Explanatory Note of Eastern Asia Earthquake and Volcanic Hazards Information Map

東アジア地域地震火山災害情報図 説明書

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1. Introduction

The Eastern Asia region is an area with high risk of catastrophic natural disasters such as earthquakes, tsunamis and volcanic eruptions. In today's highly globalized economy, when a major disaster occurs, it can create unpredictable turmoil not just in the affected area but also the rest of the world. Countermeasures against these disasters are crucial for the sustainable development. We believe that continuous efforts to develop an effective international framework to reduce the risk of earthquake, tsunami and volcanic hazards are quite important. The Sumatra earthquake on December 26, 2004 and Tohoku earthquake on March 11, 2011 clearly show the urgency of developing an information and knowledge system for infrequent natural hazards. The volcanic ash ejected from Eyjafjallajökull eruptions in Iceland on April 2000 caused more than 20,000 commercial flight cancellations a day in Europe, resulting to the largest air-traffic shut-down since World War II. The G-EVER (Asia Pacific Region Earthquake and Volcanic Eruption Risk Management) Consortium promotes earthquake and volcanic hazards reduction activities through the collaboration of different research institutes worldwide. The "Eastern Asia Earthquake and Volcanic Hazards Information Map" is the first publication map made by G-EVER Consortium.

The Eastern Asia Earthquake and Volcanic Hazards Information Map shows geology and tectonics (Chapter 2), active faults (Chapter 3), earthquakes hypocenters and source areas (Chapter 4), fatalities of major earthquakes (Chapter 5), tsunami hazards (Chapter 6), distribution of volcanoes (Chapter 7), calderas and pyroclastic falls (Chapter 8), ignimbrites (large-scale pyroclastic flows; Chapter 9), and fatalities of major volcanic events (Chapter 10). We believe that this hazards information map will provide useful information for earthquake, tsunami, and volcanic disasters mitigation efforts.

(Eikichi Tsukuda and Shinji Takarada)

2. Geology and tectonics of Eastern Asia region

The occurrences of earthquake and volcanic hazards are closely related with the geological settings. The geological map is recompiled based on the Geological Map of Asia at the scale of 1:5,000,000 (Teraoka and Okumura, 2011). Since the scale of the Eastern Asia Earthquake and Volcanic Hazards Information Map is 1:10,000,000, the legend is simplified from the original geological map. Sedimentary, extrusive and metamorphic rocks are subdivided into Q (Quaternary; 2.59-0 Ma), Tpn (Paleogene to Gelasian; 66.0-1.81 Ma), Qp (Quaternary large-scale ignimbrite; <74ka), TnQ (Middle Miocene to Calabrian; 15-0.78 Ma), KTp (Middle Cretaceous to Eocene; 133-33.9 Ma), Mz (Mesozoic; 252.1-66.0 Ma), PTr (Middle Permian to Middle Triassic; 294.6-236.8 Ma), Pz2 (Devonian to Early Triassic, 419.2-247.4 Ma), Pz1 (Neo Proterozoic to Silurian; 1000-419.2 Ma), SD (Silurian to Devonian; 443.4-358.9 Ma), Pz (Paleozoic: 541.0-252.1 Ma), PrPz1 (Meso-Proterozoic to Early Ordovician; 1600-471.8 Ma), and P∈ (Precambrian; > 541.0 Ma). The intrusive rocks are subdivided into Cz_i (Paleogene to Early Pleistocene; 66.0-0.78 Ma), Mz_i (Late Permian to Cretaceous; 260.4- 66.0 Ma), Pz2_i (Late Paleozoic; 419.2-252.1 Ma), Pz1_i (Early Paleozoic; 541.0-419.2 Ma), and P∈_i(Precambrian; >541.0 Ma). Rock type of Phanerozoic extrusive volcanic rocks are subdivided into felsic, felsic to intermediate, intermediate, intermediate to mafic, mafic, and undifferentiated. Rock type of intrusive rocks are subdivided into felsic, intermediate, mafic and ultramafic rocks/ophiolite.

Relatively younger volcanic rocks (Q, Tpn, TnQ and Cz_i) are mainly distributed in island arcs, such as Japan, Philippine, Indonesia, and Papua New Guinea. Therefore, volcanic hazards occur in these countries. The collision of the Indian and Eurasian plates resulted to significant deformations at the Himalayas and mainland China. Therefore, intra continental earthquakes cause earthquake disasters in these regions The worst earthquake (M8.0, 830,000 fatalities) occurred at Shaanxi in China on Jan. 23, 1556.

