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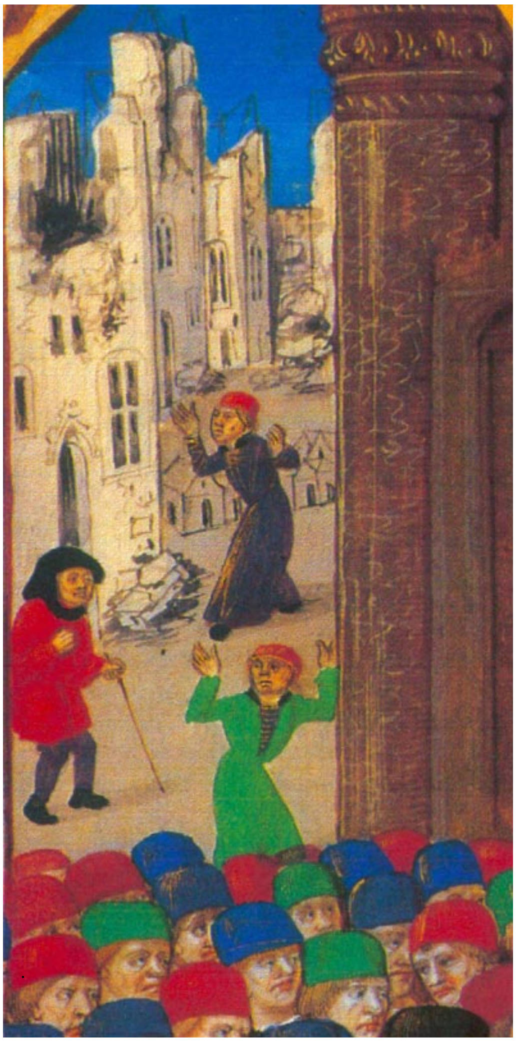

Directors:
Virginia Garcia Acosta
Roger W.M. Musson
Massimiliano Stucchi

Abstracts

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Abstracts

Historical earthquake research in the UK

Roger M.W. Musson
British Geological Survey, Edinburgh, UK

Although Britain is in an intraplate area characterised by low to moderate seismicity only, there is actually a surprisingly large amount of information about historical earthquakes available. This is due to the long intellectual and cultural history; also, the fact that British earthquakes are not very common has imparted curiosity value to even small events or to weak shaking, with the result that small historical earthquakes can be studied, and isoseismal maps completed to the lower intensities for many events.

The history of the UK can be divided into four periods for the purposes of studies of earthquakes. The first is roughly between 600 and 1400, in which the primary (or only) source of information is from monastic chronicles. Between 1400 and 1700 the historian-seismologist relies on miscellaneous documents in archives. After 1700, up to 1970, the predominant source of information is from local newspapers, and after 1970 modern instrumental and macroseismic (questionnaire) data are available.

There is also a long tradition for the study of British earthquakes; the first attempt to compile a list of events from chronicles appears as early as the late 16th century. An important event was the publication of a book-length catalogue of historical British earthquakes by Charles Davison in 1924, and this dominated work on British seismicity until the mid 1970s, which saw the first attempts to reassess historical British earthquakes from original source data.

The UK nuclear programme funded a series of studies in the 1980s and 1990s, with the result that the current UK catalogue of historical British earthquakes is based almost exclusively on up-to-date revaluations of events using original source material to derive intensity data points. The only previously unknown historical earthquakes to come to light from further historical research in the last eight years have been small (less than 3.5 ML) and it seems that the record of historical events of engineering significance is as complete as it will ever be.

Earthquake catalogues, databases and studies of historical seismicity in the Iberian peninsula

Antoni Roca

Geological Survey, Institut Cartogràfic de Catalunya, Barcelona, Spain

The purpose of this presentation is to summarize the state-of-the-art of historical earthquake knowledge and research in the Iberian Peninsula. Approaches followed in researches carried out in the last years will be commented through some case studies.

The following aspects will be outlined:

- Present situation of Earthquake Catalogues and Macroseismic Databases available
- Historical development of Catalogues
- Some examples of macroseismic research on historical earthquakes. Approaches followed, type of sources, problems encountered, solutions taken, reliability of results.
- An example on the difficulties for interpreting historical data corresponding to earthquake sequences: 1427 series in the Pyrenees
- Use of early instrumental records.
- Incorporation of historical research results into Databases.

Historical earthquake investigation in Italy

Romano Camassi
Istituto Nazionale di Geofisica e Vulcanologia, Milano, Italy

The investigation of earthquakes in Italy has a long tradition; earthquake lists are contained in prodigies compilations (Liber prodigiorum of Julius Obsequens, 4th century A.D.), but only in the second half of the XVth century is compiled a first modern repertory (Giannozzo Manetti, 1457).

During XVIth and XVIIth century many earthquake compilations are written, based on the study of the classic erudition; the best product of this tradition is the great world-wide repertory published in 1691 by Marcello Bonito, that sometimes integrally copy - with philological accuracy - testimonies drawn from books or archive documents, in some cases today lost.

This long tradition of listing of seismic events knows a great development during the XIXth century, and reach the top to the end of XIXth century in the work of Mercalli (1883) and Baratta (1901). The same one happens generally in the rest of Europe, through the job of some pioneering compilers: von Hoff, Mallet, Perrey, Rehtly, Schmidt, Kispatich, Volger, and so on.

At the end of XIXth century starts in Europe the first national organizations for the study of meteorological and seismological phenomena and the first networks of observation (in Italy in 1887). The development of the observation activity knows a clear decline after the first world war and in irreversible way in the second half of the 30' of this century.

In the first half of years '70, various Italian institutions start the compilation of regional and national parametric earthquake catalogues for hazard estimation purposes: the main products of this season of activity are an Atlas of larger Italian earthquakes (81 monographic studies with about 6.300 intensity data points), edited by D. Postpischl in 1985, and a national parametric catalogue.

After the 1980 Irpinia earthquake (end of 1983) start in Italy extensive historical investigations, involving - for the first time - a hundred of historians (two different groups supported by the National Electric Company - next by National Institute for Geophysics - and by the National Research Council), that allow to the review of information about some thousands of earthquakes.

After twenty years of historical researches is now available in Italy a large number of historical-seismological data, most of them published (Boschi et al., 1995, 1997, 2000) or available as technical reports.

The database which supports the CPTI catalogue contains more then 50.000 intensity data points (≈11.000 prior to 1880) assessed in a rather homogeneous way on the base of historical sources, most of them primary.

Actually, all most Italian energetic events are supported by recent historical investigations and intensity data; but additional investigations are in progress in different topics (archaeoseismology, paleoseismology, minor earthquakes, apparently silent areas, unknown earthquakes, ect.).

A revised earthquake data bank in South-Western Mediterranean countries – Algeria, Morocco, Tunisia – from the record sources of past seismic events

Djillali Benouar
University of Bab Ezzouar (USTHB)
Civil Engineering Department, Bab Ezzouar, Alger, Algeria

Although catalogues or listings of earthquakes in the Maghreb region were available before the work of Benouar in 1993, they cover different time periods, incomplete at a given region, and are grossly deficient in several respects, particularly in magnitude, depth and location. Some of these catalogues are new, some incomplete for any given region or time period, some out-of-date or at second hand, some others are oversimplified and misleading.

The main purpose of this work is to establish a uniform catalogue of all earthquakes reported in the Maghreb region, which satisfies the conditions of homogeneity, and to derive from this basic data set the general laws governing the space and time distribution of earthquake occurrences in the seismic source zones, and to evaluate the seismic hazard. For the Maghreb region, earthquake hazard constitutes a constant threat to human life and property, sometimes causing major economic losses and disruption. The rapid urbanisation, development of critical engineering works such as dams, nuclear power plants, industrialisation of cities with modern types of buildings and the concentration of populations living or settling in hazardous areas are matters of growing concern, as they contribute to heavier loss of life and increase considerably the cost of disaster damage.

The environment concerns and an increased official and public awareness of earthquake hazards have, in the last decade, led to a rapid rise of interest in seismicity and, seismic hazard and risk evaluations in the Maghreb countries. In order to assess the seismic hazard with a certain degree of reliability, an earthquake data of the region under survey which are as complete, homogeneous and accurate as possible are needed. For this purpose, and from the point of view of long term prediction and seismic hazard assessment, it is imperative that input data in the catalogues of the Maghreb countries be revised and homogenised.

This research work presents the methodology used to re-evaluate the seismicity of Algeria and adjacent regions, during the twentieth century. This required (1) the retrieval and revision of both macroseismic and instrumental information, (2) the development of a methodology for the assessment of seismicity, (3) the application of techniques of completing the homogenised available data, (4) the establishment of a homogeneous and complete earthquake catalogue, as the available data allow today, for the region under survey, (5) the geographic distribution of the earthquakes in order to define the seismic source zones in the region, (6) the calibration of the Atlas block and Algerian earthquakes and (7) the derivation of intensity-attenuation relationships in the Atlas zone and Algeria.

The procedure which is used to re-evaluate the seismicity of Algeria and surrounding regions is meant for historical earthquakes (pre-instrumental events) and even for twentieth century earthquakes for which there are no instrumental data, but for which intensities and radii are available, their magnitudes are calculated from macroseismic data (using calibration relationships). Other means to complete the earthquake catalogue as used as, for instance, the number of station that reported the event. This remains a fundamental mean for an effective and reliable seismic hazard assessment and thus disaster management.

Investigating the records of past earthquakes: state-of-the-art in Croatia, Macedonia, Montenegro and Slovenia

Ina Cecic

Ministrstvo za Okolje in Prostor, Agencija Republike Slovenije za okolje (MOP-ARSO), Ljubljana, Slovenia

with the collaboration of:
Ivica Sovic, GZAM, Zagreb, Croatia
Lazo Pekevski, Seismological Observatory, Skopje, Republic of Macedonia
Branislav Glavatovic, MSO, Podgorica, Montenegro

An attempt of an overview of the present situation in the research of historical earthquakes in Croatia, Macedonia, Montenegro and Slovenia is given. Each of the aforementioned countries has long history of earthquake data collecting and evaluation. The main common effort was made in the 1970's, for the UNDP/UNESCO regional project “Survey of the seismicity of the Balkan region”, when an earthquake catalogue and the atlas of isoseismal maps were compiled.

The background of the national catalogues is shown. The short overview of the investigations done in the past two decades is given. Some historical sources are mentioned and briefly discussed. None of the countries at present does have a collaboration with historians or does any other interdisciplinary research considering historical events. Some problems are recognised and ways how to solve them are discussed.

Historical earthquake research in Central Europe (Austria, Czech Republic, Hungary, Poland and Slovakia): an overview

Peter Labák
Geophsical Institut, Slovak Academy of Sciences, Bratislava, Slovak Republic

Central Europe can be characterised as an area of moderate seismic activity. The data on historical earthquakes is of crucial importance for seismic hazard assessment in this territory. Therefore the historical earthquake research represents an important part of earthquake research in the area.

