensity data more cumbersome.

Any review of corresponding systems is hampered by the fact that intensity data bases are rarely published *in extenso*, and the presence or absence of quality codes cannot easily be checked (or they may exist in working versions and be pruned out for publications purposes). Looking at major published data sets, the intensity file for the U.S.A. does not use quality codes (Coffman and Angel, 1983), neither does the Italian file published by Boschi *et al.* (1995), nor the Central Italian data base described by Monachesi *et al.* (1995). However, a more recent Italian file (Monachesi and Stucchi, 1997) does contain special codes to deal with specific different locational problems (territory, small settlement, scattered settlement, etc.). One extensive intensity data base that does use quality codes is that for the SIRENE data base in France (Levret *et al.*, 1996), in which every intensity value is given a rating A, B or C, where A indicates that the data are detailed and reliable, B less so, and C is very unreliable.

In the present paper (and in Musson, 1996) a different way of expressing quality is presented, based on the Burton *et al.* (1984) system, but using binary numbers to give a single quality code to each observation. Each quality topic can be expressed as a binary variable, counting 1 for problem and 0 for no problem. In this way, in a manner analogous to bitwise operations on a computer, a single integer can be built up that incorporates all three types of information (reliability, locational certainty, veracity).

Consider a binary number of three digits, as 110 or 001 for example. Each digit represents a different aspect of the quality of the intensity data point. A value of 0 indicates good, while a value of 1 indicates bad. The rightmost digit (reliability) expresses the extent to which the original data contain enough descriptive material for one to confidently assign intensity. Thus 0 indicates a trustworthy intensity assignment based on detailed descriptions; 1 indicates that the data contain insufficient details for one to be sure that the intensity assignment is reliable. The centre digit (locational certainty) expresses the accuracy with which the place represented by the intensity data point is known. Here, 0 indicates there is no doubt about the location. A value of 1 indicates that the description of the place is vague («in the province of X» or «at a village near Y» or some similar form of words) or the location is approximate for some other reason. The leftmost digit (veracity) expresses whether there is any doubt that the data point actually refers to the earthquake under consideration. A value of 0 indicates that there are no problems. A value of 1 indicates that the data point may possibly relate to a different earthquake, or may be a false description (*e.g.*, a hoax, a storm misrepresented), or have some similar problem undermining its credibility. The three digits are then convolved into a single integer. A quality rating of 6 (110) for example, indicates that there is no doubt that the intensity assignment is correct, but the place is vague and it may refer to the wrong earthquake (or not refer to a real earthquake at all). This integer ranges in value from 0 (best data point, no quality problems) to 7 (all possible problems present), as shown in table II.

Note that this is quite distinct from the intensity range. One could have I = 5 and Q = 1, or I = 5-6 and Q = 0 as alternative expressions in some cases. It would also be possible to have I = 5-6 and Q =1.

Table II. Binary quality code table (Q).

Integer	Bits	Problems
0	000	None
1	001	Reliability
2	010	Locational
3	011	Reliability + locational
4	100	Veracity
5	101	Reliability + veracity
6	110	Locational + veracity
7	111	All three

5. A worked example

To illustrate the system in use, macroseismic data for the Wensleydale (Northern England) earthquake of 1768 is presented. This event was selected as the data set is reasonably concise. Locations are given with respect to the U.K. National Grid (see table III).

The data are plotted in fig. 2. In this case all intensity values are plotted the same way; a useful refinement would be to plot values with Q ≠ 0 in a smaller font.

Arthuret – *... a clap of Thunder and a Shock* [Diary of George Williamson of Arthuret, Carlisle RO].

There is too little information to assign an intensity other than «felt». There is no reason to doubt that the shock was felt at this place, from the first hand diary record, so Q may be set to 0.

Beetham – *... a slight shock of an Earthquake was very sensibly felt all thro' this Parish at about a Quarter past 4 in the afternoon. 'Twas perceived in most parts of Yorkshire and Westmoreland.* [Beetham Parish Records; Kendal RO].

Not enough information to assess intensity, although probably 3-4 EMS is indicated. Technically, Q should be 2 (all through the parish) but since this is a manuscript record in the church register of Beetham village, a value of 0 is allowable. If 3-4 were assigned, Q would be 1.

Darlington – *From Darlington we have also an account of a slight shock being felt there at the same time.* [Newcastle Chronicle 21 May, p. 2].

This could be I = 3-4/Q = 1 or I = F/Q = 0. The latter is safer.

Ingleton – [see Otley].