Plate boundary data are displayed on this map. The plate boundary data are shown based on Yeats (2012), Bird et al. (2003), and Kato and Eastern Asia Natural Hazards Mapping Project (2002). The plate boundary data around Philippine is based on PHIVOLCS (2008). Relatively large-scale earthquakes (Magnitude 7-9) occur along the subductions zones (Chapter 4). The largest earthquake in this map occurred in Sumatra, Indonesia (Mw9.1) on Dec. 26, 2004 and Tohoku, Japan (Mw9.0) on March 11, 2011.

(Shinji Takarada)

3. Active faults

Distribution of active faults in eastern Asia and its surroundings has been compiled from various sources including maps and scientific papers (Abers and McCaffrey, 1988; Adiya *et al.*, 2003; Bayasgalan *et al.*, 2008; Central Geological Survey, MOEA, 2010; Choi *et al.*, 2014; Delinom, 2009; Deng *et al.*, 2007; Department of Mineral Resources, 2006; Hall, 2002; Kumahara and Nakata, 2005; Petit *et al.*, 1996; Supartoyo *et al.*, 2005; Styron *et al.*, 2010; Tingay *et al.*, 2010; Tregoning *et al.*, 2005; Tsutsumi *et al.*, 2005; Wang *et al.*, 2014).

Unpublished digital data provided by the Headquarters for Earthquake Research Promotion (HERP), Philippine Institute of Volcanology and Seismology (PHIVOLCS) and Vietnam Academy of Science (VAST) were used for the active faults maps of Japan, Philippine, and Vietnam, respectively. Similar mapping efforts were made as part of the International Lithosphere Program (ILP) Project II-2 ''World Map of Major Active Faults'' as reported by Trifonov (2004). Active faults, generally defined as faults that show recent evidence of repeated movement and have the potential to slip causing earthquake in the future, are one of the primary elements in geological hazard (e.g., England and Jackson, 2011). A large quantity of maps and papers dealing with active faults in the Eastern Asian region has been published. Multiple fault data sources with significantly different results are present in some countries and regions. In these data, preference are made on those that have been published by governmental agencies. The quality of this map is not uniform because definition of active fault, progress in active fault research, and map scale used during compilation are different in each country and region. Some active faults have considerable uncertainties in their location due to inaccurate original map, incomplete scanning and georeferencing of original map, and mis-tracing (mis-digitizing) of the traces. In the map, active faults with certain location, active faults with uncertain location, and concealed active faults are shown in red solid lines, broken lines, and dotted lines, respectively. Names of major active faults have been given (AltynTagh fault; Chelungpu fault; Haiyuan fault; Himalayan Frontal fault; Itoigawa-Shizuoka Tectonic Line; Kunlun fault; Longmenshan fault zone; Median Tectonic Line; Philippine fault; Red River fault; Sagaing fault; Sumatran fault; Talas-Fergana fault). Note that active folds and offshore active faults are not included in this map. It is certain that not all active faults are included in this map hence, areas with no mapped active faults could still be exposed to risk of earthquakes. Characteristics of major active faults that are included in this map have been summarized by Yeats (2012).

(Tadashi Maruyama)

4. Earthquakes hypocenters and source areas

The hypocenter parameters of historical earthquakes (1000-1899) were adapted from the catalog of the Global Historical Earthquake Archive (1000-1903) (Global Earthquake Model, 2015). The ISC-GEM catalog by Storchak et al. (2013) is used for the earthquakes from 1900 to 2011. For the recent earthquakes (2012 to September, 2015), data from the Preliminary Determination of Epicenters of USGS are used. Only earthquakes with magnitudes equal to 6 or higher are used from the ISC-GEM data. Earthquakes source regions (Table 1) are selected using the following procedure. Preliminary Determination of Epicenters by United State Geological Survey are mainly used for the source area delineation Earthquakes with focal depth shallower or equal to 60km and magnitude bigger or equal to 7.5 are chosen. The earthquake catalog of Japan Meteorological Agency is used for events in and around Japan, as the accuracy of hypocenters are more reliable. However, magnitude 7.0 is the minimum in and around Philippine, as large events are relatively smaller compared to earthquake magnitudes in other regions. The area of a large event was estimated using the aftershock distribution for one month. The 1920, 1927, 1950, and 1970 Jan. 04 events are estimated by the intensity maps of the Department of Earthquake Preparedness and Mitigation of State Seismological Bureau (1999). The IX equal intensity line of Chinese intensity scale is adopted. The 1905 event is based from Avouac (2007) while the 1934 event is based from Sapkota et al. (2013). Other than these events, the spatial distribution of one month aftershocks was used to deliniate the source area.

