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Earthquakes in History – Ways to Find out About the Seismic Past of a Region

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1. Introduction

The onset of the 21st century has brought a new public awareness of natural hazards. Recent catastrophic events like the 2004 tsunami in Asia or the 2005 flooding of New Orleans have made it not only to the headlines in news publications around the globe but have also contributed to a more profound desire to accumulate knowledge about natural hazards in general among people all over the world. Earthquake research belongs to the most fascinating (albeit problematic) topics in the field of natural hazard research. Hardly any other hazard claims more lives, destroys more values and can lead to catastrophic after-effects (as can be seen when looking at the 2011 earthquake with resulting tsunami and nuclear disaster in Japan). In most cases scientists are not able to forecast when and where an earthquake may take place, but only the approximate region and the probability, not the precise date and the magnitude. Geoscientists therefore by and large concentrate on assessing and mapping regions that experienced earthquakes in the past.

As a consequence, the description of past earthquakes is of utmost importance for a reliable projection of future earthquakes. Several ways exist to sum up details about historical earthquakes, the most important of which was the analysis of written documents in pre-measurement times (see Fig. 1). From the 19th century onwards the installation of seismometers has considerably improved the situation and nowadays the analysis of a new earthquake relies almost completely on measurements.

This paper strives to offer a short introduction to the following aspects:

- Historical earthquakes and their reception history
- Ancient attempts to forecast and measure earthquakes
- Early modern attempts to collect written information on earthquake events
- Early modern earthquake catalogues in Europe
- The application of early seismometers
- The expansion of a seismometer network
- Open source ways to collect earthquake information

The paper will concentrate on (but not limit itself to) German attempts in the aforementioned aspects, including a short overview of the current state of research. Of special importance in this context is the Bavarian BASE-project, which serves as a role model for a modern and complete collection of historical earthquake data

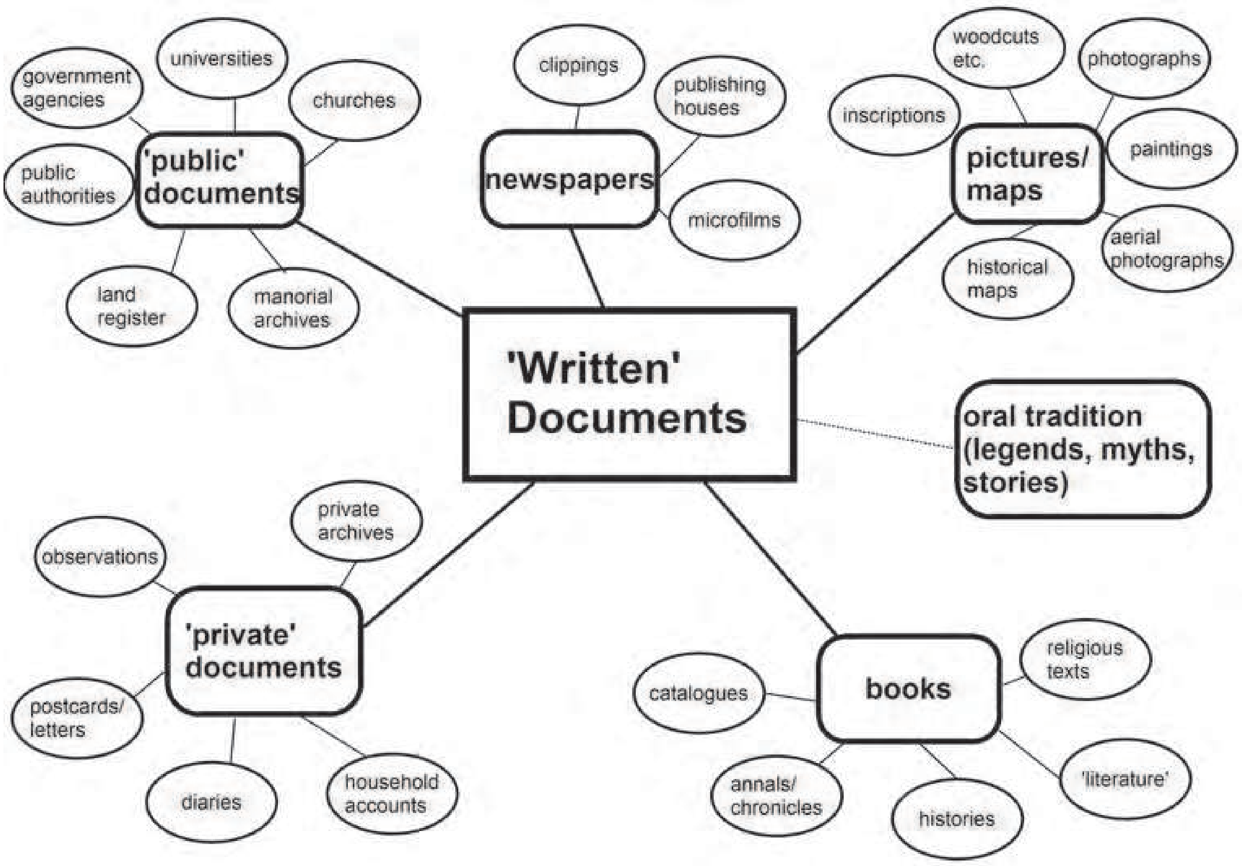


Fig. 1. A selection of sources for written documents for the analysis of historical earthquakes (F. Barnikel).

2. Historical earthquakes and aspects of their reception history

Bolt et al. (1975) point out the different causes of earthquakes as follows: they list (in that order) tectonic earthquakes, the principle of elastic rebound, the dilatancy in crustal rocks, nuclear earthquakes, reservoir-induced earthquakes and volcanic earthquakes. Even if some of these causes can be discarded for ancient times, the event of an earthquake has shaken the trust of ancient populations in a *terra firma* at all times.

Consequently, it is no wonder that the first record of an earthquake dates back to the year 1831 BC. It is mentioned in the Chinese *Chronicle on Bamboo*: “Mount Taishan quaked.” Even older, but considered not very reliable by the Chinese historians, is a reference to the year 2221 BC: “While the San-Miao was going to be destroyed, the Earth quaked, fountains sprang” (quoted after Xie, 1988). But the oldest ‘known’ (and completely unspecified) earthquake on the other hand was, as Seyfart, with a piety not typical for his time, noted in the 18th century, “undoubtedly the one triggered by God on the third day of the creation through the power of the fire inside the globe” (quoted after Fréchet, 2008).

Approximately one thousand years later the Chinese began their continuous listing of quake events, which lasts until today. Some of the descriptions are thus detailed that current research is able to reconstruct the approximate magnitude of the event. Chinese scholars first explained earthquakes with other forms of disasters, like floodings, droughts or the plague. Among the most popular lores from ancient times is the well known ancient Japanese belief that linked earthquakes to the fish species of brown bullhead (*namazu*), which were said to move their tails to and fro. Other mythological creatures include frogs (China), a snake (Philippines) or the God Poseidon himself (Greece; for the history of earthquake reception cf. Bolt et al., 1995 or Zeilinga de Boer & Sanders, 2005).

In Asia among the most severe earthquakes in China are the events in 110 AD (Dian), in 1290 (Chihli) and the 1556 event in Shaanxi. In nearby Japan some of the gravest events include the 869 AD Sanriku Earthquake, the 1293 Kamakura event, an earthquake 1498 in Honshu, and the 1707 Hoei and the 1896 Meiji events (all events before the introduction of modern seismometers). Srivastava & Das (1988) quote archaeological evidence pointing at an earthquake c. 1730 ± 100 BC in Rajasthan. The earliest earthquake records for Indochina date back to 642 BC (Prachuab, 1988). The case lies different with New Zealand for example, where no older written sources exist. But Eiby mentions that "Maori oral tradition records an important earthquake in about 1460" (Eiby, 1988), an interesting reminder of ancient ways of transmitting information.

The oldest specific date for an earthquake event in Europe and the Middle East dates back to about 1274 - 1234 BC, when the Assyrians noted an earthquake in Nineveh. But it was the Greeks who made the first attempts to write about explanations for earthquakes and their origin in Europe and the adjoining regions. Thales of Milet was the first to think that land would drift on the surface of the oceans and that the waves might cause earthquakes. In the 6th century BC Anaximenes thought that falling stones inside the globe caused earthquakes, Anaxagoras, one hundred years later, believed fire was the reason for it (for a beautiful illustration of a similar concept, see Fig. 2). In 464 BC a strong earthquake is thought to be one reason for the outbreak of the Peloponnese War, when the poor helots revolted against the rulers, of whom many soldiers, women and boys (as future soldiers) had died as a result of the event (Zeilinga de Boer & Sanders, 2005). Aristoteles wrote about a central fire inside the Earth and thus was one of the first to acknowledge the energy inside the Earth in the 4th c. BC. A lot of events were listed by the geographer Strabo and known to the more educated Greeks. In 226 BC a very notable earthquake event destroyed the Colossus of Rhodes, one of the ancient wonders of the earth. Other severe events in historic times include the 365 AD Crete event and other earthquakes 856 in Corinth, 1303 in Crete, and 1481 in Rhodes.