Since middle of 50s of the 20th century, when first descriptive catalogues were issued for the Central Europe, several parametric catalogues have been compiled. Since the Central Europe is covered by several countries, the catalogues were compiled mainly on national basis. The development of the compilation of descriptive and parametric catalogues in particular countries is presented together with the sources of the catalogues. Important cross-border catalogue – the KAPG catalogue, which was compiled in the middle of 70s – is also characterised. The impact of the BEECD project (A Basic European Earthquake Catalogue and Database) on the catalogue compilations and development of the intensity data point databases in the Central Europe is also presented.

Since 80s of the 20th century an intensive investigation of several historical earthquakes has been performed in the area. An overview is given for each country. Two examples of extensive investigation of historical earthquakes are also given. The advantages and disadvantages of the intensive and extensive investigations and use of different macroseismic scales are discussed. Impacts of the multiethnic, multilingual and multicultural character of the Central Europe on historical earthquake research are also discussed. Plans for the future are presented.

Studies on historical earthquakes in Germany

Gottfried Grünthal
GeoForschungsZentrum, Potsdam, Germany

The seismicity in Germany is moderate. North of the Alps the seismic zones in Germany show the highest activity in Europe. In historic times the maximum intensities reached values of VIII, while immediately south of Germany, the 1356 Basel earthquake had a maximum intensity of IX. The records of historical seismicity can be traced back to the 9th century. Records of intensity IX and VIII are assumed to be sufficiently complete since about 1200, intensity VII since 1700, intensity VI since 1750, intensity V since 1825 etc.

Parametric catalogues were established by Leydecker (1986) for W-Germany and by Grünthal (1988) for Central Germany. The basic data for both files are the non-parametric catalogues by Sieberg (1940) for the time up to 1799 and by Sponheuer (1952) for the 19th century. Grünthal (1988) uses an additional 154 historical sources and Leydecker (1986) an additional 9. Both parametric catalogues make use of isoseismal maps and intensity data to interpret the major events since 1850.

The two mentioned non-parametric catalogues use extensive data each in which compilations of the 19th century which either cover large areas or are more locally oriented. The quality of these compilations can vary considerably. To a large extent such secondary sources rely on sources published short after the Lisboa earthquake 1755 or stem from a cluster of earlier compilers lasting from about 1550 to 1620. The most reliable information is provided by municipal or monasteries chronicles and other contemporary sources.

In the last 10 - 15 years several systematic source studies were made. One was the EU-Project „Basic European Earthquake Catalogue and Database" (BEECD). A fundamental issue of this project was the systematic classification of the roots of the historical German earthquakes. Another systematic study was made in conjunction with national projects on seismic hazard assessments. A limited portion of the new findings was so far subject to some 10 publications by Grünthal and others. Further studies were made e. g. by Alexandre (1990), Vogt (1991, 1992, 1993) and Meidow (1995).

The general conclusions from the systematic study of sources is a general tendency of previously overestimated intensities, certain errors in locations and timing and a considerable number of fake quakes. Fake quake is here the notation for events, which are clear hoaxes, original storms, landslides or simply collapses of houses etc. without connection with an earthquake. A fake quake can also denote an event with a location error > 100 km, an intensity derivation > 1 degree or a timing error > 1 year.

Another conclusion is that there is little probability that sources on significant earthquakes lost in the last centuries can be retrieved.

The main problems encountered with respect to historical earthquake studies in Germany is the lack of personal capacity. This is on one side due to the limited interest by sponsoring bodies, on the other side due to the small interest of historians. Many new findings are still waiting for their publication. The most problematic cases have been revealed already, but much more definitely needs to be done.

An overview of historical earthquake investigation in Russia

Ruben Tatevossian
Joint Institute of Physics of the Earth, Russian Academy of Science, Moscow, Russia

1. Macroseismology of the pre-instrumental time-period (1890-1902)

Systematically, earthquake studies started in Russian Empire in 1890s: they were a part of geographical sciences. Both historical seismicity and field earthquake study attracted efforts of researchers:

a) First earthquake catalogue of Russian Empire by Mushketov and Orlov was published in 1893. It is a descriptive compilation based mainly on the primary sources. The catalogue covered all the Russian territory. Never after that such a large territory has been presented in any Soviet or Russian catalogues (because they never possessed such a large territory). But more or less regular information on earthquakes in the catalogue appeared only from end of XVIII century.

b) Field study of large earthquakes: Akhalkalak, 1899 (Mushketov, 1903), Shemakha, 1902 (Weber, 1903) and some others. These are studies of very high standards. For example, not only number of destroyed buildings is reported in villages of epicentral area, but also their total number in each village. Typical buildings are described. This enables to apply now statistical approach and take into account vulnerability of buildings when intensity assessment.

Activities of Mushketov, Weber and colleagues leaded to establishing of the first seismological organization in Russia: Permanent Central Seismological Commission (PCSC) in 1902. This opens a new period of seismological observations in Russia (instrumental and macroseismic).

2. Macroseismology of the early instrumental time-period (1903-1912)

The PCSC made great efforts in organisation of instrumental observations: it opened observatories in Pulkovo, Tbilisi, Nikolaev and some others. But, maybe because founders of PCSC started from historical seismicity and macroseismic observations, PCSC continues collecting macroseismic data and printed them together with instrumental ones in its Bulletins. This lasted up to 1912, after which macroseismic data were considered as secondary and unimportant relative to instrumental data (which are supposed to be much more informative and precise). This interrupted collection of macroseismic data and reduced interest to historical seismicity. Then follow World War I, Revolution and Civil War, which ceased seismological activities up to mid 1930s.

3. Period of regional macroseismology (mid 1930-1961)

Historical seismicity was studied on regional (Lesser Caucasus, Baikal, etc.) scale thanks to efforts of enthusiasts (Stepanyan, 1935; Bius, 1947). Most of catalogues were descriptive compilations, only partly based on primary sources.

4. Macroseismology of huge projects (1961-1982)

National Projects of Seismic zoning of the USSR became main “sponsors” of the historical seismicity studies. Because engineers needed certain numbers for their formulae this opened era of parametric historical earthquake catalogues in Russia. Projects brought not only funds, but also dictate of builders: for example, they decided that in the Caucasus must not be events with intensity higher than 8 (or, at least, not in earthquake catalogues). The magic of parameters affected also seismologists: they cared much more in giving (guessing) a certain value to epicentral intensity or source depth based on a brief description of effects, than in assessing reliability of the source of information, or finding primary sources.

5. Late Soviet and post-soviet macroseismology (1982-2002 ...)

Absence of huge projects, which enable co-operation of large research groups from several organisations, made intensive approach most common. Selected key events or very limited areas, which are important for hazard assessment, are studied. Trying to attract funds, careless researchers speculate on public interest, “discovering” historical seismic catastrophes on Russian platform.

6. Problems and Perspectives.

Problems have different grounds: historical, political, socio-economical, physical:

A) Because many archives were destroyed during World and Civil wars, very few documents, which are really primary sources, are survived.
B) Locality names were changed several times because of numerous revolutions and political cataclysms.
C) Researchers are much more interested in giving final conclusions on hazard assessment and don’t want to “open” the data sources.
D) In low active platform regions (especially with dense river network) events of exogenic origin (landslides on banks) became source of false quakes.
E) Certain number of duplications appears because different calendars were used in Russia.

Earthquakes and history:
a long-term, European-Mediterranean perspective

Paola Albini
Istituto Nazionale di Geofisica e Vulcanologia, Milano, Italy

In the last twenty years the investigation of the records of past earthquakes in the European and Mediterranean area has been approached mainly from a national perspective and occasionally only from a wider-ranging one.

The national perspective originated from aims, committments and fundings related with local issues and safety requirements of strategic power plants. Investigation on historical earthquakes performed on a national basis, though mainly focused on large earthquakes and the compilation of seismic catalogues, has undoubtedly been a first important step towards an understanding of long-term seismicity of Europe and the Mediterranean. But such a perspective has sometimes led to duplication, incorrect location and misinterpretation of earthquakes, as some examples will demonstrate.

On the other hand, the approach considering a wider space and longer time scale of investigation has been found to be rewarding in terms of improvement of our knowledge of past seismicity, as well as in terms of quality and reliability of effects distribution and evaluation of historical earthquake parameters. Regional catalogues have been compiled and essays have been published on earthquakes in Europe and the Mediterranean from Antiquity to Middle Ages (Guidoboni, 1989; Alexandre, 1991) and of neighbouring regions like inland Turkey (Ambraseys and Finkel, 1995), Egypt, Arabia and the Red Sea (Ambraseys et al., 1994).

Through the centuries, the European-Mediterranean area, although similar to a garland of independent countries, and therefore divided culturally, politically and socially, has been characterised by complex but also uniform conditions from the point of view of the production of historical records. The many sea and land routes of exchange, supporting both commercial and cultural trades, crossed the whole area and have played an important role in determining today location of the sources of information, on political changes as well as on earthquakes.

This perspective has oriented the European Union funded project “Review of Historical Seismicity in Europe – RHISE” (1988-1992). Its main achievements are here recalled, mainly because this project represented the first experience of over-national collaboration between seismologists and historians in Europe.

Further reflections are then proposed by means of a gallery of cases through the centuries and across Europe and the Mediterranean area, with the main purpose of highlighting problems, pitfalls and sidetrack trails that historians and seismologists working together have dealt with and still have to. They range from the identification of today storage of sources to problems of transmission and survival of documents, and to the geopolitical and linguistic constraints arising from the retrieval and the interpretation of records on past earthquakes.

In form of an open conclusion, an overview of the state of the art of the knowledge of large earthquakes (M≥5.5) in Europe and the Mediterranean area is proposed. Though the situation has significantly improved with respect to ten years ago, there are still areas for which the available information is scarce or scarcely documented and for which a joint effort of collaboration among researchers of different countries seems to be the way towards a better understanding of their long-term seismicity.

Investigation and research on historical earthquakes in China: introduction and suggestion

Wang Jian (1, 2)
(1) China Seismological Bureau, Beijin, China
(2) Visiting scholar, Univ. of Edinburgh, UK

China is one of the countries with longest culture tradition and much disaster suffered from earthquakes, so abundant earthquake records remained. There are two large scale collections of historical earthquake data from archives in China. One was in 1950s. In that period, there were about 200 engineer projects would be built for the new government. In order to solve the problems concerning determination of engineering sites and antiseismic intensity, historians and seismologists were organised to work together for more than two years. They perused about 8000 kinds of historical literature and recordation. Records concerning with earthquakes were put out and compiled in "Chronology of earthquake data in China", which was published in 1956. Another large scale collection happened in 1970s. This time historian and seismologists co-operated searching in extended scope. The results were listed in "Compilation of Earthquake Historical Data in China", which was published in 1977 with totally 5 volumes and 8 books.