Japan

The March 11, 2011 M9.0 earthquake (East off Tohoku earthquake) was the biggest one in and around Japan. It was an inter-plate thrust event between the North American and Pacific plates that generated huge tsunami along the east coast of Tohoku district of Japan (Ch. 6 Tsunami Hazards).

China

The 1920 Haiyuan (Gansu) M8.3 (M8.5 by China) earthquake was one of the biggest in China. It was an intra-plate strike slip event that occurred along the Hayuan fault. The 1976 Tangshan M7.6 earthquake was also an intra-plate strike slip event that killed more than 240,000 people. The earthquake caused extensive damage to a modern city with more than one million population.

Nepal

The 2015 Gorkha M7.8 earthquake was an inter-plate thrust event between the Eurasian and Indian plates. It occured in Kathmandu and caused extensive damage.

Philippine

The 1990 Baguio (Luzon) M7.7 earthquake was an intra-plate strike slip event that occurred along the Philippine fault.

Indonesia

The 2004 Sumatra M9.1 earthquake generated the huge tsunami that destroyed many countries around Indian ocean. It was an inter-plate thrust event between the Eurasian and and Indian plates and Australian plate.

Papua New Guinea

The 2000 New Ireland M8.0 earthquakes was a strange event. First, M8.0 earthquake occurred off the coast of New Ireland Province. It was an inter-plate strike-slip event between the north and south Bismarck plates. It occurred along the transform fault on November 16 at 04:54 UTC. The M7.8 earthquake followed at 07:42 UTC. It was the trust event between the Solomon Sea Plate and the south Bismarck plate located around 175 km south of the first earthquake. On November 17 at 21:01, the M7.8 third event occurred around 170 km south west of the first event. It was the same thrust event as the second one.

(Yuzo Ishikawa)

5. Fatalities of Major Earthquakes

Earthquake Fatalities Map is compiled to facilitate visual understanding of earthquake disasters in terms of their number of fatalities (deaths) and the main causes of deaths. One to seventeen disastrous earthquakes are selected for every country or region. The number of fatalities is categorized by five causes; structure (building) damage, tsunami, landslide, fire, and others (related death), when possible. It is important to understand that an earthquake and ground motions do not directly kill people, but vulnerable structures, fire, landslide, or tsunami do. The number of fatalities is based on the Significant Earthquake Database (NGDC/WDS) provided by NOAA when no references are cited.

Japan

Subduction zone and active fault are the main sources of hazardous earthquakes in Japan. Disastrous earthquakes with more than 1,000 casualties after the year 1847 are listed in the map. These include eight subduction earthquakes (including outer-rise quake), seven earthquakes on the active faults, and one with unknown source.

Among the eight subduction earthquakes, three of them are related to the Japan Trench (1896 Meiji Sanriku, 1933 Showa Sanriku, 2011 Tohoku), four of them are on the Nankai Trough (1854 Ansei Tokai, 1854 AnseiNankai, 1944 Tonankai and 1946 Tonankai), and the other is on the Sagami Trough (1923 Kanto). Principal cause of death varies by source region; Tsunami for the Japan Trench, tsunami and structures for the Nankai Trench, structure and fire for the Sagami Trench: 1923 Kanto earthquake.

The seven disastrous earthquakes that were attributed to the active faults are the 1847 Zenkoji (name of a famous temple located in the source area), 1891 Nobi, 1927 Tango, 1943 Tottori, 1945 Mikawa, 1948 Fukui, and the 1995 Kobe Hanshin Awaji (Hyogo-ken Nanbu) earthquakes. These earthquakes occurred just beneath cities caused huge numbers of structural collapse and succeeding fire, which resulted in many casualties. The 1855 Ansei Edo (Edo: previous name of Tokyo) earthquake occurred beneath Edo city but unknown source, causing many casualties by structural damage and fire. Number of casualties in Table 1 is compiled from many reports briefly listed in the table.

Bangladesh

Active fault is the main source of disastrous earthquake in Bangladesh.