Among the earliest (and most colourful) descriptions of earthquakes in the Near and Middle East belong some bible texts (as aforementioned), although they cannot be dated precisely. One example is Zechariah 14:4, which describes in detail a horizontal displacement close to an epicentre: "In that day His feet will stand on the Mount of Olives, which is in front of Jerusalem on the east; and the Mount of Olives will be split in its middle from east to west by a very large valley, so that half of the mountain will move toward the north and the other half toward the south." Other early and unspecific descriptions include Genesis 19:24f. ("Then the Lord rained upon Sodom and upon Gomorrah brimstone and fire from the Lord out of heaven; And he overthrew those cities, and all the plain, and all the inhabitants of the cities, and that which grew upon the ground"), 2 Samuel 22:8 ("Then the earth shook and trembled; the foundations of heaven moved and shook, because He was wroth") and Jeremiah 10:10 ("But the Lord is the true God; He is the living God and an everlasting King. At His wrath the earth shall tremble, and the nations shall not be able to abide His indignation"), which all describe the fury in the wrath of God. Some grave events in the region include: 526 AD in Antioch, 551 in Beirut, 749 in the Levant, 847 in Damascus, 856 in Qumis, 893 in Armenia and in Iran the same year, 1042 in Syria, 1138 in Aleppo, 1157 in Syria, 1170 in Aleppo, 1202 in Syria, 1268 in Cilicia, and 1509 in Istanbul, 1667 in Shamakhi, 1727 in Tabriz, and 1780 in Iran.

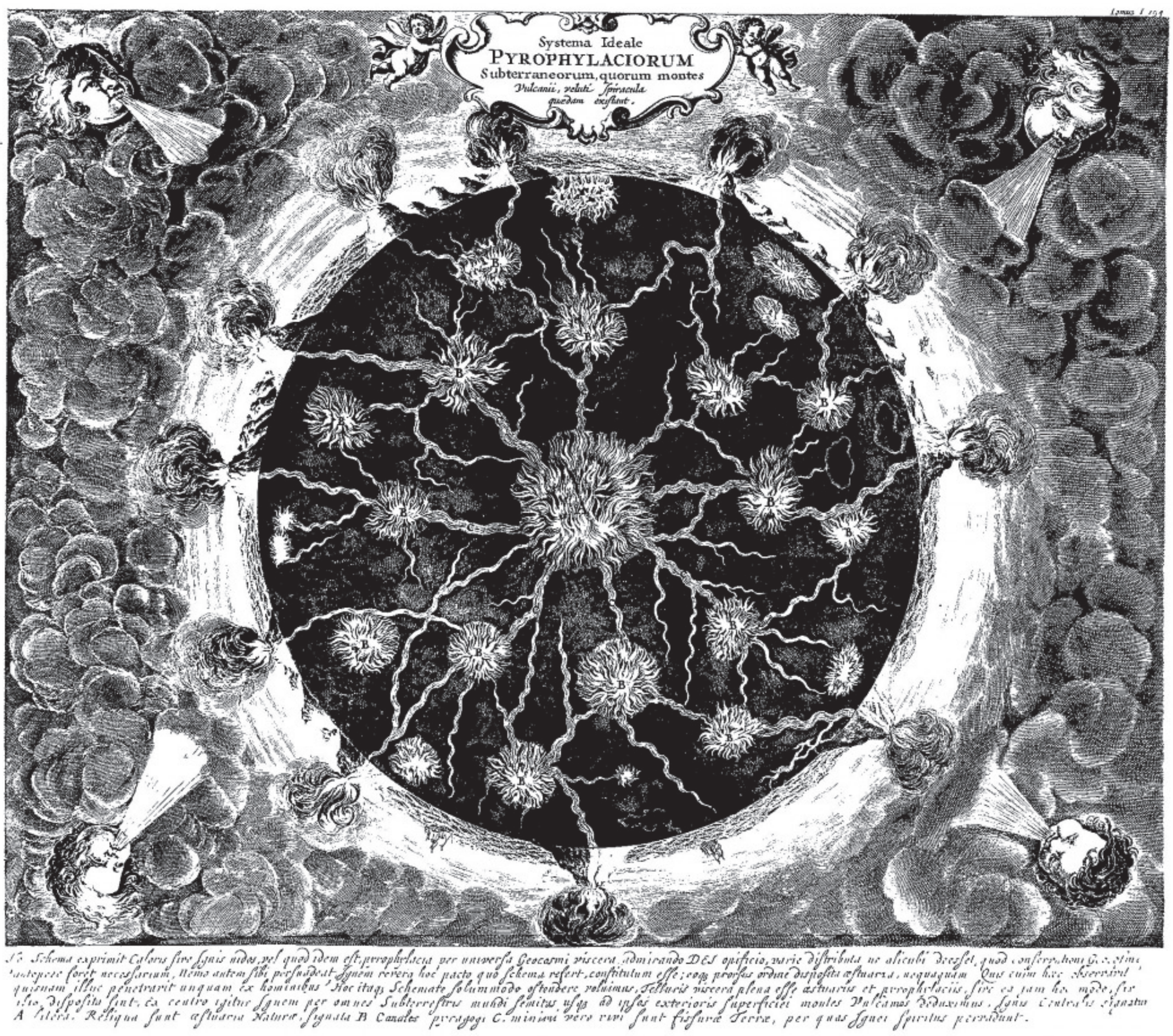


Fig. 2. The interior of the earth according to the perception of Athanasius Kirchner in the year 1678 with subterranean lakes, rivers and pools of fire.

Seneca (4 BC - 65 AD) assumed movements in the air inside the Earth as reasons for earthquakes. More severe events in Italy took place in the second millennium AD, e.g. 1169 in Sicily, 1348 in Friuli, 1693 in Sicily, 1694 in Irpinia, 1783 in Calabria, and 1857 close to Naples. The latter event led the British scientist Robert Mallet to lay down the foundations of modern seismology and to begin with the compilation of an earthquake catalogue, which in the end listed 6800 events with location and effects, just a few years after the first earthquake statistics put together by K.E.A. Hoff in 1840 (Bolt et al., 1995). Other European events of that time include the 1356 Basel event and the earthquakes in Lisbon in 1531 and 1755. It was especially the 18th century that brought a large number of new scientific developments. Isaac Newton delivered a scientific theory for the explanation of seismic waves. Several earthquake events 1750 in London led to a number of papers presented to the Royal Society. The 1755 earthquake of Lisbon, which was perceived over large parts of Western Europe, triggered off further inquiries.

From other parts of the world the 1575 Valdivia and the 1868 Arica events in South America are among the most notable. The Geological Survey of India, founded in 1857, and later the U.S. Geological Survey (founded in the year 1879) began to list and assess earthquakes worldwide and thus contributed enormously to the knowledge about earthquakes. The desire to assess and list historical earthquakes within the framework of systematic and scientific progress has gathered its enormous momentum within the past 150 years foremost in countries around the Pacific Ring of Fire, especially the USA.

3. Ancient attempts to forecast and measure earthquakes

Ambraseys (2009) notes that

> *historical evidence shows that earthquake prediction was a serious preoccupation for the early soothsayer, astrologer, or prophet, and there are many recorded instances in history of earthquakes having been forecast (Ambraseys, 2009).*

The earliest known seismoscope, which was designed to substitute sheer soothsaying, was made in China by Chang Heng in 132 AD. Its mechanism remains unknown, although it is said that his device actually measured some earthquake four hundred miles away which was otherwise unnoticed at the site of the seismoscope. It took science a very long way until Jean de Hautefeuille led the European movement to invent a device that would measure earthquakes in 1703. Nicholas Cirrillo used pendulums to measure a series of earthquakes in Naples in the year 1731. James Forbes was probably the first scientist to attempt explicitly to give a seismological instrument a "long" period, something which was finally achieved by Emil Wiechert at the turn of the century, who invented probably the oldest type of seismograph still in use today (Dewey & Byerly, 1969). But the direction, intensity and duration of seismic waves had already been recorded by Luigi Palmieri in as early as 1856 (Bolt et al., 1995).

The forecast of earthquakes has always been highly desired. From the year 373 BC in Greece stories exist that describe the reaction of rats and centipedes that flee from a severe earthquake just hours before the event. Modern studies concentrate more on electrical resistivity of rocks, electrotelluric fields, electrochemical potential or electrical conductivity of water (Sidorin, 2002). Fossil quakes may help with the forecast if a region is earthquake prone, archaeoseismology plays an important role in this context. Tree ring analyses may result in the reconstruction of historical events, just as sediments in lakes might prove ground liquefaction (Bolt et al., 1995), and there are many more fields in which palaeoseismology may contribute historical and prehistorical records. Reicherter et al. (2009) sum up the current knowledge on earthquake ground effects for hazard assessment.