There have been four editions of historical earthquake catalogues mainly. First edition of "Earthquake Catalogue in China" was edited by Prof. Shanbang Li (published in 1960), which covered the time period from 1189 BC to 1955 AD. The first catalogue was made according to the "Chronology of earthquake data in China" mainly. Totally 1180 earthquakes with magnitude greater than 4.7 were listed. Second edition of "Earthquake Catalogue in China" was edited by Prof. Gongxu Gu and Prof. Zhenliang Shi (published in 1983), which covered the time period from 1831 BC to 1969 AD. This catalogue was made according to the "Compilation of Earthquake Historical Data in China" mainly. Totally 3187 earthquakes with magnitude greater than 4.7 were listed. Third edition of earthquake catalogue was edited by Prof. Ziqun Min and Prof. Zhenliang Shi (published in 1988), which covered the time period till 1986 AD. Totally 5142 earthquakes with magnitude greater than 4.7 were listed.

Recent earthquake catalogue has been edited by Prof. Suyun Wang and Prof. Zhenliang Shi, consisted of two parts. One is "Historical Strong Earthquake Catalogue in China" (published in 1995), which covered the time period from 2300 BC to 1911 AD. Totally 1034 historical earthquakes with magnitude greater than 4.7 were listed. Earthquake during 1912 to 1990 was listed in another part, most of them have records of instruments.

Based on two large scale collections of historical earthquake data from archives and four editions of catalogues, historical backgrounds, such as culture traditions, government regime, were introduced concisely. Successful experience, characteristics and insufficiency will be analysed. Accuracy of epicentre location, non-balance in distribution of region and time will be displayed.

Characteristics and main problems of present stage will be illustrated, combining with two cases of detail investigation around future nuclear power station sites.

Suggestions about further work:

0. Recording down experience and knowledge of old experts urgently, some of them have died and many older than 70 years old.
1. Making electronic version of historical earthquake data, which are more convenient to use and securer to store, in case losing what we have got.
2. Translating and introducing, let more experts in the world realise and utilise the treasure, which should belong to the globe.
3. Continuing detail investigation, both combining with seismic hazard analysis of engineering sites and get support from research funds.
4. Developing new methods to determine the parameters of historical earthquakes
5. In the final section, institution, main experts, conferences concerning with historical earthquake investigation and research in China will be introduced briefly.
6. Intensity database, isoseismal maps and a software will be introduce and demonstrated.

Historical seismology in Japan: the state of the art

Katsuhiko Ishibashi
Department of Earth and Planetary Sciences, Faculty of Science , Kobe University, Kobe, Japan

Japan is located in an active plate boundary zone where four plates converge one another. So, many earthquake disasters had been described in abundant historical materials since around the 6th century. Since the dawning of seismology in the late 19th century, systematic collection of such historical records of earthquakes had been pursued in Japan, and around 8,400 historical records of about 250 pre-1867 earthquakes were printed in Musha's (1941, 1943, 1951) books. By using these original records historical seismicity in Japan had been basically revealed with inferred epicentral area, source size and macroseismically affected area of each event. Based on such results Imamura (1933), for example, made a broad-based forecast of great earthquakes along the Nankai trough off southwest Japan, which turned out successful by the occurrence of 1944 and 1946 M8-class earthquakes.

Since 1970's a huge amount of new historical documents of earthquakes has been collected intensively from all over the country mainly in the national earthquake prediction program. Usami and his colleagues (1981-1994) have compiled elaborately a series of books containing roughly 45,000 documents of about 340 earthquakes. Based on these primary historical sources Usami's (1996) catalogue of disastrous earthquakes in Japan includes around 240 historical events during 599-1872 with their estimated epicentre co-ordinates, magnitudes and brief descriptions, together with many other obscure events.

In the last ca. 30 years, interdisciplinary collaboration among seismologists, geologists, geomorphologists, and, especially, historians has been increasing. And, geological, geomorphological and archaeological methods of paleoseismology for prehistoric period have been effectively applied. Quantitative treatment of seismic intensity data for estimating proper epicentres and magnitudes, deduction of fault models, and seismotectonic interpretations have also become prevailing. As a result, for example, more precise space-time pattern of the Nankai trough historical earthquakes than that referred to by Imamura (1933) has been used for probabilistic evaluation of future events, and very dense data sets of obtained seismic intensity distributions of specific historical earthquakes have served effectively for calibration purpose of strong ground motion simulation, recently.

However, a few important problems still remain. First of all, published collections of original historical documents contain many valueless and unreliable materials. Nevertheless, critical reading of historical documents and minute inquiries into historical backgrounds at the times of earthquakes are insufficient in many studies. Even Usami's (1996) catalogue still includes not a few phantom earthquakes arising from somewhat notorious low-value historical documents. Secondly, although the necessity of making database of the enormous historical documents of earthquakes was pointed out in 1987, that work is not yet started.

We must also prepare such a database as estimated seismic intensities for all events and all places. In future we should reconstruct the historical seismic activity in Japan more minutely and three-dimensionally, paying special attention to slab events, based on carefully selected primary records and the latest information from modern seismology.

Historical earthquake studies in Australia

Kevin McCue
Australian Seismological Centre, Jamison Centre, Canberra, Australia

The Australian continent is entirely intraplate, surrounded by large oceans and intense seismicity. This isolation from other seismograph network agencies and the short instrumental recording period has required Australians interested in seismicity studies and earthquake hazard assessments to focus on historical studies of local earthquakes, few of which are recorded overseas even today.

Prior to the turn of the 20th century, geologists, surveyors, astronomers, meteorologists and explorers all took an active interest in earthquakes in Australia. A Seismological Committee of the Australasian Association for the Advancement of Science was formed in the late 19th century to compile lists of reported earthquakes and introduce the first pendulum seismometers.

From the historians lists, newspaper stories, lighthouse keepers logs and meteorologists files, more than 300 isoseismal maps have been compiled into three isoseismal atlases. These are now available on a CD. The Rossi-Forel scale was originally used but the modified Mercalli scale is in general use. The basic information is being added to the Australian Earthquake Database maintained by the Australian Government's Geoscience Australia.

Isoseismal maps drawn up during the post-instrumental period has enabled correlation of felt area with Richter magnitude across the country and efforts are now focused to assess regional variations. Such relationships allow seismologists to assess the magnitude of historical earthquakes for which isoseismal maps have been drawn. Because of the lack of strong motion data, studies of attenuation still rely heavily on the intensity database assembled over the last 150 years. Since the 1989 Newcastle NSW earthquake which killed 13 people and caused more than $1000M damage, digital recorders have been built in Australia and accelerographs installed in major population centres, and on dams and in buildings.

The first seismograph in Australia, a Gray-Milne instrument, was installed at Melbourne in 1888. Today, Canberra is the hub of a modern telemetered broadband national network operated by Geoscience Australia which is supplemented by local area networks run by State Governments, Universities and private infrastructure owners. There are more than 200 seismographs currently installed in Australia and the Australian Antarctic Territory.

The occurrence of 20 large Australian earthquakes over the last century should dispel the notion that earthquake risk is negligible in Australia. The Ms 6.8 Meckering Western Australian earthquake of 1968 was the impetus for engineers to develop the first Australian earthquake code, Australian Standard AS2121 - 1979, incorporating the first hazard map of Australia. The greatest uncertainties in the map are in the definition of the source zones and the choice of an attenuation relationship.

Five of the world's ten known intraplate fault-scarp-forming events of the 20th century occurred in Australia. This has instigated a search for pre-historic Recent fault scarps to improve our understanding of the source zone geometries and recurrence rates of large earthquakes used in the hazard assessments.

Post disaster response advice includes an assessment of the likelihood of a damaging aftershock and this assessment relies heavily on the historical record. Some large Australian events are part of a classic foreshock, mainshock, aftershock sequence whilst others are solitary events with no associated events.

Procedures used in the investigation of New Zealand's historical earthquakes

Gaye Downes
Institute of Geological & Nuclear Sciences, Lower Hutt, New Zealand

New Zealand's location astride an obliquely convergent plate boundary, encompassing subduction and continental collision features, results in many earthquakes, at depths ranging from shallow to 600 km. In New Zealand's short written history of 160 years, nineteen magnitude 7+ shallow earthquakes, including an M8.1 event, have been identified, fifteen of these occurring prior to 1950. In-depth studies of these major events, as well as comprehensive efforts to identify and evaluate all felt earthquakes, are not yet complete. However, the last thirty years has seen significant advances in our knowledge. This has been driven by the need to better quantify seismic hazard and risk, and more recently, the move to introduce time dependency into state-of-the-art probabilistic methods. Since 1990, major multidisciplinary studies of several pre-instrumental and early instrumental large earthquakes have been completed. Attenuation relationships based on over 200 revised isoseismal maps, earthquake locations and MS magnitudes, have been developed and body wave modelling of over 30 large earthquakes dating from 1918 carried out.

The problem now is to work out how to best store the vast amount of earthquake source parameters and effects information in a form that:

- allows accessibility and interrogation at various levels
- allows revision
- adequately represents the uncertainties
- integrates with the present National Earthquake Information Database
- links with other databases.

Development of the database will be seriously addressed in the next few years. In the meantime, completion of the historical part of the earthquake catalogue is a priority. The analysis tools developed in the last few years, the better understanding of our seismicity, the multidisciplinary collaborations, and the better accessibility of archival material are making the work faster and easier.

Several historical New Zealand earthquakes have been responsible for significant breakthroughs in global understanding. The M8.1 1855 Wairarapa earthquake is one such event. According to the eminent 19th century geologist, Sir Charles Lyell, the earthquake *yielded to no other in the magnitude of its geological and geographical importance*. The formation of a *great* fault accompanied by regional deformation confirmed his belief that elements of the landscape were achieved incrementally rather than catastrophically, and that the past could be explained by present processes. The recent analysis of this earthquake will be discussed as an example of historical earthquake investigation procedures.

Development of historical seismological investigation in the Andean Region

Alberto Giesecke
Centro Regional de Sismología para América del Sur - CERESIS, Lima, Peru

The Regional Center of Seismology for South America (CERESIS) wase stablished temporarily by UNESCO and the Government of Peru in May, 1966, for a 5-year period.

In 1971, the governments of South America were impressed by the Centre's significant role in the improvement of the region's capability to cope with earthquake disasters. The governments decided to convert CERESIS to a permanent autonomous multilateral regional organisation and to provide basic funding to support the Director's Co-ordination and Administration Office in Lima, Peru. Funds for regional projects would have to be generated by CERESIS.