China

Active fault is the main source of disastrous earthquake in China. Eighteen disasters in the 19th and 20th centuries are listed with two ancient deadliest ones in 1303 and 1556. The 2008 Wenchuan earthquake caused 87,210 fatalities, 20,000 of them by landslides (Huang and Fan ,2013). The 1933 Maowen earthquake caused 9,300 deaths including 2,500 caused by flooding and landslide after a dam broke (EERI, 2008).

India

Himalayan subduction zone and active fault are the main sources of disastrous earthquake in India. The 1905 Kangra and the 1991 Ultarkashi are Himalayan earthquakes. The 1897 Assam earthquake occurred on an active fault. The 1993 Latur earthquake is shallow intraplate event. Most casualties are caused by damage of structures.

Indonesia

Subduction zone and active faults are the main sources of disastrous earthquake in Indonesia. The 2004 Sumatra earthquake (M9.1) caused huge tsunami (see Chap. 6) and most of the fatalities are due to tsunami. The 2005 Nias earthquake (M8.5) is a subduction earthquake with 1,346 deaths caused structure collapses mainly on the Nias island located just above the source area. The 2009 Sumatra earthquake is an intra-slab earthquake with more than 1,000 deaths caused by collapse of buildings. Inland earthquakes on active faults (2006 Yogyakarta, 1917 Bali) caused fatality by building collapse or landslides. The 1992 Flores earthquake is shallow event with high tsunami induced by landslide (Tsuji et al. 1995).

Myanmar

Active fault is the main source of disastrous earthquake in Myanmar. The 1930 Pegu earthquake on the Sagain fault is the deadliest with 500 fatalities.

Mongolia

Active fault is the main source of disastrous earthquake in Mongolia. The number of casualties by earthquake in Mongolia is small because those earthquakes struck remote areas.

Nepal

Himalayan Subduction zone (Himalayan front fault) is the main source of disastrous earthquake in Nepal. The 2015 Kathmandu earthquake is typical with many death tolls by structural damage and landslides. The 1934 Bihar and 1988 Udayapur earthquakes are listed.

Papua New Guinea

Subduction zone and active fault are the main sources of disastrous earthquakes in Papua New Guinea. Two disastrous earthquakes are listed. The 1976 Irian Jaya earthquake caused about 6,000 fatalities, 90 percent of them caused by landslides. The 1998 Papua New Guinea earthquake is a subduction event of M7.1 but caused 2,200 deaths by a landslide-induced tsunami.

Philippines

Subduction zone and active fault are the main sources of disastrous earthquakes in the Philippines. The 1990 Luzon earthquake is the deadliest inland earthquake. The 1976 Moro Gulf earthquake caused tsunami causing more than 7,000 fatalities.

Taiwan

Taiwan lies on the plate boundary and many shallow earthquakes occur. The 1935 Hsinchu, 1999 Chi-Chi and 1906 Meishan earthquakes caused fatalities, more than 1,000 of which were mainly due to building structural failures.

Thailand

Seismicity in Thailand is low. Some damaging earthquakes are known in northern area.

Vietnam

Active faults are known in Vietnam, but recent earthquakes (e.g 1983 M6.8 event; Ngo et al. 2008) were not disastrous.

(Masayuki Yoshimi)

6. Tsunami Hazards

Tsunami Hazard Distribution Map is compiled to facilitate visual understanding of the occurrence, coverage and severity of tsunamis. This will also increase people's awareness on the importance of tsunami disaster mitigation endeavors. The map illustrates the regions affected by eight tsunami events which have caused considerable damages in East-Asia area; 1771 Meiwa (Yaeyama) tsunami, 1792 Unzen tsunami, 1883 Krakatau Volcano tsunami, 1976 Moro Gulf (Mindanao) tsunami, 1983 Sea of Japan tsunami, 1998 Papua New Guinea tsunami, 2004 Indian Ocean tsunami and 2011 Japan Tohoku tsunami. Brief description of each tsunami is shown in Table 4.

The eight-tsunami events were selected primarily based on their severity (number of casualties) using a list of historical tsunami events (Global Historical Tsunami Events and Runups) on NGDC/WDS Global Historical Tsunami Database. However, some events have been excluded from the list of map illustration to avoid overlap with other tsunami events (for example, 1498 Meio (Nankai) tsunami, 1707 Hoei (Nankaido) tsunami and 1896 Sanriku tsunami over 2011 Tohoku tsunami around Japan). In addition, other reasons such as a lack of tsunami wave data and scarce evidence for tsunami event result in a glaring omission of illustration. In contrast, 1976 Moro Gulf (Mindanao) tsunami, 1983 Sea of Japan tsunami, and 1998 Papua New Guinea tsunami are selected for illustration in spite of relatively minor damages. This is because they represent local tsunami disasters with wide extent of tsunami waves.