4. Earthquakes in mediaeval and modern Europe

Mediaeval earthquakes were seen as a continuation of ancient natural conditions and have found their way even into literary works of the Renaissance, like those by Shakespeare, who mentions earthquakes for example in Henry IV, Part I ("I say the earth did shake when I was born").

Ambraseys (2009) in his exhausting catalogue of earthquake events for the Mediterranean and the Middle East lists archaeological data, epigraphs and inscriptions as important sources for the analysis of past earthquake events. But he prefers the literary sources and states:

> *It is symptomatic of cultural changes since the First World War that, as instrumental, electronic or other mechanical reporting of events has grown, and news is increasingly disseminated by radio and television, a parallel decline is visible in both the volume and the quality of documentary and descriptive accounts of earthquakes in the twentieth century (Ambraseys, 2009).*

Kozák & Ebel (1996), in addition to that, suggest not to forget pictorial sources when assessing earthquake data (confer fig. 3):

> *The depictions of historic earthquakes provide some macroseismic information for reevaluating the intensities of the portrayed events. Furthermore, the depictions may be used to infer other macroseismic information, such as ground acceleration levels, soil amplification or liquefaction, and the amount of tsunami damage. In some cases, an analysis of the depictions could indicate the need to reclassify the sizes or locations of some historic earthquakes (Kózak & Ebel, 1996).*

For his catalogue Ambraseys writes about the European/Occidental sources that "for Classical, Roman and Byzantine times almost all the sources are well known, and they are relatively limited in number and mostly published" (Ambraseys, 2009). He writes that on top of that Arabic sources "have generally been identified and published", most of them being narrative histories. However, he claims, "little or no archival material survives from this early period". Ottoman sources are often connected to the cost for the repair or reconstruction of structures affected by the shock. Venetian sources, on the other hand, have a long period of observations, chiefly from coastal regions of the north-eastern part of the Mediterranean, thus adding reliable historical written material to earthquake catalogues.

During the second part of the twentieth century several scientists in developed countries realised that a new approach with respect to historical earthquakes had to be tried. In France, for example, it was Jean Vogt, who understood that historical seismicity needed a revision through a return *ad fontes* (cf. Vogt, 1979). He began to collect the original sources as far as available: periodicals, newspapers, administrative, notarial and family archives, and he did not stop short of libraries and archives of neighbouring countries. With regards to the need to identify smaller earthquake events, especially in regions with a low seismicity, Fréchet (2008) remarks:

> *Often, seismic catalogues concentrate only on the largest damaging earthquakes in a region, neglecting valuable information on foreshocks and aftershocks and on smaller events.*

And he carries on by asking for more enthusiasm from the people involved in hazard mitigation also with regards to the financial aspect:

> *For each event, it is necessary to make exhaustive use of all existing catalogues in order to identify the least trace of earthquake, aftershock, and background seismicity. Once an event date and location is known approximately, it is usually straightforward to search for original descriptions in newspapers, periodicals, etc., for the last three centuries at last (Fréchet, 2008).*

Fig. 3. Earthquake events in Rossanna and Constantinople, according to Hermann Gall, in the year 1556.

5. Criticism of the sources

But of course we are well aware of the fact that the quoting of "original" texts is often unprecise or even faulty. Many of the written sources have already been shortened, translated, paraphrased or compiled, thus distorting the information of the underlying primary sources. On top of that, some compilations may include mistakes like wrong datings. Sometimes compilations are a mixture of reliable and questionable data (e.g. Pfister, 1988; Glade et al., 2001 on that topic), as is especially the case with the "long" German catalogues of Central European earthquakes collected by Reindl (1903a, 1903b; Gießberger, 1922; Sieberg, 1940, see also Fig. 4).

An illustrative collection of problems when dealing with historical written sources is given by Kárník (1988):

> *In some cases storm effects, landslides or subsidences are reported as seismic phenomena. Another source of error is the wrong transcription of names of localities, or the case of some localities having identical or very similar names; as a consequence, earthquake epicentres have been moved to wrong places. 'New' earthquakes can originate simply by listing twice an event reported with the date given in different sources according to the Julian or the Gregorian calendar. Another source of similar manufacturing of earthquakes are errors in transcribing the dates, e.g. Jan.-June, VI-XI, etc. An opposite phenomenon may occur because of a long period of war, foreign occupation of a country, plague, or other reason for which the records either were not made or were destroyed, which results in an artificial interval of quiescence. It is imperative to work with the original reports as much as possible, but this is not easy because some old sources are not accessible to an investigator or have been destroyed or require special knowledge of language.*

The plausibility of the data can only be elicited by a thorough assessment of the data itself and a comparison of the data in question with established catalogues. In general, the co-operation of historians and geoscientists proves very valuable for the assessment of historical hazard data (Alexandre, 1990; Coeur et al., 1998), even if the majority of the historical documents only provide binominal data compared to the more valuable censored data of mostly younger documents (cf. Stedinger & Cohn, 1986).

As usual with historical data, several aspects regarding the quality of written sources need of course to be kept in mind (cf. e.g. Pfister & Hächler, 1991; Coeur et al., 1998; Fliri, 1998; Pfister, 1999; Glaser et al., 2002). The documents may differ greatly with regard to terminology, detail, educational background of the author etc. Many sources are not capable of providing all the data expected and needed for a thorough assessment of earthquakes. But the more different sources (or -later- archives) can be included, the more precise earthquake data will become overall. Excellent examples of the analysis of historical data are the publications of Galadini et al. (2001) about the Veronese earthquake of 1117, the work of Mucciarelli & Stucchi (2001) about disaster scenarios (or, for the general approach, e.g. Hammerl & Lenhardt, 1997 and Gisler et al., 2004). An up-to-date overview on German historical approaches is for example given by Grünthal (2004).

The past few hundred years have seen quite a large number of descriptive and parametric catalogues of historical earthquakes as a result of long-lasting archive work with written sources. Among the larger and exhaustive catalogues are the writings of Bonito (1691), Coronelli (1693), Seyfart (1756), whose catalogue is considered the first 'modern' catalogue (Fréchet 2008), Hoff (1840), and Milne (1911), as Ambraseys (2009) points out. In France for example major catalogue projects were undertaken from the 19th c. onwards, e.g. by Alexis Perrey (cf. Perrey, 1841), later came the global catalogue of Ferdinand Montessus de Ballore, completed in 1907 (Montessus de Ballore, 1904-1907), a process which is typical for most of the developed countries in Europe.