It was recognised that a unified catalogue of earthquake parameters was essential for progress in seismological research, particularly true for regional studies of seismicity, seismotectonics, and the evaluation of seismic hazards. The decision was made to concentrate work on hypocenter parameters and on cataloguing the distribution of intensity. The format was agreed to by the national representatives from each of the CERESIS countries. Project SISRA, a five- year million dollar project, funded by Office of Foreign Disaster Assistance of the United States, through the U.S. Geological Survey, was executed by CERESIS and produced the catalogues, maps (including a regional Neotectonic Map) and other products.

The Intensity Catalogue and the regional Maximum MM Intensity Map, for the period 1530-1981, is presented. Two examples of Use of the Map: Insurance, Oil Pipelines, Seismic Hazard Maps. The SISRA regional hypocenter parameters catalogue, 1471-1981, is permanently updated. Brief comments on historical seismicity research in Bolivia, Brasil, Chile, Colombia and Peru are included.

The CERESIS WEB offers at no cost the regional CERESIS catalogues and instructions for their use.

A review of historical seismicity studies in Central America

Walter Montero and Giovanni Peraldo
Escuela Centroamericana de Geologia, Universidad de Costa Rica,
San Pedro, Costa Rica

Central America is located in a region of high seismicity where the Cocos, Caribbean, Nazca, North America and the South American plates and the Panama microplate interact along different tectonic boundaries. For this reason, through the Central American history, a great number of damaging earthquakes impacted its population, cities, lifelines, among others.

Since the last part of XIX century and the beginning of the XX century, different authors compiled records of the principal damaging earthquakes at a country or regional level. Examples are the documents wrote by Montessus de Ballore (1888), Lardé (1915) and Diaz (1930) at the regional level and the Gonzalez (1910) at the country level (Costa Rica).

Following a time of scarce interest in seismological investigations, a new impulse in the historical seismicity research began around 1960-1970, mainly related to the impact of the plate tectonics theory in the scientific community and the concern and interest of the international and national communities in this important hazard. In 1973, Grases compiled a new earthquake catalogue for the Central American region, including a volume with different primary and secondary historical sources of the damaging earthquakes occurred in the region since 1540. This study was followed by others authors that compiled different local catalogues. Among these we mention, Leeds (1974) catalogue for Nicaragua, Jorgensen (1966) and Viquez and Toral (1987) catalogues for Panama, Miyamura (1980) for Costa Rica and Suttee (1981) for Honduras.

The above studies did scarce research in the original or primary sources. Beginning in 1990, new efforts where focused in investigating the original sources of information and in developing historical earthquake databases. Feldman (1993) wrote a book about the historical Central America earthquake and volcanic activity based in research did it in Spanish and National archives, documenting in a better way many of the damaging earthquakes of the region. At the same time, Peraldo and Montero (1994) and (1999) wrote documents about the historical seismicity of Costa Rica (1538-1910) and of Central America (precolumbian-1899), respectively. To better assess the earthquake hazard at the regional and country level, Rojas et al (1993) compile a parametric Central American catalogue (1500-1990). More recently, Ambraseys and Adam's (2001) compiled a descriptive catalogue for Central America, covering the period 1898-1995. Also, Malign (1997) elaborated a Tsunami catalogue for Central America. We present examples of the types of earthquake information included in some of the previous compilations and catalogues.

At present, we suggest a comprehensive review of the Central American earthquake catalogue is necessary in order to accomplish international standards. Also, systematic research of principal historical damaging earthquakes is necessary because many of these events are incompletely documented or there is scarce earthquake parameter interpretation. These pitfalls produce significant earthquake mislocations or they are not clear related to specific seismic sources. All these limitations affect seismic hazard estimations and seismic codes.

Past and present in Mexican earthquakes catalogues. An example of multidisciplinary efforts

Virginia García Acosta
Centro de Investigaciones y Estudios Superiores en Antropologìa Social - CIESAS
Mexico City, Mexico

Mexican earthquakes written reports go as far as 15th century, while Mexican earthquakes catalogues were published until the last quarter of the 19th and the beginning of the 20th centuries. Nevertheless, the 1985 Mexican earthquakes demonstrated that knowledge concerning the history of such phenomena was still scarce and precarious. In fact those earthquakes acted as triggers, because it was then when it began the development of a new field of investigation now known as disaster historical research.

An initial task was to retrieve the history of earthquakes in Mexico in order to produce an exhaustive inventory. The main result was published some years ago as "Los sismos en la historia de México" (Earthquakes in Mexican History). It contains a vast and varied body of information about every event and covers 450 years of Mexican seismological history. This catalogue has led to an increasing number of historical studies, as well as to the development of chronologies, local analyses, and case studies stemming from seismological as well as from social and anthropological perspectives.

This paper will focus the background of this parametrical catalogue, addressing mainly methodological items: sources, qualitative vs. quantitative data, multidisciplinary efforts, and so. Our main objective is to answer to questions such as: What has be done? How has it been done? What is left to be done?

1800 to 1931 pre-instrumental California earthquakes

Tousson Toppozada
California Geological Survey, Sacramento, CA, USA

Earthquake parameters [epicenters and magnitudes] were routinely determined using seismographic records starting in 1932 in southern California by Caltech, and in 1942 in northern California by U.C. Berkeley.

We estimated the parameters of pre-instrumental earthquakes by comparing their felt intensity effects to those of modern instrumented earthquakes. We researched the felt effects mostly from newspaper accounts and rare diary entries back to the 1849 Gold Rush. From ~1800 to the 1840s earthquake effects and damage were occasionally noted in the annual reports from the Catholic missions in the coastal region between San Diego and Sonoma, and rare travellers' notes. The 1769 Portola expedition felt earthquakes in the Orange-Los Angeles border region. A 1700 giant offshore earthquake was interpreted from Native American oral traditions in northern California and Oregon, and correlated with records of tsunami run-up in Japan [Satake and others 1996].

We interpreted the descriptions of earthquake intensity effects in terms of the Modified Mercalli scale [MMI], plotted the reporting towns and their MMI values on maps, and drew isoseismal contours to separate zones of equal MMI. We estimated pre-instrumental epicenters to be in the centers of maximum MMI shaking, and estimated magnitudes from the size of the areas shaken, using relations developed by Toppozada and Branum (2002) between moment magnitude M of modern earthquakes and areas shaken at various MMI.

The uncertainties in the estimates of epicenter and magnitude for pre-instrumental (pre~1932/1942) earthquakes in sparsely populated areas can be about 50 to 100 km and 0.5 M unit. Uncertainties may be smaller for post-1860s earthquakes in the densely populated San Francisco Bay area. We attempted to improve estimates of the relative epicenters and M of neighbouring earthquakes by comparing their shaking intensities at surrounding points.

We list ~400 earthquakes of M>5.5, more than half of which occurred before 1932. The M>5.5 record is probably complete back to 1932 state-wide, and back to the 1849 Gold Rush only for the well populated and studied San Francisco bay area. The record is possibly complete for M>6 back to ~1910 state-wide, and from 1800 to 1833 within 50 km of the 21 missions near the coast between San Diego and Sonoma. The improved earthquake history has shed light on the major [M~7 or larger] San Francisco bay area events, and on the cycles of seismicity associated with them.

The Parkfield earthquake prediction was based on the discovery that M~6 events have occurred quasi-regularly from 1857 to 1966. However, Parkfield is only part of the end zone of the great 1857 earthquake, which extends ~75 km further to the NW. We found that the total seismicity in this 75 km end zone has decreased steadily since 1857. This could reflect the decay of the stress loading due to the maximum 1857 fault displacements ~100 km SE of Parkfield of ~9 m, and might explain why the predicted earthquake has not yet occurred.

Long-term seismicity; the state of the art and practice. Case histories from the Eastern Mediterranean, Near East and India

Nicholas N. Ambraseys
Department of Earthquake Engineering,
Imperial College of Science and Technology, London, UK

The interaction between different disciplines that constitute the basis for mitigation of earthquake risk can best be portayed by the relation that describes seismic risk, which is the preoccupation of decision makers, planners, engineers and politicians alike. Seismic Risk can be defined by the following relation: [Seismic Riskl] = [Earthquake Hazard] * [Structural Vulnerability] * [Value], in which Earthquake Hazard is the probability of occurrence, within a specific period of time and given area, of a potentially damaging earthquake, which is beyond human control but knowledge of it is possible. Vulnerability is the degree of loss resulting from the occurrence of an earthquake of a given magnitude, and it is subject to human control. Value may be taken either in the sense of capital value or of production capacity of a vulnerable element.

This definition makes a clear distinction between Earthquake Hazard, which includes tectonics, seismology, strong-ground motions, seismic regionalization and tsunamis, specialities which constitute engineering seismology, and Vulnerability, which includes building materials, foundations, structural engineering, and retrofitting, specialities which constitute earthquake engineering. It is the amalgamation of these specialities and their balanced and co-ordinated support that would lead to the mitigation of Seismic Risk.

To begin with, not all of the existing regional and global parametric earthquake catalogues from which the earth-scientist or engineer may cull the information he needs fulfil the condition of transparency. Some of these catalogues are fresh and pertinent, some out-of-date or at second hand, some misleading. It is not satisfactory, therefore to acquire information from the historian or seismologist and use that information without understanding fully the basic principles on which the information has been obtained and what really means in terms of completeness and uncertainties.

The user of catalogues must be aware of the quality of the data, of the uncertainties associated with them and of the completeness of the data. He should prefer data from reliable long-term datasets, that give a far fuller understanding of earthquake hazard because they are based on human experience of earthquakes over a much greater segment of the geological time-scale.

Much of the information in such datasets comes from historical data and their use should aim to be indicative, to expose points for further analytical or field clarification rather than prescriptive, since in fact the prescriptions have to be based on rather arbitrary assumptions. It is not sufficient, therefore, merely to lay hand on a few historical earthquakes and use them to model seismicity.

For the early period mislocation of instrumental epicentres is the norm while for earthquakes before the 1940s, macroseismic locations are more reliable but they must be used with caution. For the later period location accuracy is not better than 30km, but improves to about 5-10 km for more recent events. However, bearing in mind that an earthquakes of MS, say between 6.5 and 7.5, will have ruptured faults 30 km to more than 100 km in length, the epicentre indicates nothing more than the general location of the event, and alone, without knowledge of the location of the causative fault, is of little use for design purposes. Focal depths are more uncertain.

Intensity, which was devised two centuries ago, is a convenient means of conveying in a single rating of the scale a measure of the effects of the ground motion on man-made structures and on the ground itself. By definition it is a vague measure, either of the strength of ground shaking or of the weakness of man-made structures or a combination of the two. Intensity tells us little about the nature and level of the ground motion.

Nevertheless the distribution of intensity may be used for the assessment of the magnitude of the associated event, for constraining the dimensions of the seismic source and for the identification of subcrustal events, particularly for earthquakes in the pre-instrumental period.

For the purpose of assessing intensity and reducing subjectivity it is important to distinguish between damage caused by dynamic or inertia earthquake loading, and damage caused by secondary, quasi-static after-effects such as foundation spreading, liquefaction, slides, rockfalls and aftershocks.