Coastal lines that have been severely affected by these tsunami events are highlighted in pink (volcanogenic tsunamis) or blue (seismic tsunamis) on the map. The colored lines indicate the regions with roughly 1 m waves (runup height), except in the case of 2004 Indian Ocean tsunami with roughly 2 m waves. The regions were determined by the data of runup heights in the historical documents, survey reports, scientific articles, numerical simulation results, and online databases cited below. It is noteworthy that the extent of these regions contain some degree of inaccuracy stemming from the quality and quantity of referred information. Maximum runup height of each tsunami event and its observation location are also indicated by blue bar and red circle, respectively on the map.

In East-Aisa area, tsunami events are usually triggered by seismic activity along subduction zones around the Pacific Rim. In some cases, tsunami waves are caused by other factors such as an earthquake outside the subduction zone, volcanic eruption, aerial and submarine landslide. Each tsunami events are briefly described as follows (also see Table 4).

1771 Meiwa (Yaeyama) tsunami

Meiwa (Yaeyama) tsunami occurred in 24 April 1771 around Ryukyu Islands, Japan. It was triggered by an earthquake and probably an accompanying submarine landslide (e.g., Matsumoto and Kimura, 1993), though it is still controversial. Based on historical documents, about 12,000 people were killed by the disaster, and Imamura (1938) estimated the earthquake magnitude at Mw = 7.4. Goto et al. (2010) concluded that maximum runup height was estimated at 30 m at Ishigaki Island, based on historical documents and distribution of coral boulders.

1792 Unzen tsunami

Unzen tsunami occurred on May 21, 1792 at Ariake Bay, Japan. It was caused by the volcanic debris avalanche from Mt. Mayuyama, which was triggered by the volcanic earthquake. Tsunami was propagated over the Ariake Bay and hit the opposite side (Kumamoto district). Based on historical documents analysis, Tsuji and Hino (1993) concluded that the tsunami casualties were 5,158 in Kumamoto district. They argued that the overall death toll may be over 10,000, and more than 15,000 people were killed through a sequence of the event. Akagi (2001) reported the maximum runup height reached about 50 m in Nagasaki district based on his paleographical researches.

1883 Krakatau Volcano tsunami

Krakatau tsunami occurred on August 27, 1883 around the Sunda Strait, Indonesia. It was caused by the devastating eruption of Krakatau Volcano. The maximum runup height reached 42 m at the northern region of the Sunda Strait (Choi et al., 2003). Pararas-Carayannis (2003) reported 36,417 people were killed through the sequence of the event.

1976 Moro Gulf (Mindanao) tsunami

Moro Gulf tsunami occurred on August 16, 1976 in Mindanao Island, Philippines. It was caused by an earthquake with a magnitude of 8.0, and killed over 8,000 people (Soloviev et al., 1992). The maximum runup height reached 4-5 m around Moro Gulf based on field investigations (Nakamura, 1977; Soloviev et al., 1992).

1983 Sea of Japan tsunami

The Sea of Japan tsunami occurred on May 26, 1983 in the Sea of Japan. It was caused by an intraplate earthquake with a moment magnitude of 7.8 (Kanamori and Astiz, 1985). The tsunami waves hit the coastal areas around the Sea of Japan with a maximum height of 15 m at Akita, Japan (Shuto, 1983; Hatori, 1991; Disaster Control Research Center (DCRC), Graduate School of Engineering, Tohoku University and Japan Nuclear Energy Safety Organization (JNES) , 2010). The tsunami waves killed 100 people in Japan and three people in South Korea (Lander et al., 2003).

1998 Papua New Guinea tsunami

Papua New Guinea tsunami occurred on July, 17 1998 in Sandaun Province, Papua New Guinea. It was caused by a huge submarine landslide triggered by a relatively small earthquake with a magnitude of 7.1 (Tappin et al., 2008). The tsunami waves with a maximum height of 15 m and killed more than 2,200 people (Lander et al., 2003; Joku et al., 2007). Davies et al. (2003) reported a wide extent of the tsunami damages.

