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Introduction to thematic collection "Historical and geological studies of earthquakes"

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Abstract

This thematic collection contains eight papers mostly presented at the 2016 AOGS meeting in Beijing. Four papers describe historical earthquake studies in Europe, Japan, and China; one paper uses modern instrumental data to examine the effect of giant earthquakes on the seismicity rate; and three papers describe paleoseismological studies using tsunami deposit in Japan, marine terraces in Philippines, and active faults in Himalayas. Hammerl (Geosci Lett 4:7, 2017) introduced historical seismological studies in Austria, starting from methodology which is state of the art in most European countries, followed by a case study for an earthquake of July 17, 1670 in Tyrol. Albini and Rovida (Geosci Lett 3:30, 2016) examined 114 historical records for the earthquake on April 6, 1667 on the east coast of the Adriatic Sea, compiled 37 Macroseismic Data Points, and estimated the epicenter and the size of the earthquake. Matsu'ura (Geosci Lett 4:3, 2017) summarized historical earthquake studies in Japan which resulted in about 8700 Intensity Data Points, assigned epicenters for 214 earthquakes between AD 599 and 1872, and estimated focal depth and magnitudes for 134 events. Wang et al. (Geosci Lett 4:4, 2017) introduced historical seismology in China, where historical earthquake archives include about 15,000 sources, and parametric catalogs include about 1000 historical earthquakes between 2300 BC and AD 1911. Ishibe et al. (Geosci Lett 4:5, 2017) tested the Coulomb stress triggering hypothesis for three giant (M~9) earthquakes that occurred in recent years, and found that at least the 2004 Sumatra–Andaman and 2011 Tohoku earthquakes caused the seismicity rate change. Ishimura (2017) re-estimated the ages of 11 tsunami deposits in the last 4000 years along the Sanriku coast of northern Japan and found that the average recurrence interval of those tsunamis as 350–390 years. Ramos et al. (2017) studied ~ 1000-year-old marine terraces on the west coast of Luzon Island, Philippines, and interpreted that coral boulder on top of the terrace was transported by the tsunami. Arora and Malik (Geosci Lett 4:19, 2017) compiled the paleoseismological data from trenches excavated along the Himalaya arc and argued that grouping of multiple events occurring within several decades would lead to an overestimation of seismic hazard scenario.

Introduction

Large earthquakes cause human and property damages. Earthquake occurrence rate, called seismicity, is high in some countries such as Japan and damaging earthquakes have occurred more frequently than in other countries such as Austria. Typical recurrence interval of large or great earthquakes at particular places is usually long, more than several decades. Modern seismological observations started about a century ago, and the instrumental data are limited only for the last 100 years at maximum. Therefore, use of non-instrumental seismological data such as historical or geological data is essential to study earthquakes in the past, to estimate the recurrence characteristics, and to contribute to the completeness and correctness of the earthquake catalog, which is the basis for seismic hazard analysis.

The thematic collections contain eight papers on historical and geological studies of earthquakes. Most of them were presented at the session SE 05 "Paleo- & Historical Earthquake Research and Quantitative Analysis of

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Seismicity" at the 13th annual meeting of AOGS held in Beijing in August 1–5, 2016. Four papers describe historical earthquake studies based on historical documents, one paper is on instrumental data, and three papers are on paleoseismology using geological methods. In the following, we briefly describe the methodologies and contents of each paper.

Historical seismology

Historical seismology, unlike conventional seismology based on instrumental data, uses historical documents, preferably contemporary sources, to study earthquakes in the past. Many countries in Europe or Asia have long written history, and historians use such documents to study human history. Such historical documents contain descriptions of past earthquake damages, and they can provide important scientific information on past earthquakes. In order to best utilize such historical materials and examine their reliability, seismologists often need to collaborate with historians. Here we have four papers describing background, case studies, and history of historical seismology in Europe and Asia.