For instance I find that maximum intensity in any destructive earthquake in rural areas in south-eastern Europe and in the Middle East appears to be effectively the same; that is, intensity "saturates" at VII-VIII MSK at which all local type of constructions are destroyed or damaged beyond repair and any town or village would thus appear equally, but no more, devastated at so- called higher intensities.

Also landslides, spreading and liquefaction of the ground, are too much factors of other conditions besides the ground accelerations, and making appraisals of intensity on the basis of such ground effects, would be subjective and often misleading. In spite of the subtleties which are involved in its definition and assessment, which requires engineering knowledge, intensity values estimated by seismologists are adopted by the engineer as a means to assess ground accelerations and velocities. Modern textbooks and building codes feature tables and formulae for the conversion of intensity into ground acceleration, which is convenient but very unreliable. It is futile to seek a meaningful one-to-one relationship between intensity and any other single quantity which can be used for design purposes, a relationship that can best be described as a 21st century anachronism.

The method of contouring intensity data cannot be separated from the method of information collection and intensity allocation. If the information is sufficient then the method of contouring should be allowed to work with modal intensity values.

This procedure is particularly important when a few isolated high intensities exist within a background of many sites of much lower intensity, and conversely when isolated low intensities exist in the far-field within a background of "not felt". The use of low intensity radii that include the furthermost location from which the shock was reported, even by single observer, has a considerable bearing on the determination of the radius of perceptibility, which leads to grossly overestimated magnitude.

Homogeneously-defined isoseismals, may be used, however, to assign magnitudes to their causative earthquakes by calibrating sets of isoseismals against magnitudes, a method that gives stable results, but which must be applied to well-defined tectonic environments rather than to individual countries or global conditions. Having assessed the magnitude of the earthquakes in terms of magnitude, one may use an appropriate attenuation model to estimate ground motions.

The derivation of calibration functions between magnitudes and their corresponding sets of isoseismals for a specific tectonic environment needs internally consistent data on both; the isoseismals must be drawn on maps of intensity points assigned from examination of primary historic macroseismic information, and the magnitude data must be re-evaluated uniformly.

As for the use of synthetic isoseismal maps for engineering purposes, this reminds me of Leo Pomerance who once said about the person who was searching under a street lamp for his house key, which he had dropped some distance away, but he searches there because there is more light.

Reliable magnitudes are essential for the derivation of recurrence relations, particularly at large magnitudes where recurrence curves steepen. They are also important for the scaling of ground motions and for placing constraints on the bounds of rupture zones. A cause for concern is the reliability of magnitudes reported in different parametric catalogues, particularly for events before the advent of the magnitude scale in the 1950s.

No formal method can be devised to test the completeness of long-term data other than by testing their implications. Formal statistical tests are as valid as the distributional assumptions on which they are based. Since these assumptions are rarely likely to be always satisfied, such tests may best be regarded as indicators to the extent to which a particular conclusion would be supported, or not, by the data, if in fact the assumptions were justified, and hence, of the extent to which that conclusion is likely to remain valid despite departure from those assumptions.

Frequency-magnitude relations calculated with different magnitude scales differ. They also differ when calculated in terms of MS or MW. The reason for this is, that because of scaling, MS is not related linearly to log(Mo), and smaller events contribute proportionally more moment than large ones.

Regarding ground motions, we know how to assess uncertainties in defining them, but we know also that peak ground acceleration is a poor index by which to express the damage potential of a ground motion. At present, and for a broad class of structures, displacement is probably the most widely used parameter to limit damage and also to quantify it in terms of design criteria. For the engineer, analysis of existing strong-motion recordings is the most common method used to estimate future ground shaking in terms of peak or spectral acceleration or displacement. This method must rely on good quality data bases, uniformly processed records supported by reliable seismological and soil mechanics information and reliable associated data banks.

There is at present a multitude of CDs and internet sites that can provide strong motion data. Whilst the availability of data via such mass media is extremely valuable, it must be recognised that use of this data cannot be made indiscriminately. And although there is a great need for data storage and dissemination on a European and World level, and that CD-ROMs or the Internet can provide the uninitiated engineer with readily available strong-motion time-histories, the indiscriminate use of some of the data in existing CD-ROMs or active Internet-sites is likely to generate misleading results. The derivation of attenuation laws and site-specific design parameters must rely on good quality data bases and reliable associated data banks rather than on statistics of many records of questionable quality.

To the best of my knowledge there are at present world-wide 125 local or regional attenuation laws for peak ground accelerations, and 85 for response spectral ordinates, derived from the data available at the time, using different definitions for the variables involved and different procedures.

Uncertainties in the derivation of scaling laws depend on how well dependent variables are known. Teleseismic locations are known to have larger uncertainties compared with those from local networks and like epicentres, focal depths based on teleseismic arrival times alone lack precision.

The use of a unified magnitude scale in attenuation studies is also an important consideration. Adoption of Ms rather than ML stems from the fact that the former is not only the best estimator of the size of a crustal earthquake, but also because seismicity in Europe is generally evaluated in terms of Ms.

While there can be no objection to modeling and calculating ground motions the best we can, but with so many uncertainties in the input data, whose accuracy for predictive purposes is little known, that there is a degree of precision beyond which refinement becomes pointless. Moreover, a too sophisticated model carries with it the danger that its weaknesses and assumptions may not be appreciated. Conversely, a too simple model may be discredited just because it exposes the underlying assumptions too clearly. I would prefer a simple model in which the number of variables is justified by the available data. Over-parametrisation of the model alone is not recommended.

Recent studies show that seismic activity the is both regional and long-time dependent, which renders particularly problematic the assessment of hazard from short-term observations. The true, long-term nature of the frequency-magnitude distribution is hampered not only because the 20th century record is too short but also because test areas may be too small to disclose the repeat time of large earthquakes as the shape of the frequency-magnitude distribution from short-term observations cannot be defined at large magnitudes. The implication is that large earthquakes in a test area are less frequent, when predicted from the long-term dataset than from the usual 100-year instrumental period, making the notion of recurrence time, in its usual definition questionable, and the characteristic model an artefact of incompleteness of data in space and time. Incomplete data and clustered seismicity is the principal reason why statistics from short-term data alone cannot quickly answer the question of seismic hazard evaluation.

Considering that most major urban and industrial developments are spreading into areas of little-known seismicity, and that time rarely allows for the acquisition of adequate data, the engineer is likely to be forced on occasions to step across the hazy borderline of safety by accepting an element of risk over and above what would otherwise have been considered to be normal. To accept what is an acceptable risk, a certain amount of informed judgement, detailed technical evaluation of the structure and experience is needed, rather than results from a probabilistic treatment of short-term seismicity data. Much statistical ingenuity has been spent on devising techniques for tackling this problem, but there are doubts about how useful and how well-founded some of these techniques really are, and the statistician here should take a background role. He can point to features in the data that look anomalous because they depart from some standard model, but whether the anomalies are to be ascribed to peculiarities of the model, or to peculiarities of the process by which the input data were recorded, is not a question the statistician should be asked to answer. It should be referred back to the seismologist, geophysicist or engineer. If an important effect is really present it should not take a statistician to bring it out.

Finally, to anyone who is really concerned with historical seismicity it is becoming increasingly apparent that the site of a damaging earthquake is a full-scale laboratory from which significant discoveries may be made, by historians, seismologists, geologists, engineers, sociologists or economists, not to mention politicians. As our knowledge of the complexity of earthquakes has increased, we become more and more aware of the limitations which nature has impose in our capacity to model on purely theoretical bases. It is field observations and measurements that allow the interaction of ideas and the testing of theories. Through the field study of earthquake effects on structures and on the ground itself, a unique opportunity exists to develop an understanding of the behaviour of man-made structures, when tested by nature.

Indian earthquakes – fictions, facts, friction and futures

Roger Bilham

Department of Geological Sciences, University of Colorado, Boulder, CO, USA

The 1737 earthquake in Calcutta appears in numerous lists of earthquakes as the world's third most disastrous earthquake. 300,000 dead are attributed to this event. Yet the total population of Calcutta in 1737 did not much exceed 3000 and the records in the graveyard of the church show no more than a handful of burials that year. This so-called earthquake did not happen. Although a cyclone flooded the Ganges/Brahmaputra delta, the number of deaths from drowning in Calcutta itself may have been fewer than 100.

Despite the debunking of this myth almost a decade ago, many textbooks and popular reference books continue to list the Calcutta 1737 earthquake as the third most deadly earthquake in the world. The news of this non-event is difficult to suppress particularly since most news reporters grab facts uncritically from the web or from published encyclopaedias and perpetuate errors. The truth and the lie have equal weight.

The reasons for the exaggerated account of the Calcutta event can be traced to a pair of news reports in the popular press of 1737. But errors in interpretation have arisen much more recently that are also difficult to overcome. For more than half a century the traditional view of great Himalayan ruptures was that four had occurred in the past two centuries, and that their magnitudes all exceeded magnitude 8. We now know that only the 1934 and 1950 Mw>8 earthquakes occurred in the Himalaya, the 1897 Shillong event was not in the Himalaya and the 1905 Kangra earthquake was Mw=7.8.

Sparse seismological data and/or geodetic data for these events have permitted us to improve our understanding of seismic hazard in the Himalaya. We recognize now that perhaps more than 65% of the Himalaya has failed to rupture in the past two centuries and perhaps twice this long, suggesting that one or more large events may be overdue.

In our quest to estimate recurrence intervals for future great Himalayan ruptures we have largely exhausted our instrumental sources of information, and the search must now focus on geological and archival research. Geological evidence for large earthquakes in history and pre-history include the mapping of paleo-liquefaction features and the measurement of historic offsets of frontal faults. This is presently in its infancy and its completeness is rendered questionable by the absence of a mapped surface rupture for *any* recent Himalayan earthquake. Yet, two excavations of the frontal thrusts of the Himalaya reveal occasional slip events of more than 8 m.

Archival research has recently exhumed evidence for several large earthquakes that damaged monasteries in southern Tibet and northern India. In particular, an earthquake in 1505 in the central seismic gap of the Himalaya may represent the most recent event in this region. If this is the case, the amount of slip currently available (according to geodetic data) now approaches 9.5 m, sufficient to drive a Mw>8.2 earthquake. Is it possible that the style of great Himalayan ruptures is typified by these unusual great events, more than by the relatively small 1905 and 1934 ruptures which had no surface rupture?

It is also possible that a class of deep damaging earthquakes is much more common in the Himalaya than previously suspected. The base of the flexed Indian plate beneath the Himalaya is in a state of severe compression. Earthquakes >40 km below the shallow thrust earthquakes that have hitherto been considered the main source of Himalayan hazards can destroy north Indian and Himalayan cities (cf. Udaypur 1989), and it is quite probable that historical archives will include information on these events, in addition to shallow thrust earthquakes. Could the M=7.8 1833 Nepal earthquake have been one of these deeper events?