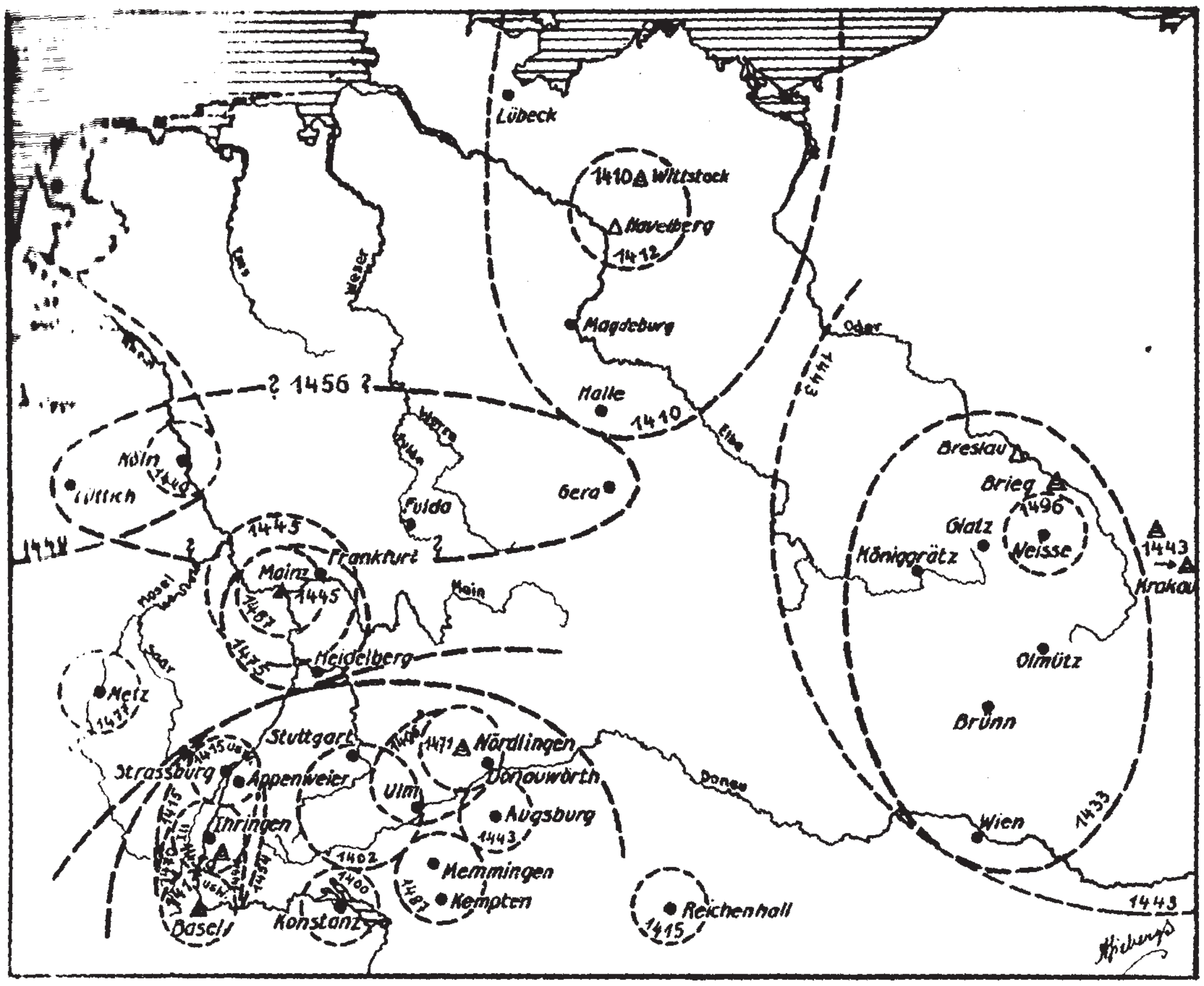


Fig. 4. Earthquakes in central Europe in the 15th century, according to Sieberg (1940).

6. Early modern attempts to collect written information on quake events, the case of Bavaria

Earthquakes which can be perceived in Bavaria are, in most cases, not "Bavarian" earthquakes *sensu stricto*. "Real" Bavarian earthquakes have usually been less severe so far, stronger events took place in the neighbouring countries Switzerland or Austria, sometimes also in Italy. Some of the earthquake events perceived in Northern Bavaria have occurred in what is today the Czech Republic. Kárník (1988) remarks that "the important role of historical data is most evident in regions of medium or low seismicity", just as is the case in Bavaria. In order to find out about the epicentres of historic earthquakes, the simplest way is to screen and assess historical documents, especially written documents.

Since a thorough assessment of historical documents (the value of which has been proven many times, foremost in the field of hydrology, cf. Stedinger & Cohn, 1986; Alexandre, 1987; Baker, 1987; to name only a few of the eminent publications on that topic) filed in the numerous archives all over the state of Bavaria would have proven too time-consuming and costly by far (cf. Coeur et al., 1998; Barnikel & Becht, 2004), a new way had to be found to gather as much relevant information as possible in a shorter period of time. Especially local archives, which have found to be among the most productive and important sources for documents describing hazardous natural events from the 1800s and older (cf. Barnikel & Becht, 2003) cannot be screened by natural scientists alone. Eventually, people with access to local documents, like librarians or historians, need to be encouraged to contribute to the growing data base as a kind of open-source catalogue.

7. The BASE-project as example for historical analysis

The old Bavarian earthquake catalogue lists four events from the 14th until the 17th century, the earliest one being the 1390 event in Bad Reichenhall. BASE adds 232 events from the 4th century until the 17th century, the oldest one being a (questionable) earthquake recorded in Memmingen in 369 AD. The past few centuries are of course much better represented in the data base than the older ones. The renaissance of natural sciences after the 1500s led to a more profound occupation with natural hazards. More people noted earthquakes and reported them. As a not surprising result we have more detailed information about quakes for the past few centuries than for the time before 1500. More than half of all events filed in the BASE-catalogue date back to the 18th and 19th centuries, whereas the 10th and 15th centuries are, astonishingly enough, only sparsely represented (see Kárník's remark above).

A more problematic part of the assessment was the inclusion of earthquakes mentioned only in maps of important publications (especially Sieberg, 1940, whose compilation is problematic enough – see also Fig. 4). Those maps are in general quite speculative and only in very few cases specific. But in order to get a complete picture of the seismic situation in Bavaria it was necessary to include events which were shown as relevant for Bavaria in these maps. This resulted in the inclusion of at least 232 different earthquakes (project BASE II).

Thus, in a first step all existing data about earthquakes felt in Bavaria needed to be collected. This step was limited to already published data in 27 crucial publications over the past two centuries (Perrey, 1844; Boegner, 1847; Volger, 1857; Credner, 1884; Gümbel, 1889; Langenbeck, 1892, Günther, 1897; Günther n.d.; Gümbel, 1898; Brunhuber, 1903; Reindl, 1903a, 1903b; Günther & Reindl, 1904; Reindl, 1905a, 1905b; Credner, 1907; Reindl, 1907; Heritsch, 1908; Messerschmitt, 1907; Gießberger, 1922; Sieberg, 1940; Sponheuer, 1952; Schmedes, 1979; Leydecker & Brüning, 1988; Wolf & Wolf, 1989; Bachmann & Schmedes, 1993; Schmedes et al., 1993). The data were filed in a specially designed data base (Fig. 5), which was modified from the one successfully used in the HANG-project about natural hazards in the Alps (Barnikel, 2004). A second, future step will be the inclusion of (validated) contributions made by citizens all over Bavaria who share an interest in earthquakes and have access to local publications or documents which may have been denied wider distribution in journals or other scientific publications and are, therefore, largely unknown.

Germany's standard earthquake catalogue was first published by Leydecker (1986) in the year 1986 (in parts based on the catalogue published by Grünthal, for example in 1988) and issued on behalf of the German Federal Institute for Geosciences and Natural Resources. It claimed full coverage for all quakes from intensity MSK-1964 IV (Sponheuer, 1965) upwards and listed about 1900 events with either their epicentres in Germany or with macroseismic

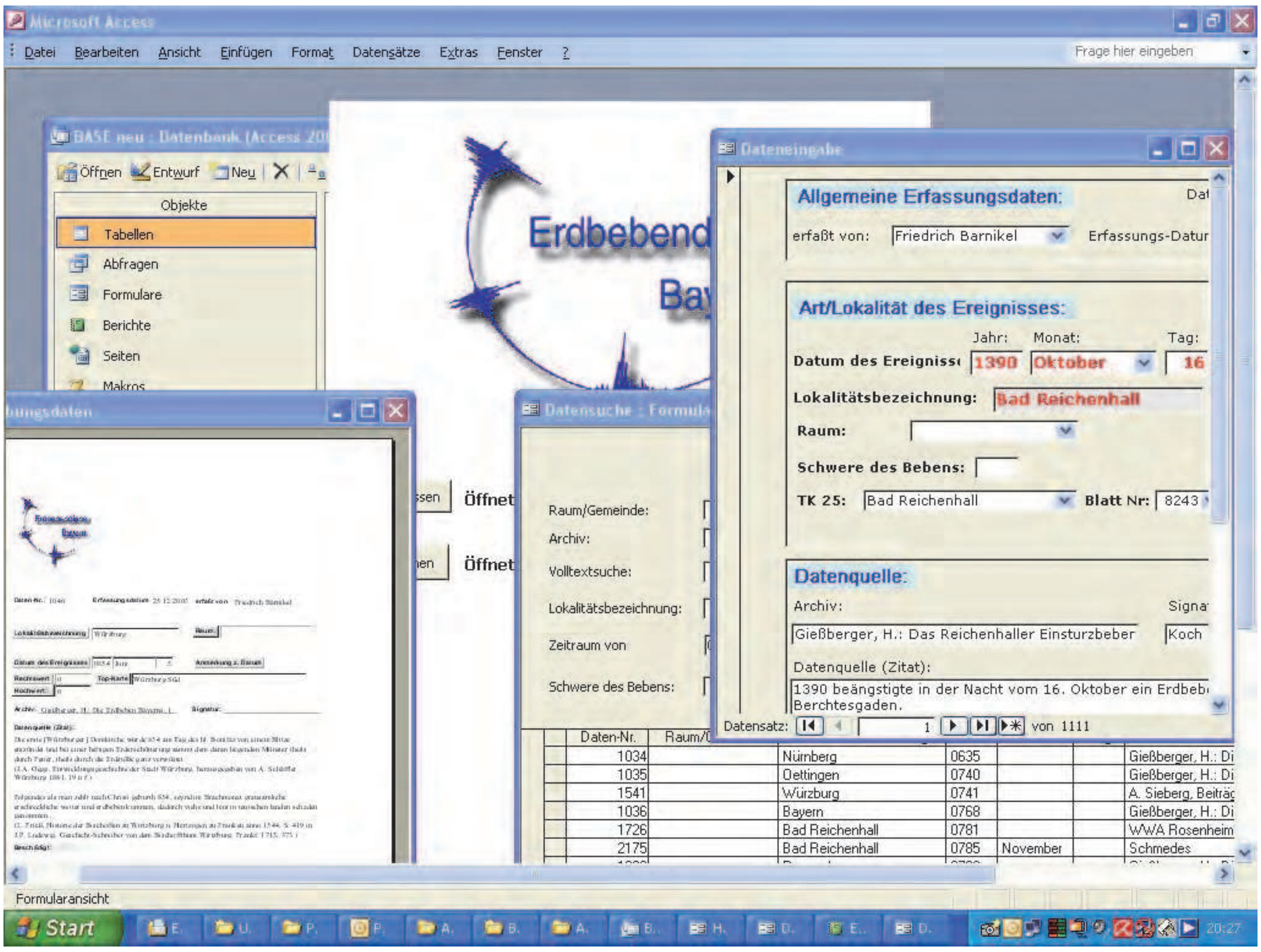


Fig. 5. BASE data bank, screenshot.