Hammerl (2017) introduced historical seismological studies in Austria, a typical country in central Europe where seismicity is relatively low and damaging earthquakes occur on average once in several years to several decades. In such countries, studying historical earthquakes is important particularly for the planning and construction of new nuclear power plants or designing building codes such as the EUROCODE. She first described methodology of historical earthquake studies which is state of the art in most European countries and can be applied to other countries. The first step is to establish "family trees" of literature and source materials to examine their dependencies. It is important to select contemporary sources and critically interpret the background such as the authors and location where the source was written. Through such examination, some earthquakes are concluded as "fake" events. Once the reliability is established, the time, location, and intensity can be estimated from the descriptions to construct Intensity Data Points (IDP) or Macroseismic Data Points (MDP). The results for each earthquake are further compiled as parametric catalogs. The paper demonstrates the above-mentioned method by means of a case study, the earthquake of July 17, 1670, one of the strongest earthquakes in Austria. By using contemporary records, she compiled 29 MDP data and estimated that the largest intensity was 8 on the 12° European Macroseismic Scale at Hall of Tyrol.

Albini and Rovida (2016) demonstrated another case study of the historical seismology in Europe. They examined historical records on the earthquake on April 6, 1667 on the east coast of Adriatic Sea. The source regions belonged to three different countries (Republic of Ragusa, Republic of Venice, and Ottoman Empire); the collected 253 records of the earthquake are in different languages and archives. They compiled 37 MDPs, from which they estimated the epicenter near Ragusa (today Dubrovnik) and the size of the earthquake as $Mw = 6.4 \pm 0.3$. By studying the travel routes of some of the eyewitness reporters or officials who examined the earthquake effects, it was estimated how the earthquake news were spread.

Matsu'ura (2017) summarized historical earthquake studies in Japan with its history. Seismicity in Japan is high; earthquake with M~7 occurs once a year on average. Compilation of historical records documenting earthquakes and their damage amounts to about 28,000 pages in modern characters, from which about 8700 Intensity Data Points have been estimated. The estimated epicenters of historical earthquakes are 214 for the period between AD 599 and 1872, among them focal depth and magnitudes were estimated for 134 events. The Intensity Data Points reveal important seismological characteristics. Slight differences in seismic intensity distribution of recurrent great interplate earthquakes such as Kanto earthquakes along Sagami Trough (in 1703 and 1923) or Tokai/Nankai earthquakes along Nankai Trough (in 1707 and 1854) indicate that the source regions of these recurrent earthquakes were slightly different. The seismic intensity distribution of modern earthquakes shows some characteristic distributions depending on the sources (e.g., shallow crustal earthquake, interplate earthquake, or deep earthquake within subducted slab). She also introduced the history of historical seismological research in Japan. The oldest compilation of earthquakes dates back to 9th century when 23 earthquakes were already listed. Since 1878, several efforts of historical earthquake studies and compilations of source materials have been continuously conducted in Japan.

Wang et al. (2017) introduced historical seismology in China, which has nearly 4000 years of history. The recording of earthquakes started as far back in 16–11 century BC. Historical earthquake archives were published first in AD 977, then repeated several times including those in the 1950s and 1980s that include about 15,000 items of historical earthquake sources. Based on those source materials, several editions of parametric catalogs "catalog of Chinese earthquakes" have been compiled and published since 1960s. The most recent edition includes 1034 historical earthquakes (between 2300 BC and AD 1911) and 4289 modern earthquakes (AD 1912–1990). Series of atlas of isoseismals, or seismic intensity distribution, have been also published. Using the modern, instrumentally recorded moderate and small earthquake catalog, they introduced a new quantitative method to define seismic density. The spatial distribution of modern seismic density indicates that some historical earthquakes occurred in the regions where modern seismic density is relatively high. Their results imply that some zones of high seismic density index could be used in principle to indicate the location of unrecorded historical or paleoseismological events in China and elsewhere.