Geodetic measurements suggest that the Himalaya are frictionally locked to the Indian plate except during rupture. It is thus relatively easy to monitor the development of elastic strain that will eventually drive future Himalayan thrust events. In contrast, earthquakes deep in the Indian plate are less easy to quantitify geodetically, both because of their great depth and also because the rate of accumulation of flexural elastic strain is at least an orders of magnitude slower.

Scientific results and historical context of the 1811-1812 New Madrid, Central U.S. earthquakes: a new look at old data

Susan E. Hough
U.S. Geological Survey, Pasadena, CA, USA

Through its short history, the central/eastern United States has experienced only 5 earthquakes with Mw > 7.0. Four of these occurred during the New Madrid sequence of 1811-1812: the principal mainshocks on 16 December, 1811, 23 January, 1812, and 7 February, 1812, and the so-called "dawn aftershock" following the first mainshock. Much of the historic earthquake research done in the United States in recent decades has focused on the New Madrid Seismic Zone (NMSZ). In 1973 Otto Nuttli called the modern Earth science community's attention to the sequence with a compilation and interpretation of original accounts of the earthquakes.

Later work by Johnston and others established a detailed fault rupture scenario, and analyzed the earthquakes based on a compilation of macroseismic and instrumental data from earthquakes in similar stable continental regions (SCRs) worldwide. Johnston's work revealed that the New Madrid mainshocks were among the largest -- if not the largest -- SCR earthquakes in the historic record. This suggests that the largest New Madrid earthquakes may represent the archetype for the most damaging earthquakes to be expected in intraplate regions. For this reason, their importance transcends the specific issue of earthquake hazard from the New Madrid Seismic Zone.

In 1990 the New Madrid Seismic Zone (NMSZ) was targeted for focussed investigations under the auspices of the National Earthquake Hazards Reduction Program (NEHRP). This investment has improved significantly our understanding of both the earthquakes and the NMSZ. Various analysis techniques have been used to image fault structure in some detail and to develop a chronology of prehistoric NMSZ events. Physical mechanisms have also be developed to account for the puzzling observation that New Madrid seems to represent a cluster of activity that is long-lived in historic terms but short-lived on a geologic scale. In particular, post-glacial rebound has been advanced as a plausible mechanism to account for the onset of New Madrid activity in the late Holocene.

To understand fully the 1811-1812 New Madrid earthquakes and the NMSZ, it is necessary to have an accurate understanding of their magnitude and rupture areas. Since Nuttli's seminal study, published magnitude values have ranged from 7.0 to 8.75. Almost all of these estimates were based on macroseismic effects, which provide the most direct constraint on source size for the events. My talk will focus on the interpretation of such data, and the critical importance of understanding them in their historic context.

The New Madrid earthquakes occurred very early in the history of the United States, less than a decade after the Louisiana Purchase brought territory west of the Mississippi River into the Union. Historic accounts of the earthquakes are therefore sparse, although compilations from over 100 locations have been assembled by painstaking efforts on the part of several researchers. Critical to the interpretation of these accounts is an understanding of "westward expansion": the migration of early American settles into the mid-continent and beyond. This migration followed major river valleys such as the Ohio and Mississippi. Early settlements therefore clustered along waterways, where, as decades of modern seismological investigations have revealed, substantial amplification of seismic waves is expected. Indeed, site response was documented explicitly in a number of historic accounts.

Additionally, in 1811-1812, news and other information traveled along waterways, so accounts from river valley towns made their way to newspapers more efficiently than did accounts from settlers further in-land. Combined with absence of surveying to identify regions where shaking was not felt, or only very lightly felt, one is left with a compilation of accounts heavily biased towards those with unusually strong shaking.

Although it is impossible to account precisely for all such effects, it is essential that they be considered in the interpretation of macroseismic data because regressions between intensity and magnitude are almost always derived from earthquakes with better spatial sampling. Analyzing the New Madrid intensity values with a consideration of historic context yields preferred values of Mw 7.2-7.3, 7.0, and 7.4-7.5 for the December, January, and February mainshocks, respectively, and of 7.0 for the "dawn aftershock." These values are consistent with other lines of evidence, including general scaling relationships between fault area and magnitude

Finally, I show that carefully compiled and interpreted accounts of historic earthquakes can provide clues into the complexity of earthquake sequences associated with large mainshocks. Accounts from the New Madrid sequence allow us to identify and investigate not only large aftershocks, but also remotely triggered earthquakes that occurred well outside the NMSZ. Remotely triggered earthquakes represent a potentially important new wrinkle in historic earthquake research: Their ground motions can sometimes be confused with mainshock ground motions, potentially leading to an inflated estimate of intensities generated by the mainshock. On the other hand, these results provide further illustration that, if carefully analyzed, old data can provide important new insights into not only old earthquakes, but also into new science.

Examples of case histories from Austria, Slovakia / Hungary and Germany. Different kind of sources - where they are stored and their value for historical earthquake research

Christa Hammerl

Zentralanstalt für Meteorologie und Geodynamik - ZAMG, Wien, Austria

In this presentation it will discussed different kind of sources, their value for historical earthquake research and the archives where they are stored. Generally, contemporary and original sources can be distinguished by:

archival sources (municipal reports, survey of damage, diaries, invoices, paintings, etc.) and
serial sources (annals, chronicles, newspapers, periodicals, etc.)

These sources can be found in the following Austrian archives:

Austrian National Library – Collection of pamphlets, manuscripts, incunabulum, newspapers, etc.
Austrian State Archives – Archive of the Republic, General Administrative Archive, War Archive, Finance and Aulic Chamber Archive, Family, Court and State Archive, etc.
Provincial archives (one for each province of Austria)
Municipal archives
Ecclesiastical archives
Archive of the dioceses
Monastery archives
Aristocratic family archives, etc

Examples of different kind of sources in different periods and territories:

Wrong interpretation of place-names leads to wrong parameters of an earthquake.
1201 – former "Murau"/ Austria earthquake
Improving the information about earthquakes by studying contemporary sources even there is poor information.
1443 – Slovakian earthquake
Taking account the origin place of sources – the spreading of the news, especially in the northern part of the far field, of the 1348 earthquake is mostly related to the distribution of information by internal communication between monastic communities.
1348 former "Villach"/ Austria earthquake
Paintings as auxiliary tools to written sources.
1763 Komarno earthquake (border Slovakia/Hungary)
Beginning of the first damage surveys during the period of the Austrian Monarchy; the picture of the amount of damage was well documented, a microzonation could carried out.

1794 Leoben/ Austria earthquake

Problems of identification of place names because of historical reasons. In the Austrian Monarchy were used different names for the same place in Austrian, Slovakian and Hungarian language.

1858 Zilina/ Slovakia earthquake

Serial sources in the 19th century – newspapers.

1811 Styria/ Austria

One has to take into account during the identification of foreshocks, main earthquake and aftershocks that the time when an earthquake occurred was recorded in local time until the 19th century.

1861 Biblis/Germany

Documentation of the historical disasters in Japan: a rapid increase in the Edo Period (17th to the middle of 19th century)

Itoko Kitahara
Toyo University, Tokyo, Japan

Three generations of systematic compilation of historical documents describing past earthquakes have been done in Japan. The Imperial Earthquake Investigation Committee, established after the 1891 Nobi Earthquake, took a first measure to investigate the earthquakes in Japanese historical ages. The compilation was made by Tayama Minoru in 1899, covering 1896 earthquakes from 416 A.D. to 1864. In addition, the two revised volumes were published in 1904.

The Earthquake Research Institute established after the great Kanto earthquake of 1923 asked Musha Kinkiti to revise the former editions. Eventually he elaborated the four volumes during 1942 to 1951.

The latest revision has been done by Usami Tatsuo since 1977. Now it consists of the twenty-one volumes including 45,000 cases from 416 to 1872 A.D. Moreover, an electronic data-base from the Usami's compilation has been made by Ueda Kazue. It enables us to search by time and date, region, reference, supplement and so on in each article. According to Usami (1988), disastrous earthquakes in the vicinity of the capital increase suddenly at the time of the opening of a new government by the 17th century. This suggests at least two things; firstly the information of the disasters was spread all over Japan since the 17th century, and secondly the disastrous earthquakes occurred in many places in these times. The present paper concerns these two points.

Most of the newly-added articles of earthquakes in the Edo period (the Tokugawa regime) were derived from documents remaining in the local areas. There were four social classes (samurai, peasant, craftsman, and merchant), basically sustained by agrarian economy in the Edo period. The villages of the shogunate estates and the daimyo domains had been superintended by offices of the rural administration. Under these rural offices, the farmers and the urban populace lived in self-governing units. When the villages or the wards were damaged by the natural disasters, they soon reported the damages to their rural offices in order to get relief and exempt tax.

The rapid increase of the materials on disasters since the 17th century owed to this administrative documentation or to the diaries of these local literati. Woodprints describing disaster were also published in popular black markets among the urban population centers, whenever the destructive natural disasters such as large earthquakes, volcanic eruptions, tsunamis or floods occurred in the late Edo period.

In this paper I analyze the socio-informational structure in the Edo period, categorizing the disaster documents. The issue of information accessibility in the Early Modern period is characterized by the fact that administrators hid or forbade unfavourable information. The peculiar problems of disaster information was often passed over or allowed to prevent false rumours and to secure the whole society.

Case studies of past earthquakes and tsunamis from Japanese historical documents and paleoseismological methods

Kenji Satake
Active Fault Research Center, GSJ/AIST, Tsukuba, Japan

Recurrence of large subduction-zone earthquakes around Japan has been estimated from historical records. Along the Nankai trough, off southwest Japan, large earthquakes repeated since 684 AD, with recurrence intervals of ~200 and ~100 years before and after 1605 earthquake, respectively. Number of Japanese historical documents recording earthquakes had significantly increased in the Edo period (started in 1600 AD) all around Japan except Hokkaido. The earthquake recurrence along the Kuril trench has not been well studied, because of the relatively short written history in Hokkaido (started around 1800 AD). Recent paleoseismological work showed that an unusual earthquake occurred in the 17th century. Because large Kuril earthquakes are felt in Tohoku and Tokyo, they might be recorded if continuous observations were made. Local government records (called Nikki) had reported felt earthquakes since 1650's, and the annual numbers of events are comparable to felt reports of modern seismic observations.

Paleoseismlogical data from archaeological sites or trenching surveys provide physical evidence of historical earthquakes. Liquefaction features such as cracks or sand-blow have been found at many archaeological sites, and they were dated with an error of several decades to a few centuries. Some of them might indicate strong ground motion from large earthquakes along the Nankai trough. Occurrence of additional earthquakes during the apparently longer (~200 year) intervals has been suggested from such features. The 1596 Fushimi earthquake (M 7.8) caused several thousands of fatalities and damaged Kyoto, Osaka, and Kobe, much wider area than the 1995 Kobe earthquake. Trenching surveys on the Arima-Takatsuki fault system revealed the most recent event horizon was consistent with the 1596 date, offering a strong candidate of causative fault.