effects on Germany, but originating in neighbouring countries. Today it lists more than 2500 events relevant for Germany before 1906. Leydecker not only shaped the German earthquake catalogue, he also, together with his late colleague van Gils, issued the European earthquake catalogue with more than 8500 events (intensity IV and more) for the covered countries until 1906 (van Gils & Leydecker 1991). The latest addition of interest is the earthquake catalogue for southeastern Europe (Shebalin et al., 1998) with approximately 2000 events before 1906. Other important catalogues for earthquakes relevant for Bavaria are the Swiss catalogue (Swiss Seismological Service, 2002), the Austrian catalogue (Austrian Central Institute for Meteorology and Geodynamics, 2006) and the latest catalogue for central and northern Europe by Grünthal & Wahlström (2003). Between all catalogues slight discrepancies can be found, most of them regarding the precise location of the epicentre, its coordinates, the intensity and the corresponding radius. Even the Bavarian earthquake catalogue, although based on the German catalogue, shows some minor differences to the German catalogue.

Consequently all existing earthquake catalogues with possible relevance for Bavaria had to be screened in order to find more earthquake events to be included in the BASE data bank (Grünthal, 1988; Leydecker, 1986ff; Swiss Seismological Service, 2002; Shebalin et al., 1998; Austrian Central Institute for Meteorology and Geodynamics, 2006) and the Kövesligethy formula (see Equation 1) was used to determine the intensity of earthquakes from neighbouring countries. As a result all earthquakes with a calculated intensity of $I \geq 3$ (with $\alpha = 0{,}001$) for Bavaria were included.

$$I = Io - 3 \cdot \log(R/h) - 1.3 \cdot \alpha \cdot (R-h) \quad (1)$$

8. The application of early seismometers

In Bavaria the recording and scientific assessment of earthquakes is principally undertaken by the Department for Geo- and Environmental Sciences at the Ludwig-Maximilians-University of Munich and the Bavarian Environment Agency (together forming the Bavarian Seismological Service). Instrumental recording of earthquakes in Bavaria began with the 1000kg Wiechert seismometer in Munich-Bogenhausen in 1905. Today the Geophysical Observatory in Fürstenfeldbruck is the data centre for a modern digital seismological network in Bavaria.

An interesting finding when comparing pre-instrumental data with the seismographs from Bogenhausen is the difference of the geographical distribution of the earthquakes before 1905 and after. Before 1905 most earthquakes felt in Bavaria took place in either the Alps or the northern fringe of the Bohemian Forest. But a surprisingly high number of events happened all over central Europe with no apparent connection to the more active seismic regions. After 1905 we find quite a different picture, which obviously is connected to the installation of seismological stations in Bavaria, that were able to record also smaller earthquakes, "invisible" in the past. A large number of events was recorded for the Ries crater around Nördlingen, although most epicentres are still found in the Alps or the northern Bohemian Forest (cf. Barnikel & Geiss, 2008, who compare the two periods).

But even the introduction of seismometers does not mean highly precise earthquake data from that moment onwards.

Batlló (2008) points out that

> *in the early XX century, fundamental concepts of seismic source physics […] were yet to be discovered, as well as the benefits of computer technology and digital signal processing.*

9. An open source project to collect earthquake information

In order to complete the existing data base of historical earthquakes in Bavaria or relevant for Bavaria, the Bavarian Environment Agency has teamed up with the Department of Geography at the University of Munich, which offers expertise in historical assessment of natural hazards (see Barnikel & Becht, 2004). The project BASE (Bavaria's Seismicity in Historical Documents), which is currently running in its ninth year, works with historical written documents and all information about earthquakes relevant for Bavaria stored in them. The first two parts of the project (BASE I and II) dealt with the inclusion of data from already published literature, the current parts (BASE-NET and BASE20) are aiming at the inclusion of earthquake data from original written documents (letters, postcards, etc.) and the setting up of an internet website to enable interested and informed citizens of Bavaria to contribute to the data base in the future.

Of special importance in this context, when working with historical written sources, is always the exact quotation of the written texts to ensure accessibility for later evaluations. BASE links the data on the event to other researched material, like pictures or maps. The data was then compared with the data in the German and European catalogues and, if necessary, adjusted (with regards to time, coordinates etc.). Important for the data files are descriptions of the impact an earthquake had on the society. The more details about damages or destructions we get, the more accurate our intensity estimations will later become. Therefore, all the data have been graded after the new EMS-98-Intensity-Scale (Grünthal, 1998), which allows a direct comparison of data from different centuries and of data from different documentary sources.

Some examples of historical written data may illustrate the particular problems and chances of working with this kind of sources in the BASE-project: "In the year 740 AD the Earth trembled so much in the Swabian Countries for almost a year that many monasteries and churches collapsed" (after Gießberger, 1922). This text was found in a manuscript from 1723, therefore at least a second-hand source. Even if authors often used to simply copy older texts without changing them, a description of an earthquake almost a thousand years later is highly problematic (see Barnikel, 2004, who deals at length with this topic). The nature of the information is also doubtful. The destruction of numerous churches and monasteries (some of them certainly wooden structures as were common in these times) sounds improbable. In addition to that, no other known source recorded that many devastating earthquakes in that year in Bavaria. The validity of this source, as a result, remains very poor.

Several sources were found for a suspected earthquake in 841 AD in Würzburg (after Boegner, 1847; Gießberger, 1922; Sieberg, 1940; the mentioned sources date back to e.g. 1578, 1644, 1692 and 1756 respectively): "AD 841 an earthquake hit the town of Würzburg about twenty times and with it came terrible hail and a great storm", depicting the ancient belief that earthquakes were connected to atmospheric events. Judging from the text the event in question sounds more like a heavy storm which shook the buildings and inhabitants of Würzburg and is nowadays considered to be a fake. These "original" sources, used in the secondary sources exploited by the BASE-project, are of course hardly precise and valid, since they cannot be considered as contemporary (real contemporary sources being very rare and far between). Often sources like these make use of data already written down in older documents, thus only quoting other sources and thereby adding "new" evidence where there is none (cf. the exemplary analysis of a series of earthquakes in southern Germany found to be fakes by Grünthal & Fischer, 2001), or just mix up the dates, as is the case with earthquakes listed after either the Julian or the Gregorian calendar (as for example Grünthal & Wahlström (2003) point out; also see chapter 5).

Much more precise and valid in general are understandably younger documents, one example being an earthquake in 1889: "On February 22nd, 2 o'clock and 40 minutes in the afternoon, a heavy blow sounded, which was accompanied by a short rolling sub-surface, so that the windows clattered in many houses. This blow seemed to move from W to E. In the lower part of town the same was felt so heavily that the inhabitants of the surrounding streets ran terrified onto the streets." This information appears not only much more reliable, it is also very precise in terms of date, time, place, process and effect. It is especially this kind of source we need to specify an earthquake.

The BASE-project so far was able to collect a total of 516 events which were perceived and, consequently, recorded in Bavaria. Astonishing enough is the fact that about 76% of these events could not be linked to a specific date or place from the earthquake catalogues of the surrounding areas (the European earthquake catalogue by van Gils & Leydecker (1991) or the German earthquake catalogue by Leydecker (1986ff.), although quite a few events must be considered fakes, especially when just mentioned by a few (or only one) sources. Only 122 earthquake epicentres in addition to the 24 events already listed in the Bavarian earthquake catalogue could be specified. Most of these events took place in either Switzerland (23%) or Austria (16%), just under 10% in the German state of Baden-Württemberg, the Czech Republic or Italy respectively. The large number of uncertain epicentres for earthquakes felt in Bavaria is nevertheless puzzling, but so is the fact that both, the German and the European catalogue, list a significant different number of German quakes with the same intensity span for the time period up to 1905. The European catalogue mentions 1019 events in Germany before 1906, the German catalogue 1821.