Table III. Macroseismic data for the 15 May 1768 Wensleydale (North England) earthquake.

Place	Nat Grid E	Nat Grid N	Intensity	Q
Arthuret	338	568	F	0
Beetham	349	479	F	0
Darlington	429	514	F	0
Ingleton	369	472	F	0
Keighley	406	441	F	0
Kendal	351	492	5	0
Lancaster	347	461	F	0
Leyburn	411	490	4	1
Malham	390	462	5	0
Manchester	382	398	–	4
Middleton	342	458	4	1
Newcastle	424	564	F	0
Northumberland	390	560	F	2
Otley	420	445	F	0
Settle	381	463	F	0
Skipton	398	451	F	0
Staindrop	412	520	F	0
Swaledale	404	498	F	2
York	460	451	F	0

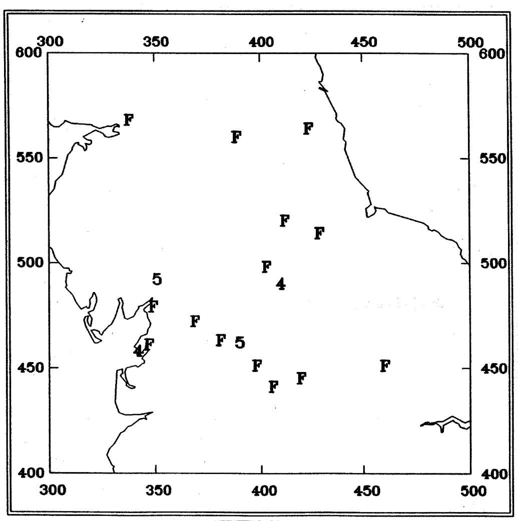

Fig. 2. Macroseismic data for the earthquake of 15 May 1768. The margin labels are the U.K. National Grid in kilometers.

Keighley – *By accounts from Keighly and Skipton we hear, that the Earthquake was felt there ... about five o'clock, and it is very likely has been universal throughout the N. West parts of Yorkshire.* [Manchester, Mercury 24 May, p. 4].

There is no information beyond that the earthquake was felt.

Kendal – ... *at Kendal ... they had one shock, which lasted near two seconds, and happened during the time of Divine service,* *which greatly terrified the people in church; and immediately prior to its being felt there, a rumbling noise was heard like that of a heavy carriage passing over a rough pavement; its direction seemed to be from East to West, and the river was very much agitated.* [Newcastle Chronicle, 21 May, p. 2].

We hear from Kendal, that ... about ten Minutes past Four, during Divine Service, the Congregation in the Church were surprised with an uncommon Noise in the Air, resembling that of Carriages at a Distance; this continued about two thirds of a Minute, and was immediately followed by a Shock of an Earthquake, which lasted about half that Time, but was so violent, that during its Continuance, the Glass shivered from the Windows, the Supporters, Beams, and Seats, were all in Motion, and the Hearers, with Looks expressive of the greatest Consternation, were preparing to quit that Place, when happily the Shock ceased, but left so deep an impression on the Minds of many, especially Women, that though the Vicar (who before was descending from the Pulpit) resumed his Discourse, they most of them left the Church before the Service was over. The Shock was felt thro' the whole Town and Parts adjacent, but we hear of no other Damage being done than terrifying and alarming the Inhabitants. [Manchester Mercury, 24 May, p. 4].

There is more detail in this report than in the others for this earthquake. The earthquake was both strong and frightening, but not damaging, and an intensity of 5 can be assigned for Kendal, with Q = 0.

Lancaster – [see Settle].

Leyburn – *... a smart shock was felt at Leyburn ... and in that neighbourhood ... This earthquake was preceded by a rumbling noise, like thunder at a distance, and its course seemed to be from West to East. The agitation, of a door, which was shut at that time, appeared as though some person wanted to make a forcible entrance.* [Newcastle Chronicle, 28 May, p. 2].

... at 15 Minutes past Four in the Afternoon, a smart shock of an Earthquake was felt at Leyburn ... [etc. York Courant, 24 May, p. 2].

This is a nice example. The account indicates intensity 4 EMS (doors rattle) and nothing else, but assigning this intensity value to the whole of Leyburn on the basis of one door is doubtful. Assigning Q = 1 solves the problem.

Malham – *Extract of a letter from Malham ... About five o'clock ... there happened here a very sudden and terrible shock of an earthquake. It lasted about a minute; and I already hear from Settle, and the moors above this village for five or six miles, that they have been visited in the same manner. It may have extended farther, but this is all I can say at present.* [Caledonian Mercury, 28 May, p. 2].