Date and size of the last giant earthquake in the Cascadia Subduction Zone, off the west coast of the United States and Canada, was determined from Japanese tsunami records. American paleoseismological studies had shown that a large earthquake occurred about 300 years ago. Japanese historical studies had shown that tsunami caused damage and flooding at seven sites along 1000 km of Pacific coast. The origin time of the Cascadia earthquake was estimated as around 9 pm of January 26, 1700. The tsunami heights were reconstructed in the range of 1-5 m, using different criteria to capture various uncertainties. The seismic moment (Mw ~9) was also estimated by comparing the reconstructed heights with calculated heights by tsunami simulation from several fault models.

Current issues in historical seismology of Israel

Iaakov Karcz
Jerusalem, Israel

Israel lies near the junction of the Eurasian, African and Arabian Plates. Its tectonic pattern is dominated on the south by the Arabo-Nubian craton (AN), on the west by the Syrian Arc (SA), a sigmoidal belt of Late Cretaceous-Neogene folds and faults that extends up to Palmyra, and on the east by the Dead Sea Rift (DSR), a complex transform along which the Arabian Plate slips northwards relative to the African Plate at a mean long term rate of 5 to 10 mm/y. DSR includes colinear and offset segments, and shows local bends and stepovers with associated transpressive blocks and transtensional pull-apart basins. Subsidiary normal and strike slip faults provide a venue for strain partitioning. The ongoing motion along DSR and the convergence of Eurasia and Africa require rotations, displacements, and space readjustments also across the SA. Recent seismic activity shows strong clustering along the Gulf of Elat and the Dead Sea segments of DSR and some activity along its NW aligned subsidiaries. Some low magnitude events occur also away from the DSR but no clear trends are evident. Estimates of instrumental and historic seismic slip are about one third of the total slip, the difference attributed mostly to aseismic movements, or/and to underrepresentation of mega-earthquakes with long recurrence interval. So far, geodetic observations did not reveal any consistent lateral motion along a seismically quiet DSR segment. Both repeated levelling and geological mapping suggest differential vertical movements along the SA system.

Dozens of catalogues and lists of historic earthquakes in Israel, Jordan, Syria and Lebanon appeared in the 20th century, creating an illusion of a firm and exhaustive data base, and shifting the attention (and funding) to other palaeoseismic studies. Critical examination shows however that this database is neither complete nor reliable. Some of the shortcomings reflect a hoist of political (past and present) and cultural constraints, but many others are due to inadequate search for primary materials and excessive reliance on inbred and incestuous catalogue information, as well as to sloppy research and blunders in evaluation of dates, locations and damage (DLD). Blending of such information with archaeological and sedimentological data often leads to vicious rather than wondrous interpretative cycles. While it is tempting to parameterize the existing catalogues and argue over characteristic earthquakes, seismic gaps and earthquake migration, the current challenge may well lie in the more mundane recovery of local materials, both in Israel and in the adjoining countries, which would improve the perception and resolution of information in records and chronicles written from afar.

Filling the Antiquity gap in Italy: contribution from the archaeoseismological approach

Fabrizio Galadini
Istituto di Geologia Ambientale e Geoingegneria, CNR, Roma, Italy

The archaeoseismological information related to the Antique earthquakes which affected Italy has been derived from an "areal approach", aimed at defining synchronous damage at different sites throughout an extended area. This approach responds to the need to corroborate the "seismic hypothesis" with evidence of ubiquitous destruction. The key aspect is the evidence of damage in archaeological stratigraphic units which can be correlated throughout a large area. Despite this sound base for the archaeoseismological interpretation, problems derive from 1) the chronologically close occurrence of several earthquakes and 2) the investigation of events related to periods of decadence or political instability. As for point 1, indeed, neither archaeological dating nor traditional methods of numerical dating can discriminate events occurred in a time span of few years.

Some factors may hinder the definition of a reliable archaeoseismological hypothesis related to events occurred during periods of decadence or political instability (point 2). The archaeologically synchronous evidence of structure collapses throughout a large area may be due to war events or the bad preservation of buildings. In Italy and probably in large part of western Europe, this aspect is typical of the Late Antiquity. The experience gathered during numerous archaeological excavations related to early Imperial buildings which collapsed during the 4th-6th centuries clearly indicates a state of abandonment (sometimes with espoliation of the structure) preceding the collapse, documented by the presence of thick strata of reworked material over the floors.

In such cases the attribution of the seismic cause to the destruction is definitely difficult, since the old age and the bad preservation of the buildings may represent the main cause of the structure collapse. Moreover, even if the occurrence of an earthquake can be demonstrated through other sources of data, the high vulnerability of the buildings or the incorporation of false coseismic collapses into the whole picture of the coseismic effects may result in an amplification of the earthquake size.

The contributions that archaeoseismology may give to the knowledge of the Antique earthquakes in Italy must necessarily take into account the above reported problems. Both aspects, contributions and problems, are analysed in the cases of 1) the earthquake which affected the Sulmona Plain (central Italy) at about the half of the 2nd century AD; 2) the 346 AD earthquake (southern Italy); 3) the 508 AD Rome earthquake and 4) the destruction of archaeological structures during the Late Antiquity in the Colfiorito area (central Italy). In case 1, the occurrence of a destructive earthquake in the middle of the 2nd century AD is proved by the evidence of synchronous destruction/abandonment at several sites in the Sulmona Plain and from an epigraph mentioning the restoration of a weigh-house damaged by an earthquake.

This earthquake i) may be an ancient "twin" of the numerous historical events which affected the Sulmona area (particularly the 1349, 1456 and 1706 earthquakes) or ii) it may have been due to the activation of the fault bordering the plain (to which no historical earthquakes can be related). In the latter case the elapsed time since the last activation of the mentioned fault is probably about 1,800 years.

As for the 346 AD earthquake, available data yield a picture of possible coseismic effects in a large part of southern Italy. However, factors such as: 1) the problematic attribution of the seismic cause to all the archaeological cases of destruction; 2) the occurrence of more earthquakes in a short time span (346 AD, 375 AD) over approximately the same area, whose effects are difficult to distinguish even by means of a detailed and rich archaeological stratigraphy and 3) the increased vulnerability of many structures during the Late Antiquity, may be responsible for the amplification of the earthquake size. Hence the two extremes of the knowledge should be represented (e.g. two different pictures of the earthquake should be available): 1) the data definitely indicating the earthquake occurrence (i.e. the epigraphs) and 2) data of point 1 plus the critically reviewed archaeological data consistent with the earthquake occurrence.

As for the 508 AD Rome earthquake, contrasting factors (changed use of pre-existing buildings, lack of maintenance of monuments, "political" restorations by King Theodericus, ...) hinder the attempt to define the impact the 508 AD earthquake had on Rome. Archaeological evidence indicates, however, probable strong effects related to this event. This is true 1) if we assume that the investigated cases of destruction have been induced by the earthquake and 2) if we assume that those cases are not earthquake-related, since they definitely indicate the presence of structures characterised by a high vulnerability during the 6th century AD.

The scarcity of settlements during the Late Antiquity in the Colfiorito Plain hinders the application of the "areal" approach which may permit to correlate the evidence of destruction at different sites. For this reason, the seismic cause for the collapses of buildings in the ancient town of Plestia and for the destruction of the Roman hydraulic works (built for the drainage of the Colfiorito basin) cannot be proposed on the basis of the available data.

The Mexican earthquakes of 1800, 1845 and 1858: a comparative study on their political and social effects

América Molina del Villar
Centro de Investigaciones y Estudios Superiores en Antropologìa Social - CIESAS
Mexico City, Mexico

This study presents a comparison between three nineteenth-century earthquakes which affected intensely the central, western and southern regions of Mexico on March 8, 1800, April 7 and 10, 1845, and June 19, 1858. This research is based on one of the most complete historical catalogs, *Los sismos en la historia de México* [Earthquakes in Mexican History], in which Virginia García and Gerardo Suárez include reports from the year 1 pedernal [1 flint, according to the nahua calendar], to 1912.

This catalog is the result of an interdisciplinary project that brought together seismologists, anthropologists and historians. I began participating in this project in 1987, with the case study of the impact of the June 19, 1858, earthquake on Mexico City. A detailed analysis of the quake's national and local effects was allowed by the catalog's rich documentation, which includes reports on damages to the city's buildings, streets and neighbourhoods. Studying the governmental and social response to this earthquake was particularly important. Irene Márquez, who also participated in this project, carried out a similar study on the March 8, 1800, earthquake.[1] The purpose of this study is to compare the data and methodology used in these two case studies.

Several years after these studies, I became interested in comparing the 1800 and 1858 earthquakes with the one occurred on April 7, 1845, which was very similar to that of September 19, 1985.[2] The 1845 earthquake is one of the most documented event in *Los sismos...*, including detailed reports on its effects on certain Mexico City buildings and newspaper articles its impact outside the capital.

All this data allows us to estimate the intensity and geographical reach of this earthquake. Comparing these three nineteenth-century earthquakes is useful for establishing two parameters: first, what case studies are already available, and second, what these case studies can contribute to the study of other historical earthquakes. In the light of these previous works, I would like to stand out the methodological tools that can be used to study past earthquakes and those that can be used in further research.

[1] These studies are published in: Virginia García Acosta, ***Los sismos en la historia de México***, v.2, Fondo de Cultura Económica, Centro de Investigaciones y Estudios Superiores en Antropología Social, 2001.

[2] Virginia García Acosta made a first comparison of these three nineteenth-century earthquakes in the Primer Simposio Internacional sobres riesgos geológicos y ambientales en la ciudad de México [First International Symposium on Geological and Environmental Risks in Mexico City], Mexico City, October 2000, with the paper “Perspectiva histórica de los riesgos y desastres y su impacto en el valle de México” [Historical Perspective on Risks and Disasters, and their effect on the Valley of Mexico], in which she refers to the impact of the three earthquakes on Mexico City population.

Revision of the earthquake catalogue for Switzerland and neighbouring regions: the example of the December 1720, Lake of Constance earthquake

Monika Gisler
Schweizerischer Erdbebendienst – ETHZ, Zürich, Switzerland

Switzerland is characterised by moderate seismic activity, with uneven distribution in time and over the Swiss territory, mostly concentrated in the Wallis, the Basel area and central Switzerland. The existing Swiss earthquake catalogue is spanning the time period 250 to 2000; however, reliable instrumental information is available only since 1975 and the bulk of the catalogue is derived from macroseismic input. The assessment of seismic hazard for Switzerland relies therefore chiefly on the historical record of earthquakes, providing information over the last 1000 years. However, the Swiss earthquake catalogue and macroseismic database have not been significantly improved since 1975. To proceed with the evaluation of seismic hazard for Switzerland, a substantial revision of the macroseismic database and of the Swiss earthquake catalogue was required.