2004 Indian Ocean tsunami

Indian Ocean tsunami occurred on December, 26 2004 near Banda Aceh, Indonesia. It was caused by a typical subduction zone earthquake with a magnitude of 9.1 (Chlieh et al., 2007). The tsunami waves with a maximum height of 51 m (Kim et al., 2013) killed approximately 290,000 people. Many measurements of runup height around the Indian Ocean have been published (e.g., Narayan et al., 2005; Choi et al., 2006; Tsuji et al., 2006; Research Group on the December 26, 2004 Earthquake Tsunami Disaster of Indian Ocean, 2007). Data obtained from numerical simulation result for Indian Ocean Tsunami was used to complement the field measurements (Research Group on The December 26, 2004 Earthquake Tsunami Disaster of Indian Ocean, 2005).

2011 Japan Tohoku tsunami

Japan Tohoku tsunami occurred on March 11, 2011 along the Japan Trench. It was caused by a typical subduction zone earthquake with a magnitude of 9.1 (Hirose et al., 2011). The tsunami waves with a maximum height of about 40m (The 2011 Tohoku Earthquake Tsunami Joint Survey Group, 2011; Goto et al., 2012), killed 18,378 people (Mizutani, 2012). The 2011 Tohoku Earthquake Tsunami Joint Survey Group (2011) has summarized the data of runup height measured by many researchers.

(Dan Matsumoto)

7. Volcanoes in Eastern Asia region

Distribution of Holocene volcanoes (<10ka) are shown on this hazard information map. The name and distributions of the volcanoes are based on "Volcanoes of the World (third edition)" (Siebert at al., 2010). Most of the volcanoes are distributed in island arcs. However, several volcanoes are distributed in the continental region. The total number of volcanoes shown on the map in each country are as follows: Indonesia (141), Japan (128), Philippines (50), Papua New Guinea (56), China (11), Taiwan (7), Vietnam (6), Mongol (5), South Korea (3), North Korea (3), Myanmar (3), Russia (1), and Malaysia (1).

(Shinji Takarada)

8. Caldera and pyroclastic falls

East and Southeast Asia (excluding Russia and United States) experienced 3,535 eruptions during Holocene time based on database of Smithsonian Global Volcanism Program (2013). Sorting by Volcanic Explosivity Index (VEI; Newhall and Self, 1982) allows us to list up 4 eruptions of VEI7, 19 eruptions of VEI6 and rest of VEI5 (Table 5). There is no eruption of VEI8 or larger during Holocene time. The location of eruption vent is shown as solid triangle with resulting caldera rim of present topographic decompression. Extent of pyroclastic fall deposit is shown as broken line quoted from literature describing the area of pyroclastic fall observed and/or pyroclastic fall deposit is identified. These two criteria are ideally identical but highly dependent on the condition during observation and/or survey performed in each country. In this map we adopted 4 eruptions of VEI7 (Tambora 1815AD, Rinjani 1257AD, Chambaishan936AD, Kikai 7ka) and 10 eruptions of VEI6 (Pinatubo 1991AD, Krakatau 1883AD, Dakataua 800AD, Rabaul 540AD, Witori 3.4ka, Mashu 7.6ka, Ulreung 8.8ka, and Moekeshi 9.5ka)(Table 6). Lack of distribution information in literature for the 6 eruptions reflects the missing distribution in oceanic area. We added 3 Pleistocene large-scale eruptions (Aira 30ka, Toba 74ka, and Aso 90ka), which are well-documented which could be used for comparative examples for hazard assessment.

(Ryuta Furukawa)

9. Ignimbrite

Distribution of large-scale ignimbrites (pyroclastic flow deposits; VEI6-8) is shown on the hazard information map. Information about the distribution of large-scale ignimbrites are very useful for the evaluation of hazards and risk mitigations for the future volcanic catastrophic events. The large-scale ignimbrites are shown on the map as “Qp”. Twelve large-scale ignimbrites are selected on the map (Table 7): Ito (30ka; Aira Caldera, Japan, 350km^3), Aso 4 (90ka; Aso Caldera, Japan; 600km^3), Hachinohe (15ka; Towada Caldera, Japan; 20km^3), Toya (110ka; Toya Caldera, Japan; 170km^3), Shikotsu (40ka; Shikotsu Caldera, Japan; 300km^3), Kussharo 4 (120ka; Kussharo Caldera, Japan; >150km^3), Changbaishan (938AD; Tianchi volcano, China and North Korea; >100km^3), Pinatubo (1991AD; Pinatubo volcano, Philippines; 10.4km^3), Krakatau (1883AD; Krakatau Caldera, Indonesia; 13.6km^3), Tambora (1815AD; Tambora caldera, Indonesia; 100km^3), Toba (74ka; Toba Caldera, Indonesia; 2,500-3,000km^3), and Rabaul (540AD; Rabaul Caldera, Papua New Guinea; 11km^3). There are four ignimbrites of VEI6, seven ignimbrites of VEI7, and one ignimbrite of VEI8 are selected. Some pyroclastic fall distributions associated with these ignimbrites are also shown on the map (Chapter 8).