Some walls were thrown down near Malham ... [Caledonian Mercury, 30 May, p. 3].

This example is more debatable. The walls thrown down are dry stone walls used for fencing fields. The author's experience is that this is a very reliable indicator of intensity 5 EMS, hence the Q value of 0. Others might not agree, and assign Q = 1. It could be argued that «near Malham» is an imprecise location, and therefore Q should be either 2 or 3. Here it is assumed that «near» means «very near» (since Malham is rather a small place).

Manchester – *At Manchester some walls were moved in a right line, and the flagging of a kitchen was observed to heave.* [Mallet, 1853, p. 163].

Mallet's sources are three in number: Annual Register, vol. 11, p. 114, which doesn't mention Manchester, and Cotte, P., in «Mém. Math. et Phys. prés. à l'Acad., & C., t. vii, p. 475» and Gazette de France 30 May, 6 June. Neither of these French references have been traced. It is clear that the account above purposing to relate to Manchester is a corrupt version of the report relating to Middleton from a foreign source. Therefore this is a completely mistaken account with the wrong place, from a non-contemporary source. Q is therefore at least 4. Because the error is demonstrable, no actual value for I has been given. Note the distinction between «place is poorly defined» (Q = 2) and «place is mistaken» (Q = 4).

Middleton – *At Middleton, near Lanchester, it was also felt at the same time, where the walls which surrounded a field adjoining the place, were observed very sensibly to move, from whence it seemed to pass in a direct line across the street, and through a house, wherein the chairs, dresser, pewter, and other furniture were greatly shook, and the flags of the floor observed to heave.* [Newcastle Chronicle, 21 May, p. 2].

There is no Middleton near Lanchester. This can be stated for a fact, after scrutiny of an exactly contemporary 1″ to 1 mile map of the area (Armstrong and Jeffreys, 1768). This seems to be a printer's error for Middleton near Lancaster, which does exist. This identification is supported by the fact that this report comes in the same paragraph immediately after an account from Kendal, suggesting a western origin. The next paragraph, begins «From Darlington we also have an account ...» suggesting that a new document is now being dealt with. The shaking of furniture suggests intensity 4 EMS, but the detail seems to relate to a single house. Q is therefore 1.

Newcastle – ... *a little after four'clock, two slight shocks of an earthquake, at about half a minute's distance of time from each other, were sensibly felt in this town* ... [Newcastle Chronicle, 21 May, p. 2].

... *numbers of people observed it in Newcastle* ... [Newcastle Journal, 28 May, p. 3].

This is similar to the other cases where the detail is minimal.

Northumberland – ... *numbers of people observed it in ... most parts of Northumberland* ... [Newcastle Journal, 28 May, p. 3].

Any location given to this report is an arbitrary location in Northumberland, therefore Q = 2.

Otley – ... *three slight shocks of an Earthquake, at about half a minute's distance of time from each other, were sensibly felt at Otley, Skipton, Settle, Ingleton, and all the north-west parts of this county.* [Leeds Intelligencer, 24 May, p.?].

This is similar to the other cases where the detail is minimal.

Settle – *A smart shock of the earth (which lasted about a quarter of a minute, but did no damage) was also felt at the same time at the following places, viz. Settle, in the West-Riding; Lancaster; Staindrop, & C. in the county of Durham; in many places of Swaledale, in the North-Riding, and in the city of York.* [Newcastle Chronicle, 28 May, p. 2].

This is similar to the other cases where the detail is minimal. From the information that no damage was done one could arrive at something like 3-5 EMS, but it is debatable if that would be any more useful than assigning «F» for felt in this instance.

Skipton – [see Keighley].

Staindrop – [see Settle].

Swaledale – [see Settle].

Swaledale is a valley, not a town or village, so Q = 2 in this case.

York – [see Settle].

A smart Shock of the Earth ... was also felt ... in several parts of this City. [York Courant, 24 May, p. 2].

This is similar to the other cases where the detail is minimal.

6. Discussion

The advantage of the system presented here is that it can be very easily handled by computer, and takes up only one column in a computer file. It also ranks the assignments by quality, in that a lower code number always indicates a more useful data point than a higher one. (A data point that definitely refers to a known place is always more useful than one which is locationally vague; and a data point that definitely is true and ascribed to the right earthquake is always more useful than one which might not satisfy these criteria. From these two judgements the hierarchy of usefulness follows automatically.)