In total a number of 1673 references to earthquakes in Bavaria for the time up to 1905 have been collected. For these references date, time, location, quotation, details about the earthquake itself, damages and other crucial information are listed in the data base. The exceptions are of course those earthquakes which have been extracted from maps, where no further information from within Bavaria could be found. These earthquakes are attributed to their origin outside Bavaria and are listed in the data base under the names of Bavarian cities and towns on the maps.

10. Outlook from the BASE-Project

As a result, data from the BASE-project are useful with regard to several aspects (cf. Barnikel et al. 2009):

- The data is compiled in a catalogue which in the future can be accessed by every user via internet. It is not only a valuable tool for specialists, it also helps the public understand geodynamics better.
- The catalogue can be enlarged and improved by citizens, thus including more man-power in scientific research and showing the public that everybody can contribute to the betterment of science and society, as an open-source project it will be a kind of Web 2.0-try to link science and public (project BASE-NET).
- This step will produce new pieces of information from areas which have not produced earthquake reports so far. Hopefully this will help to judge the tentative records only based on maps or mathematic calculations so far.
- The data will help us to calibrate existing catalogues, especially the Bavarian catalogue, and should serve as a model for the calibration of other existing catalogues.
- The list of known earthquakes will be prolonged significantly and so provide a basis for future risk modelling.

Another step, as mentioned above, will be the inclusion of (validated) contributions made by citizens all over Bavaria who share an interest in earthquakes and have access to local publications or documents which may have been denied wider distribution in journals or other scientific publications and are, therefore, largely unknown. Of course a *caveat* must be kept in mind, namely that "the tendency of some chroniclers to attract attention by exaggerating of manufacturing information is known" (Kárník, 1988).

The figure of unknown earthquake-epicentres remains a problem that needs to be solved. The inclusion of data from local archives is, consequently, of utmost importance. The future presentation of the BASE-DB on the web (www.erdbeben-in-bayern.de) is an important step to reach this goal and serves as an example for other catalogues. The inclusion of the original text sources is crucial in this respect, because it allows later adjustment and validation. But a future assimilation of the existing catalogues from the different European countries will also be important. The BASE-project collects, in addition to that, written data for events after 1905 in a second step. A comparison between the written sources and instrumental data from the seismometre may prove useful for the calibration of older written data. Another step should be an examination, how reliability scales (cf. Papadopoulos et al., 2000) could be used to classify the reliability of the historical earthquakes collected by BASE and the implementation of indicative magnitude values (cf. Sibol et al., 1987; Cavallini & Rebez, 1996; Papazachos & Papaioannou, 1997) could be valuable. In the end the catalogue should then be ready to be used in further scientific studies about earthquakes in southern Germany.

In general, earthquake catalogues need to be screened for double entries and uncertain data. In Europe a lot of promising steps have already been undertaken in that direction. Further historical studies can enormously contribute to a more precise analysis of the seismic situation of a region. The cooperation with historians might prove useful as is the microfilming and scanning of historical seismograms worldwide (cf. Lee & Benson, 2008). Especially since the teleseismic instrumental recording dates back to 1889, as Stein et al. (1988) point out. And the expansion of the now existing Global Digital Network of seismic stations will support a much more reliable assessment of earthquake events in the future (cf. Beck, 1996). Especially in regions with low seismicity a data sample covering at least several centuries is highly recommended for the understanding of earthquake generating processes, even if "historical information is normally not suitable for statistical processing because its homogeneity can be rarely guaranteed" (see Kárník, 1988). A result can be a seismic risk map including all sorts of entries, as the impressive work of Tyagunov et al. (2006) shows, and catalogues that are consistent, complete and, in the best of cases, merged across political boundaries (Bayliss & Burton, 2007).

11. Acknowledgment

The authors want to thank the Bavarian Environment Agency for funding the BASE-project.

12. References

Alexandre, P. (1987). Le Climat en Europe au Moyen Age, In: *Recherches d'histoire et de sciences sociales,* Vol. 24, ISSN 0249-5619

Alexandre, P. (1990). *Les séismes en Europe occidentale de 394 à 1259 – Nouveau catalogue critique.* Communications Observatoire Royal de Belgique, Série Géophysique, Brussels, Belgium

Ambraseys, N. (2009). *Earthquakes in the Mediterranean and Middle East*, Cambridge University Press, ISBN 978 0 521 87292 8, Cambridge, UK

Austrian Central Institute for Meteorology and Geodynamics (Ed.) (2006). *Katalog des Österreichischen Erdbebendienstes der ZAMG*, Avaiable from http://www.zamg.ac.at

Bachmann, C. & Schmedes, E. (1993). Ein Schadensbeben in Neuhausen, Landkreis Landshut am 7. Februar 1822 – eine Zeitungsente, In: *Z. angew. Geol.,* Vol.39, No.2, (1993), pp. 106-107, ISSN 0044-2259

Baker, V.R. (1987). Paleoflood hydrology and extraordinary flood events, In: *Journal of Hydrology,* Vol.96, pp. 79-99, ISSN 0022-1694

Barnikel, F. & Becht, M. (2003). A historical analysis of hazardous events in the Alps – the case of Hindelang (Bavaria, Germany). In: *Natural Hazards and Earth System Sciences*, Vol.3., No.6, pp. 625-635, ISSN 1561-8633

Barnikel, F. (2004). Analyse von Naturgefahren im Alpenraum anhand historischer Quellen am Beispiel der Untersuchungsgebiete Hindelang und Tegernseer Tal, Bayern, In: *Göttinger Geographische Abhandlungen,* Vol. 111, Göttingen, Germany, 210 pp., ISSN 0341-3780

Barnikel, F. & Becht, M. (2004). Möglichkeiten einer Bewertung des regionalen Gefährdungspotentials auf der Basis historischer Naturgefahrenforschungen. In: Geomorphologische und hydrologische Naturgefahren in Mitteleuropa, Becht, M. & Damm, B. [Eds.] *Zeitschrift für Geomorphologie,* N.F., Supplement Vol. 135, pp.1-10, ISSN 0372-8854

Barnikel, F. & Geiss, E. (2008). The BASE-Project – An open-source catalogue for earthquakes in Bavaria, Germany. In: *Natural Hazards and Earth System Sciences,* Vol.8, No.6, pp. 1395-1401, ISSN 1561-8633

Barnikel, F.; Vetter, M.; Geiss, E.; Frank, C. & Witossek, G. (2009). Bavaria's Seismicity in Historical Documents, Extended Abstracts, *6th European Congress on Regional Geoscientific Cartography and Information Systems (München)*, pp. 312-315, München, Germany, June 9-12, 2009

Battló, J.; Stich, D. & Macià, R. (2008). Quantitative Analysis of Early Seismograph Recordings. In: *Historical Seismology (modern Approaches in Solid Earth Sciences)*, Fréchet, J., M. Meghraoui & M. Stucchi (Eds.), 385-402, Springer, ISBN 978-1-4020-8221-4, Heidelberg, Germany

Bayliss, T.J. & Burton, P.W. (2007). A New Earthquake Catalogue for Bulgaria and the Conterminous Balkan High hazard Region, In: *Natural Hazards and Earth System Sciences,* Vol.7, pp. 345-359, ISSN 1561-8633

Beck, S. (1996). Introduction to the Topical Section on Historic Earthquakes, *Pure and Applied Geophysics*, Vol.146, No.1, pp. 3-4, ISSN 0033-4553

Boegner, J. (1847). *Das Erdbeben und seine Erscheinungen – Nebst einer chronologischen Uebersicht der Erderschütterungen im mittleren Deutschland vom 8. Jahrhundert bis auf die neueste Zeit und ihres Zusammenhanges mit vulkanischen Erscheinungen in entfernten Ländern*, Frankfurt a.M., Germany

Bolt, B.A.; Horn, W.L.; Macdonald, G.A. & Scott, R.F. (1975): *Geological Hazards*, Cambridge University Press, ISBN 3-540-06948-8, Cambridge, UK

Bonito, M. (1691). *Terra tremante*, Naples, Italy

Brunhuber, A. (1903). Zwei Erdbeben im Gebiete der Oberpfalz, *Berichte des naturwissenschaftlichen Vereins zu Regensburg*, Vol.9, No.2, pp. 1-14

Cavallini, F. & Rebez, A. (1996). Representing earthquake intensity-magnitude relationship with a nonlinear function, *Bulletin of the Seismological Society of America*, Vol.86, No.1A, pp. 73-78, ISSN 0037-1106

Coeur, D.; Lang, M.; Naulet, R.; Burnet, R. & Strazzeri, D. (1998). Histoire et connaissance des phénomenes naturels extremes. *Ingénieres-EAT*, pp. 15-26