(Shinji Takarada)

10. Fatalities of major volcanic events

Fatalities of major volcanic events are compiled to facilitate visual understanding of volcanic disasters in Eastern Asia. The number of fatalities (deaths) and the main causes of deaths due to volcanic events are displayed. Five to thirty worst top volcanic events are choosen in each country: Japan (25; Table 8), Philippines (15; Table 9), Indonesia (30; Table 10) and Papua New Guinea (5; Table 11). The total number of fatalities is categorized by seven causes; pyroclastic flow (pink), debris avalanche (yellow), tephra fall and ballistic (green), lahar (blue), wave and tsunami (light blue), volcanic gas (orange) and other related death (purple; such as disease and starvation). The fatalities data are complied mainly based on Siebert et al. (2010).

Japan

The worst top 25 fatalities caused by volcanic events in Japan after 1400AD are listed in Table 8. The most hazardous volcanic events in Japan was the 1792 Unzen Mayuyama debris avalanche, which caused 15,000 fatalities. The debris avalanche produced large tsunami within Ariake Bay area and caused 10,000 fatalities (Chapter 6). The debris avalanche killed 50,000 people. The 2nd hazardous volcanic event was the 1783 Asama eruption, which caused 1,491 fatalities due to pyroclastic flow, debris avalanche, and lahar. The 3rd event was the Oshima-Oshima 1741 debris avalanche, which caused 1,467 fatalities at the coastal area due to tsunami. The 4th event was the Hokkaido-Komagatake 1640 debris avalanche, which caused 700 fatalities in Funka Bay area due to tsunami. The 5th event was the Akagi 1947 lahar, which caused 699 fatalities. The 6th event was Bandai 1888 debris avalanche, which caused 477 fatalities in total. The 7th event was the Tateyama 1958 debris avalanche, which caused 279 fatalities mainly due to the associated lahar. These indicate that the main cause of death from volcanic events in Japan are debris avalanche and associated tsunami or lahar.

Philippines

The worst top 15 fatalities caused by volcanic events in the Philippines after 1400AD are listed in Table 9. The most hazardous volcano in the Philippines is Mayon. Nine volcanic events of Mayon volcano are included in the worst 15 volcanic events. The worst event in Philippines is the Mayon 1875 lahar, which caused more than 1,500 fatalities. The 2nd worst event is the Taal 1911 eruption, which caused more than 1,335 fatalities due to pyroclastic flow. The 3rd worst event is the Mayon 2006 lahar, which caused 1,266 fatalities. The 4th worst event is also the Mayon 1814 eruption, which caused 1,200 fatalities due to pyroclastic flow and lahar. The 5th event is the Pinatubo 1991 eruption, which caused 800 fatalities. The main causes of fatalities were pyroclastic flow (25), lahar (100) and related death mainly due disease at evacuation camp (450). The main causes of fatalities in Philippines are pyroclastic flows and lahars as clearly shown on the list.

Indonesia

The worst top 30 fatalities caused by volcanic events in Indonesia after 1400AD are listed in Table 10. The worst event is the Tambora 1815 caldera-forming eruption (VEI7, Table 7) which caused 60,000 fatalities. About 1,100 people were killed by pyroclastic flows and about 49,000 people died due to famine and disease on Sumbawa and Lombok islands. The 2nd worst event is the Krakatau 1883 caldera-forming eruption (VEI6, Table 7), which caused 36,417 fatalities.

About 2,000 people were killed by pyroclastic flows and about 34,417 people were killed by the associated tsunami. The 3rd worst event is the Kelut 1586 eruption, which caused about 10,000 fatalities due to pyroclastic flows. The 4th worst event is also the Kelut 1919 eruption, which caused about 5,110 fatalities due to pyroclastic flow and lahar. The 5th event is the Galunggung 1822 eruption, which caused 4,011 fatalities due to pyroclastic flow. The 1976 eruption at Dieng volcano caused 145 fatalities in total due to volcanic gas. The main causes of fatalities in Indonesia are pyroclastic flows, lahars, debris avalanches as shown in Table 10.