There is still a degree of personal judgement in the operation of this system, as is shown by some of the cases in the worked example above. The hardest decision is usually how much data are enough for a «good» intensity assignment; this tends to be a personal decision which cannot really be codified in any way. In any system of this sort, personal judgement inevitably comes in when deciding what is «good» or «detailed» data, and this applies to the French system of Levret *et al.* (1996) as much as to that presented here.

The decision about locational uncertainty is much more straightforward, although there is still scope for debate. A report along the lines «all over SE England windows were rattled ...» clearly has a quality code of at least 2. If the report were to read «all over London ...» instead, it could be argued that modern London is so large that this is a very imprecise location. Since this system is intended for use with historical data, and since large conurbations are a modern phenomenon, this may be a specious argument. The argument as to how precise a location is «near Malham» in the worked example, is another example of a judgement call.

The question as to whether the «bit is set» for veracity or not ought not to be controversial. In most cases where a seismologist has grounds for suspecting that a report is wrong in some way he will be able to formulate a case which relies on something better than «personal judgement».

Note also that the reliability code can be used to deal with those cases where a reasonable amount of data describing effects at a place exist, but are so confusing and contradictory that one is very uncertain about the intensity value that should be assigned. A quality code of 1, 3, 5 or 7 (*i.e.* with the reliability bit set) does not necessarily mean that the intensity value should be regarded as ± 1 or any other number. If $I = 5$ and $Q = 1$, this should not be interpreted necessarily as implying that the intensity was 4-6; it might translate, if the truth were fully known, to 4-5 or 3-5 or something else.

There is a problem in dealing with historical intensity data (and this comes back to the «filter of interpretation») that the data may clearly indicate intensity 5 in every written word, yet the seismologist may feel that the whole account is exaggerated and that the intensity is only 4. In which case it is easy to write intensity 4 even though there is no actual evidence for this. From this it is easy to get into the habit of subtracting one from every intensity value to account for a perceived innate exaggeration in historical accounts. The danger here is that one is practically making up the data to suit one's opinions as to what ought to have occurred. Using a quality system is a better alternative; one can assign an intensity value that reflects the data and assign a quality code that reflects one's mistrust of the data. This can then be carried through into subsequent analysis of the macroseismic data. Thus one could formulate a principle that isoseismals should be drawn only with respect to data points with a zero quality rating; this would prevent the course of the isoseismal being distorted by the presence of a data point based on a report believed to be exaggerated.

This system does not carry directly over into discriminating between different data points when a map is made. Some extra system is necessary, which will depend on the preferences and styles of the user. An obvious choice would be to plot all intensity values that had $Q > 0$ in a smaller font or a different colour.

Comparing this system with that used in Levret *et al.* (1996), the equivalence in table IV can be suggested.

Table IV. Equivalence of two quality systems.

Levret *et al.* (1996)	This paper
A	0
B	1-3
C	4-7

This only holds partly, as to some extent class C is really an intensification of B. Equating it to Q = 4-7 is really adding a further judgement about the unreliability of the data which may not be justified in all cases in which this code is used in the SIRENE data base. Using a binary system attempts to reduce the degree of subjectivity in assigning quality – one is only choosing between «good» and «bad» as opposed to choosing between «good», «bad» and «very bad».

7. Conclusions

Consideration of the processes involved in the transmission of historical earthquake data from the original observers to the investigating seismologist indicates that much distortion of information is possible, through a series of selective filters. It is therefore important to pay attention to the quality of the intensity assignments that result. One can usefully discriminate between the certainty of an intensity assignment (how well the data fits the scale) and the quality of an intensity assignment (how well one can trust that the value is a true reflection of what really happened). The expression of uncertainty is usually in the form of ranged intensity values; the expression of quality requires an extra symbol or rating of some sort.

A scheme has been presented which allows one to express (albeit with some subjectivity) the quality, or rather the lack of it, of individual data points by the use of binary numbers which can be written as a single integer value from 0 to 7, such that 0 is the best rating and 7 is the worst.

This system is ideally suited to computerised files of historical intensity data, and can be interfaced with a computer plotting program in a variety of ways depending on the method preferred for plotting intensity data points. By preserving information on the reliability of individual intensity data points, the system enhances the reliability of the final determination of earthquake parameters, since these can be weighted in favour of «good» data points as opposed to «weak ones».

To some extent the system is also applicable to modern data sets. Since these are usually determined by field study, it is unlikely that quality codes greater than 1 would be required for modern data sets other than occasionally.

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