Coronelli, P. (1693). Epitome cosmografica: delle cause de' tremuoti, Cologne, Germany

Credner, H. (1884). Die erzgebirgisch-vogtländischen Erdbeben während der Jahre 1878 bis Anfang 1884. *Zeitschrift für Naturwissenschaften*, Vol.57, pp. 1-29

Credner, H. (1907). Die Sächsischen Erdbeben während der Jahre 1904 bis 1906, Aus den Berichten der mathematisch-physischen Klasse der Königlich Sächsischen Gesellschaft der Wissenschaften zu Leipzig, Vol.59, pp. 333-355

Dewey, J. & Byerly, P. (1969). Earthquake Monitoring. *Bulletin of the Seismological Society of America,* Vol.59, No.1, pp 183-227, ISSN 0037-1106

Eiby, G.A. (1988). Documenting New Zealand Earthquakes. *Historical Seismograms and Earthquakes of the World*, Lee, W.H.K.; H. Meyers & Shimazaki, K. (Eds.), 232-240, ISBN 0-12-440870-2, San Diego, USA

Fliri, F. (1998). *Naturchronik von Tirol*, Wagner, ISBN 3-7030-0313-8, Innsbruck, Austria

Fréchet, J. (2008). Past and Future of Historical Seismicity Studies in France. In: *Historical Seismology (modern Approaches in Solid Earth Sciences)*, Fréchet, J., M. Meghraoui & M. Stucchi (Eds.), 131-145, Springer, ISBN 978-1-4020-8221-4, Heidelberg, Germany

Galadini, F.; Galli, P.; Molin, D. & Ciurletti, G. (2001). Searching for the source of the 1117 earthquake in northern Italy: A multidisciplinary approach. In: *The Use of Historical Data in Natural Hazard Assessments, Advances in Natural and Technological Hazards Research*, Glade, T., Albini, P. and Francés, F. (Eds.), 3-27, Kluwer, ISBN 0792371542, Dordrecht, Netherlands

Gießberger, H. (1922). Die Erdbeben Bayerns I. Teil. *Abhandlungen der Bayer. Akad. der Wissenschaften Mathematisch-Physikalische Klasse,* Vol.29, No.6

Gisler, M.; Fäh, D. & Kästli, P. (2004). Historical Seismicity in Central Switzerland. *Eclogae geo. Helv.,*Vol. 97, pp. 221-236, ISSN 0112-9402

Glade, T., Albini, P. & Francés, F. (Eds.) (2001). *The Use of Historical Data in Natural Hazard Assessments. Advances in Natural and Technological Hazards Research*, Kluwer, ISBN 0792371542, Dordrecht, Netherlands

Glaser, R.; Jacobeit, J.; Deutsch, M. & Stangl, H. (2002). Hochwasser als historisches Phänomen. *Rundgespräche der Kommission für Ökologie*, Vol. 24, pp. 15-30, ISSN 0938-5851

Grünthal, G. (1988). Erdbebenkatalog des Territoriums der Deutschen Demokratischen Republik und angrenzender Gebiete von 823 bis 1984, *Veröffentlichungen des Zentralinstituts für Physik der Erde,* Vol. 99, ISSN 0514-8790

Grünthal, G. (Ed.) (1998). European Macroseismic Scale 1998. *Cahiers du Centre Européen du Géodynamique et de Séismologie,* Vol.15, ISSN 1340-4202

Grünthal, G. & Fischer, J. (2001). Eine Serie irrtümlicher Schadenbeben im Gebiet zwischen Nördlingen und Neuburg an der Donau vom 15. bis zum 18. Jahrhundert. *Mainzer naturwissenschaftliches Archiv* Vol. 39, pp. 15-32, ISSN 0542-1535

Grünthal, G. & Wahlström, R. (2003). An earthquake catalogue for central, northern and northwestern Europe based on MW magnitudes, Avaible from http://www-app1.gfz-potsdam.de/catalog/index.html

Grünthal, G. (2004). The history of historical earthquake research in Germany. *Annals of Geophysics,* Vol. 47, No. 2/3, pp. 631-643, ISSN 1593-5213

Gümbel, C.W. (1889). Das Erdbeben vom 22. Februar 1889 in der Umgegend von Neuburg a.D. *Aus den Sitzungsberichten der mathematisch-physikalischen Classe der k. bayer. Akad. der Wiss.*, Vol. 19, No. 1, pp. 79-108

Gümbel, C.W. (1898): Ueber die in den letzten Jahren in Bayern wahrgenommenen Erdbeben. *Aus den Sitzungsberichten der mathematisch-physikalischen Classe der k. bayer. Akad. der Wiss.*, Vol. 28., pp. 3-18

Günther, S. (1897). Das bayerisch-böhmische Erdbeben vom Jahre 1329, *Jahresbericht der Geographischen Gesellschaft*, Vol. 17, pp. 76-88

Günther, S. (n. d.) : Münchener Erdbeben- und Prodigienlitteratur in älterer Zeit, *Jahrbuch für Münchener Geschichte*, Vol. 4, No. 15, pp. 234-256

Günther, S. & Reindl, J. (1904). Seismologische Untersuchungen. *Aus den Sitzungsberichten der mathematisch-physikalischen Classe der k. bayer. Akad. der Wiss.*, Vol. 33, No. 4, pp. 631-671

Hammerl, C. & Lenhardt, W. (1997). *Erdbeben in Österreich*, Leykam Verlag, ISBN 3701173346, Wien, Austria

Heritsch, F. (1908). Über das Mürztaler Erdbeben vom 1. Mai 1885, *Mitteilungen der Erdbeben-Komission der Kaiserlichen Akademie der Wissenschaften in Wien*, Vol. 32

Hoff, K.E. von (1840). Geschichte der natürlichen Veränderungen der Erdoberfläche, Chronik der Erdbeben und Vulkanausbrüche, Gotha, Germany

Kárník, V. (1988). Compilation and Processing of Historical Data: Summary Remarks. In: *Historical Seismograms and Earthquakes of the World*, Lee, W.H.K.; H. Meyers & Shimazaki, K. (Eds.), 139-141, ISBN 0-12-440870-2, San Diego, USA

Kozák, J. & Ebel, J.E. (1996). Macroseismic Information from Historical Pictorial Sources, *Pure and Applied Geophysics,* Vol. 146, No. 1, pp. 103-111, ISSN 0033-4553

Langenbeck, R. (1892). Die Erdbebenerscheinungen in der oberrheinischen Tiefebene und ihrer Umgebung. In: *Geographische Abhandlungen aus den Reichslanden Elsass-Lothringen,* Gerland, G. (Ed.), Stuttgart, pp. 1-120, 1892.

Lee, W.H.K. & Benson, R.B. (2008). Making Non-Digitally-Recorded Seismograms Accessible Online for Studying Earthquakes. In: *Historical Seismology (modern Approaches in Solid Earth Sciences)*, Fréchet, J., M. Meghraoui & M. Stucchi (Eds.), 402-412, Springer, ISBN 978-1-4020-8221-4, Heidelberg, Germany

Leydecker, G., (1986). Erdbebenkatalog für die Bundesrepublik Deutschland mit Randgebieten für die Jahre 1000-1981, *Geol. Jb.*, Vol. E 36, 83 pp., ISSN 0016-7800, avaible from http://www.bgr.bund.de

Leydecker, G. & Brüning, H.J. (1988). Ein vermeintliches Schadenbeben im Jahre 1046 im Raum Höxter und Holzminden in Norddeutschland – Über die Notwendigkeit des Studiums der Quellen historischer Erdbeben, *Geol. Jb.*, Vol. E 42, pp. 119-125, ISSN 0016-7800

Messerschmitt, J.B. (1907). Die Erdbeben in Bayern 1905 bis 1907, *Die Erdbebenwarte*, Vol. 4, pp. 94-96

Milne, J. (1911). Catalogue of Destructive Earthquakes AD 7 to AD 1899, *British Association for the Advancement of Science, Seismology Reports*, Vol. 80, pp. 694-740

Montessus de Ballore, F. de (1904-1907). Ephémérides sismiques et volcaniques, *Ciel et Terre*, pp. 24-28

Mucciarelli, M. & Stucchi, M. (2001). Expeditious seismic damage scenarios based on intensity data from historical earthquakes. In: *The Use of Historical Data in Natural Hazard Assessments, Advances in Natural and Technological Hazards Research*, Glade, T., Albini, P. and Francés, F. (Eds.), 3-27, Kluwer, ISBN 0792371542, Dordrecht, Netherlands

Papadopoulos, G.; Vassilopoulou, A & Plessa, A. (2000). Historical Earthquakes and Tsunamis in the Corinth Rift, Central Greece, *Institute of Geodynamics - National Observatory of Athens*, Vol. 12, pp. 9-120