In the studies of past earthquakes, it is often assumed that the seismicity rate, or a number of earthquakes occurred in particular time period, has been stationary, or temporally constant. On the other hand, it has been proposed that large earthquakes change the stress states in the surrounding region and affect the seismicity rate. This hypothesis, called the static Coulomb stress triggering, was introduced in the 1990s and has been applied to many earthquakes in the world. Ishibe et al. (2017) tested the hypothesis for three giant (M~9) earthquakes that occurred in recent years, i.e., the 2004 Sumatra–Andaman earthquake (Mw 9.1), the 2010 Maule earthquake (Mw 8.8), and the 2011 Tohoku earthquake (Mw 9.0). The results supported the triggering hypothesis for the 2004 and 2011 giant earthquakes, while it was not clear for the 2010 earthquake.

Paleoseismology

For older earthquakes that occurred in prehistorical time, geological methods have been used to study their occurrence. Three papers adopt three typical methods commonly used in paleoseismology, i.e., tsunami deposit, marine terraces, and active fault surveys.

The 2011 Tohoku earthquake was the largest earthquake instrumentally recorded in Japan. However, historical documents and tsunami deposit studies have shown that the similar earthquakes and tsunamis occurred in Sendai plain in AD 869 and in AD 1611 (e.g., Sawai et al. 2012). Recurrence interval of such giant earthquake ranges from 400 to 740 years. Along the Sanriku coast, which is located north of Sendai plain with saw-tooth topography, more recent tsunamis caused damages in 1933 and 1896, while few tsunami deposit studies were made before 2011. Ishimura (2017) re-estimated the ages of tsunami deposits which he previously sampled on the Sanriku coast. Ages of 11 deposits in the last 4000 years were estimated using dating methods of ^{14}C, ^{137}Cs, and ^{210}Pb. He concluded that the average recurrence interval of historical and paleo-tsunamis along the Sanriku coast is 350–390 years.

Large or great earthquakes along subduction zones often cause coastal uplift or subsidence, depending on the distance from the fault to coast lines. During the 2011 Tohoku earthquake, for example, the Pacific coast of northern Japan subsided up to 1 m. If the earthquake source is closer to land, the coast is uplifted for more than 1 m as evidenced during the 1703 or 1923 Kanto earthquakes along Sagami Trough. Such sudden coastal uplifts are preserved as marine terraces. Ramos et al. (2017) studied marine terraces on the west coast of Luzon Island, Philippines. While this coast faces the Manila Trench, where occurrence of giant interplate earthquakes and associated tsunami have been speculated, the fault modeling suggests the coast will subside during such a giant earthquake. The newly found evidence of 1000-year-old uplift of terrace, which was estimated from ^{230}Th dating of fossil corals, may be due to local onland faults or upper-plate structures in the forearc region. They also found coral boulders of similar age on top of ~ 5 m high terrace, suggesting a possibility of tsunami boulder. The tsunami modeling from inland fault shows a possibility of more than 3 m tsunami.

Many large earthquakes such as the 2005 Kashmir (Mw 7.6) or 2015 Gorkha (Mw 7.8) earthquakes occur along the Himalaya, and some of them produced surface rupture. By conducting trenching surveys across active faults, occurrence of past surface ruptures or earthquakes can be examined. Arora and Malik (2017) compiled the paleoseismological data from numerous trenches excavated by previous workers along the entire Himalaya arc and recalibrated the radiocarbon ages. They showed that the pattern of past earthquake scenarios consists of overlapping multiple earthquakes with an average rupture length of ~ 300 km (Mw 7.8–8.0), rather than two or three giant earthquakes rupturing the entire Himalayan arc. The time intervals of recent large earthquakes such as the 1905 Kangra earthquake (Mw 7.8), the 1934 Bihar–Nepal earthquake (Mw 8.2), and the 1950 Assam earthquake (Mw 8.4) are short within the resolution of geological dating method, hence the above earthquakes would have been considered as a single event with larger size if they are studied by geological method in the future. They argue that such grouping of multiple events would lead to an overestimation of seismic hazard scenario in Himalaya.

Authors' contributions

All the authors acted as Guest Editors for the contributed papers. This introduction was first drafted by KS. All authors read and approved the final manuscript.

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