During the years 1999-2002, a complete revision of the macroseismic database and of the Swiss earthquake catalogue has therefore been undertaken. As a result, ECOS – the Earthquake Catalogue of Switzerland – is a key step in the upgrade of the databases for earthquake hazard assessment of Switzerland and neighbouring regions. The project intended to compile a complete inventory of intensity points for earthquakes with intensities equal or larger than VI in Switzerland and neighbouring regions; it incorporates all relevant information compiled in existing national databases and/or earthquake studies in Switzerland, France, Germany, Italy and Austria in order to derive a unified earthquake catalogue with uniform source parameters.

The ECOS core is MECOS-02, the revised Macroseismic Earthquake Catalogue of Switzerland, which includes a comprehensive database of historical and macroseismic information built by collecting and analysing primary sources and compilers of historical information and by merging all available macroseismic information and earthquake studies.

This included the collection and analysis of primary sources and compilations and the merging of existing macroseismic information and earthquake studies. An interdisciplinary team of historians and seismologists collected and reviewed historical documents and literature, in order to improve the historical dataset and the re-evaluation of the macroseismic fields of the events.

To present reflections, problems and findings of the project the example of the 20 December 1720 earthquake in the Lake of Constance region will be discussed. After giving some general information on the proceeding of ECOS, I will mainly focus on the historical investigation of the event as well as the interpretation and assessment of intensities.

The literacy of the event will be presented and the contemporary sources and reflections that led to the intensity assignment will be described. Problems such as the adjustment of date and location will be discussed. Furthermore general questions of method and completeness will be brought into discussion, e.g. how to deal with a heterogeneous set of historical information and its macroseismic assessment.

Assessing the completeness of historical earthquake data sets

Massimiliano Stucchi
Istituto Nazionale di Geofisica e Vulcanologia, Milano, Italy

The assessment of the completeness of historical earthquake data (such as parametric catalogues, for instance) has usually been approached in seismology - and mainly in PSHA - by means of statistical procedures. Such procedures look "inside" the data set under investigation and compare it to seismicity models, which often require more or less explicitly that seismicity is stationary. They usually end out determining times (Ti), from which on the data set is considered as complete above a given magnitude (Mi); before Ti the relevant part of the data set is considered as incomplete and, for that reason, non suitable for statistical analysis. As a consequence, significant portion of historical data sets are not used for PSHA mostly in cases where they give unique information.

Statistical methods may work in some areas. However, in areas where seismicity is non-stationary or where the recurrence time of large earthquakes is longer than the time-span covered by the parametric catalogues, statistical procedures may lead to inconsistent results.

Dealing with historical data sets - which are incomplete with little exceptions, although this does not mean that they are of low value - it seems more appropriate to estimate "how much incomplete" the data sets can be and to use them together with such estimates. In other words, it seems more appropriate to assess the completeness looking "outside" the data sets; that is, investigating the way data have been produced, preserved and retrieved.

As a first step we have compared the current catalogue of Italy with the seismicity model used for PSHA. We have found that these models require that the current catalogue should be "highly incomplete" in the range $5.5 \leq M < 7.3$, to such an extent that it would not be acceptable from the historical point of view.

We have then started investigating - according to a historical approach - the completeness of 15 Italian "site seismic histories", that are, the sequences of the seismic effects recorded at a place, no matter which earthquakes have produced them. Some preliminary results show how effective this approach can be.

This paper also wants to stress the great value of the collection of intensity data points (IDP) which are increasingly being offered to the user in digital form (such as NOAA, US; DOM and CFTI, Italy; SISFRANCE, France; CERESIS, South America; EMID, a starting point towards a European-Mediterranean Intensity Database). Although IDP alone cannot represent the whole historical information, they have contributed to develop a number of rigorous procedures for historical seismology. As an example, IDP can be used for determining preliminary models of the seismogenic source which has generated the related earthquake, while "site seismic histories", obtained by a simple query of a well compiled intensity database, have become a useful tool for independent assessment and/or calibration of seismic hazard estimates.

The combination of historical, instrumental and geological evidence for large earthquakes: excerpts from the European experience

Gianluca Valensise
Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

Historical seismology is often considered a rather elitarian discipline that is reluctant to exchange views and data with - or simply contribute data to - the scientific community dealing with the assessment of seismic hazard. In contrast, experiences conducted in Europe during the last decade prove the opposite, showing that the value of historical seismology data goes well beyond the mere compilation of earthquake catalogues. This added value has brought new insight and new fundamental results on seismogenic processes in many parts of Europe. We will describe this new trend by reference to three distinct and innovative lines of investigation:

1) full parameterization of the source of large historical earthquakes by automatic processing of intensity data. New and widely tested computer procedures allow the location, orientation and physical dimensions of an historical earthquake source to be assessed with great accuracy. Sources derived by this procedure can then be compared with sources derived from instrumental or geological data and interpreted in the same physical frame of reference. Typical uncertainties with respect to instrumentally detected sources for earthquakes in the M range 5.5-6.5 are 5-10 km for location, 3-5 for source length and 10°-20° for source strike;

2) development of fault segmentation models where the historical evidence is directly compared with geological observation that describe the large-scale texture of a seismogenic zone. Applications to important seismic sequences formed by similarly large earthquakes (e.g., Calabrian earthquakes of 1783) have (a) illustrated how seismicity is “modulated” by the geological structure, (b) shed light on dynamic interactions between adjacent faults, and (c) increased dramatically the value of historical research for predicting the locus of future large earthquakes;

3) understanding the role of minor seismicity that occurs immediately before or after a large earthquake, or at any time during the seismic cycle of major seismogenic structures. When placed into a seismotectonic context delineated using good geologic, instrumental and geodetic observations, minor historical earthquakes may help defining the exact geometry of the main seismogenic trends and deriving their fundamental recurrence properties.

The presentation will elucidate on these three lines of investigation using practical examples drawn from Italian, Greek, French, Spanish and Swiss earthquakes and from recent compilation efforts.

Re-evaluation of early instrumental earthquake locations: methodology and examples

Robin Adams

International Seismological Centre, Thatcham, UK

The difficulties of locating earthquakes in the early instrumental period are not always fully appreciated. The networks were sparse, and the instruments themselves were of low gain, often had inappropriate frequency response and recording resolution, and their timing could be unreliable and inaccurate. Additionally, there was only limited knowledge of earth structure and consequent phase identification and propagation.

The primitive Zöppritz tables for *P* and *S*, with no allowance for the core, did not come into use until 1907, and remained the main model until the adoption of the Jeffreys-Bullen tables in the mid-1930s. It was not until the early 1920s that studies of Hindu Kush earthquakes revealed that earthquake foci could have significant depth. Although many early locations are creditably accurate, others can be improved by use of more modern techniques. Early earthquakes in unusual places often repay closer investigation. Many events after about 1910 are well enough recorded to be re-located by computer techniques, but earlier locations can still be improved by using more recent knowledge and simpler techniques, such as phase re-identification and graphical re-location.

One technique that helps with early events is to locate events using the time of the maximum phase of surface waves, which is often well reported. Macroseismic information is also valuable in giving confirmation of earthquake positions or helping to re-assess them, including giving indications of focal depth. For many events in the early instrumental period macroseismic locations are to be preferred to the poorly-controlled instrumental ones. Macroseismic locations can also make useful trial origins for computer re-location. Even more recent events, which appear to be well located, may be grossly in error due to mis-interpretation of phases and inadequate instrumental coverage. A well converging mathematical solution does not always put the earthquake in the right place, and computer location programs may give unrealistically small estimates of error. Examples are given of improvements in locations of particular earthquakes in various parts of the world and in different time periods.

Historical earthquakes in Sicily

Raffaele Azzaro
Istituto Nazionale di Geofisica e Vulcanologia, Catania, Italy

The state of knowledge of past earthquakes in Sicily is inhomogeneous because of both different seismic styles in different sectors and complex historical events. Eastern Sicily is one of the Italian regions with high seismic risk and is characterised by the occurrence in the past of large, destructive events (magnitude larger than 7.0, intensity up to XI MCS) over a territory which is densely urbanised today. These events are known only by historical data, with the exception of the 1908 Messina earthquake, which represents the largest event (Io = 11 MCS, Ms = 7.3) in Italy at the dawn of the instrumental period. It caused extensive destruction in the northeastern sector of Sicily as well as in southern Calabria; rules of earthquake resistant construction were introduced, for the first time in Italy, as a consequence of this event.

Two of the most significant seismic events from the historical record in Sicily are the 1169 and 1693 Val di Noto earthquakes. The Jan. 11 1693 earthquake (Io = 10-11 MCS, Ms = 7.0) is the best known among the largest events that have occurred in the southeastern sector of the island. In spite of the existence of a large amount of coeval reports and recent studies, the interpretation of this earthquake is still debatable because it affected large coastal areas and was preceded by a strong foreshock (Io = 8-9 MCS, Ms = 5.9). Although historical data are somewhat unclear, the Feb. 4 1169 earthquake shows some analogies with the 1693 one. Both the events probably had their epicentres along the Ionian coast between Syracuse and Catania, since they destroyed all the coastal localities and heavily damaged towns in inland Sicily. These large earthquakes seem to occur rarely, with return periods of some hundreds of years.

In Western Sicily information on large events is sparse. Evidence for significant seismic hazard implications became apparent for the first time only after the 1968 Valle del Belice earthquakes. At this point it is unclear if this is a zone in which seismicity may occur with very long return periods (thousands of years) or alternatively the catalogue may be incomplete (as it appears from recent archaeoseismological studies at Selinunte) and the region may be more active than records suggest. Even if characterised by a moderate maximum magnitude ($Ms \leq 5.9$), the 1968 seismic sequence was destructive because several damaging (Io = 8-9/10 MCS) shocks occurred in a short time-span (hours to days). As a result four towns were almost raised to the ground, abandoned and reconstructed in different sites and many other villages suffered such large damage as to appear drastically modified in their urban layout.

Finally, a peculiar case in the seismological framework of Sicily is represented by the region of Mount Etna. Albeit characterised by low-energy earthquakes ($Ms < 5.0$) like other volcanic areas, this area is very frequently affected by severe to destructives events (intensity up to 10 MCS) which, fortunately, affect restricted zones due to the shallowness of hypocentres.

Since the early-1800s the activity of Etna, including eruptive and seismic phenomena, has been regularly reported and so a qualitatively homogeneous set of historical information has been collected. The availability of a large dataset of macroseismic information has allowed the compilation of a specific catalogue (no magnitude threshold adopted) for investigating in detail the space-time evolution of seismic sequences and the possible relationships with eruptive activity.