Papazachos, C. & Papaioannou, Ch. (1997). The macroseismic field of the Balkan area, *Journal of Seismology*, Vol. 1, ISSN 1735-1669

Perrey, A. (1841). Tremblements de terre dans les différentes siècles et aux différentes époques de l'année, *Comptes Rendus hebdomadaires des séances de l'Académie des Sciences*, Vol. 12, pp. 1185-1187

Perrey, A. (1844). *Mémoire sur les Tremblements de Terre resentis en France, en Belgique et en Hollande,* Bruxelles, Belgium

Pfister, C. (1988). *Das Klima der Schweiz von 1525-1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft.* Academia Helvetica 6, Haupt, ISBN 3-258-03956-9, Bern, Switzerland

Pfister, C. & Hächler, S. (1991). Überschwemmungskatastrophen im Schweizer Alpenraum seit dem Spätmittelalter, *Würzburger Geographische Arbeiten*, Vol. 80, pp. 127-148, ISSN 0510-9833

Pfister, C. (1999). *Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen*, Haupt, ISBN 3-258-05696-X, Bern, Switzerland

Prachuab, S. (1988). Historical Earthquakes of Thailand, Burma, and Indochina. In: *Historical Seismograms and Earthquakes of the World*, Lee, W.H.K.; H. Meyers & Shimazaki, K. (Eds.), 253-266, ISBN 0-12-440870-2, San Diego, USA

Reicherter, K.; Michetti, A.M. & Silva, P.G. (Eds.) (2009). Palaeoseismology: Historical and Prehistorical Records of Earthquake Ground Effects for Seismic Hazard Assessment, *Geological Society Special Publication*, Vol. 316, ISSN 0305-8719

Reindl, J. (1903a). Beiträge zur Erdbebenkunde von Bayern, *Aus den Sitzungsberichten der mathematisch-physikalischen Klasse der Kgl. Bayer. Akademie der Wissenschaften*, Vol. 33, No. 1, pp. 171-203

Reindl, J. (1903b). Die Erdbeben der geschichtlichen Zeit im Königreiche Bayern, *Die Erdbebenwarte*, Vol. 2, pp. 235-243

Reindl, J. (1905a). Die Erdbeben Nordbayerns, *Abhandlungen d. Naturh. Gesellsch.*, Vol. 15, No. 3., pp. 3-46

Reindl, J. (1905b). Ergänzungen und Nachträge zu v. Gümbels Erdbebenkatalog, *Aus den Sitzungsberichten der mathematisch-physikalischen Klasse der Kgl. Bayer. Akademie der Wissenschaften*, Vol. 35, No. 1, pp. 31-68

Reindl, J. (1907). Die Erdbeben Bayerns im Jahre 1904, *Die Erdbebenwarte*, Vol. 4, pp. 178-184

Schmedes, E. (1979). Die seismische Aktivität im Raum Bad Reichenhall, *Geol. Jb.*, Vol. C 22, pp. 91-101, ISSN 0016-7800

Schmedes, E.; Loibl, R. & Gebrande, H. (1993). Ein Schadensbeben in Regensburg am 8. Februar 1062 – eine Fehlinterpretation historischer Quellen, *Z. angew. Geol.*, Vol. 39, No. 2, pp. 103-105, ISSN 0044-2259

Seyfart, F. (1756). *Allgemeine Geschichte der Erdbeben.* Frankfurt, Germany

Shebalin, N.V.; Leydecker, G.; Mokrushina, N.G.; Tatevossian, R.E.; Erteleva, O.O. & Vassiliev, V.YU. (1998). Earthquake Catalogue for Central and Southeastern Europe 342 BC - 1990 AD, Final Report to Contract ETNU - CT 93 – 0087. Avaible from http://www.bgr.bund.de

Sibol, M.; Bollinger, G. & Birch, J. (1987). Estimation of magnitudes in central and eastern North America using intensity and felt area, *Bulletin of the Seismological Society of America*, Vol. 77, No. 5, pp. 1635-1654, ISSN 0037-1106

Sidorin, A Ya. (2002). Search for Earthquake Precursors in Multidisciplinary Data Monitoring of Geophysical and Biological Parameters, *Natural Hazards and Earth System Sciences*, Vol. 3, pp. 153-158, ISSN 1561-8633

Sieberg, A., (1940). Beiträge zum Erdbebenkatalog Deutschlands und angrenzender Gebiete für die Jahre 58 bis 1799, *Mitteilungen des Deutschen Reichs-Erdbebendienstes*, Vol. 2, 111 pp.

Sponheuer, W. (1952). Erdbebenkatalog Deutschlands und der angrenzenden Gebiete für die Jahre 1800 bis 1899, Deutsche Akademie der Wissenschaften, *Mitteilungen des Deutschen Erdbebendienstes*, Vol. 3

Sponheuer, W. (1965). Bericht über die Weiterentwicklung der seismischen Skala, *Veröffentlichungen des Institutes für Geodynamik*, Vol. 8, ISSN 0448-942X

Srivastava, H.N. & Das, S.K. (1988). Historical Seismicity and Earthquake Catalogues for the Indian Region. *Historical Seismograms and Earthquakes of the World*, Lee, W.H.K.; H. Meyers & Shimazaki, K. (Eds.), 335-348, ISBN 0-12-440870-2, San Diego, USA

Stedinger, J.R. & Cohn, T.A. (1986). Flood frequency analysis with historical and paleoflood information, *Water Resources Research*, Vol. 22, No. 5, pp. 785-793, ISSN 0043-1397

Stein, S.; Okal, E.A. & Wiens, D.A. (1988): Application of Modern Techniques to Analysis of Historical Earthquakes. *Historical Seismograms and Earthquakes of the World*, Lee, W.H.K.; H. Meyers & Shimazaki, K. (Eds.), 85-104, ISBN 0-12-440870-2, San Diego, USA

Swiss Seismological Service (Ed.) (2002). ECOS - Earthquake Catalog of Switzerland, ECOS Report to PEGASOS, Version 31.3.2002, avaible from: http://www.seismo.ethz.ch

Tyagunov, S.; Grünthal, G.; Wahlström, R.; Stempniewski, L. & Zschau, J. (2006). Seismic Risk Mapping for Germany, *Natural Hazards and Earth System Sciences*, Vol. 6, pp. 573-586, ISSN 1561-8633

Van Gils, J.M. & Leydecker, G., 1991. Catalogue of European earthquakes with intensities higher than 4, Bundesanstalt für Geowissenschaften und Rohstoffe BGR, avaible from: http://www.bgr.bund.de

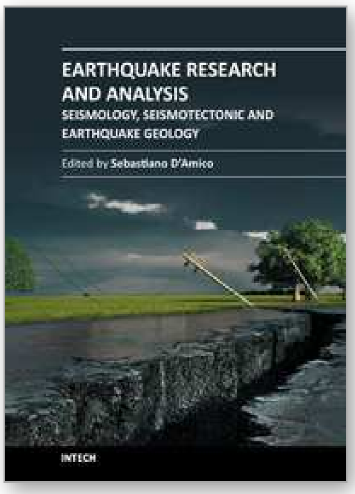
Vogt, J. (1979). Les tremblements de terre en France, *Mémoire du Bureau de Recherches Géologiques et Minières*, Vol. 96, ISSN 0071-8246

Volger, O. (1857). *Untersuchungen über das Phänomen der Erdbeben in der Schweiz, Erster Theil: Chronik der Erdbeben in der Schweiz*, Gotha, Germany

Wolf, P. & Wolf, H. (1989). Das Erdbeben in Regensburg von 1062 – Wirklichkeit oder wissenschaftliches Phantom? *Die Oberpfalz*, Vol. 77, No. 2, pp. 35-43, ISSN 0342-9873

Xie, Y. (1988): Historical materials of Chinese Earthquakes and Their Seismological Analysis. In: *Historical Seismograms and Earthquakes of the World*, Lee, W.H.K.; H. Meyers & Shimazaki, K. (Eds.), 162-170, ISBN 0-12-440870-2, San Diego, USA

Zeilinga de Boer, J. & Sanders, D.T. (2005). *Earthquakes in Human History,* Princeton University Press, ISBN 9780691050706, Princeton, USA



Earthquake Research and Analysis - Seismology, Seismotectonic and Earthquake Geology
Edited by Dr Sebastiano D'Amico

ISBN 978-953-307-991-2
Hard cover, 370 pages
Publisher InTech
Published online 08, February, 2012
Published in print edition February, 2012

This book is devoted to different aspects of earthquake research. Depending on their magnitude and the placement of the hypocenter, earthquakes have the potential to be very destructive. Given that they can cause significant losses and deaths, it is really important to understand the process and the physics of this phenomenon. This book does not focus on a unique problem in earthquake processes, but spans studies on historical earthquakes and seismology in different tectonic environments, to more applied studies on earthquake geology.