Papua New Guinea

The worst top 5 fatalities caused by volcanic events in Papua New Guinea after 1400AD are shown in Table 11. The worst event is the Ritter Island 1888 debris avalanche, which caused 3,000 fatalities due to tsunami. The 2nd worst event is the Lamington 1951 eruption, which caused 2,942 fatalities due to pyroclastic flows. The 3rd worst event is the Long Island 1660 eruption, which caused about 2,000 fatalities due to pyroclastic flow and tsunami. The 4th event is the Rabaul 1937 eruption, which caused 507 fatalities due to pyroclastic flow and tephra falls. The 5th event is also the Rabaul 1850 eruption, which caused more than 500 fatalities due to tephra fall. The main causes of fatalities in Papua New Guinea are tsunami, pyroclastic flow, and tephra fall.

(Shinji Takarada)

日本語要旨

東アジア地域地震火山災害情報図は，国立研究開発法人産業技術総合研究所地質調査総合センターの G-EVER 推進チームが中核となり，アジア各国の地質調査機関（PHIVOLCS, CVGHM, CEA, VAST, Academia Sinica）のメンバーとともに作成した災害情報図である．ここでは，東アジア地域の地質とテクトニクス（第 2 章），活断層（第 3 章），地震の震央と震源域の分布（第 4 章），主要地震による犠牲者（第 5 章），津波災害（第 6 章），火山の分布（第 7 章），カルデラと降下火山灰（第 8 章），大規模火砕流堆積物（第 9 章），大規模噴火による犠牲者（第 10 章）について取りまとめている．

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Table 1. Hypocenter parameters of earthquake source areas. When the local time date is different from the origin time, the local time date is shown on the map.

Origin time (UT) (yyyy/mm/dd time)		Magnitude (M)	Moment M (Mw)	Latitude	Longitude	Depth (km)	Local time date	Remarks
1905/4/4	0:49	M7.9		32.636	76.788	20.0		
1920/12/16	12:05	M8.3		36.888	105.606	15.0		Haiyuan, China
1923/9/1	2:58	M7.9		35.331	139.136	23.0		Kanto, Japan
1927/5/22	22:32	M7.7		37.645	102.489	15.0	1927/5/23	Gulang, China
1934/1/15	8:43	M8.0		26.885	86.589	15.0		Bihar, Nepal
1935/12/28	2:35	M7.6		-0.29	98.255	30.0		
1944/12/7	4:35	M8.1		33.682	136.204	15.0		Tonankai
1946/12/20	19:19	M8.3		33.116	135.895	15.0	1946/12/21	Nankai
1950/8/15	14:09	M8.6		28.363	96.4449	15.0		
1951/11/24	18:50	M7.8		23.092	121.214	30.0	1951/11/25	
1952/3/4	1:22	M8.1		42.084	143.899	45.0		Tokachi-oki
1964/6/16	4:01	M7.6		38.399	139.29	15.0		
1965/1/24	0:11	M8.2		-2.608	125.952	20.0		
1966/3/12	16:31	M7.5		24.122	122.583	30.0	1966/3/13	
1968/5/16	0:49	M8.2		40.86	143.435	29.9		Tokachi-oki
1968/8/1	20:19	M7.6		16.316	122.067	25.0	1968/8/2	
1968/8/10	2:07	M7.6		1.514	126.234	23.0		
1969/8/11	21:27	M8.2		43.424	147.859	30.0	1969/8/12	
1970/1/4	17:00	M7.1		24.185	102.543	11.3	1970/1/5	Tonghai, China
1970/4/7	5:34	M7.4		15.791	121.63	25.0		
1970/4/12	4:01	M6.9		15.136	122.064	22.5		
1971/1/10	7:17	M7.7		-3.184	139.722	30.0		
1971/7/14	6:11	M8.0		-5.524	153.85	40.0		
1972/4/25	19:30	M7.5		13.402	120.275	25.0	1972/4/26	
1972/12/2	0:19	M8.0		6.405	126.64	60.0		
1973/6/17	3:55	M7.8		43.188	145.808	44.3		
1975/7/20	19:54	M7.3		-7.231	155.2949	45.0	1975/7/21	
1975/10/31	8:28	M7.5		12.574	126.141	23.0		
1976/7/27	19:42	M7.6	Mw7.6	39.62	118.098	15.3	1976/7/28	Tangshan, China
1976/8/16	16:11	M8.0	Mw8.0	6.175	124.047	20.0	1976/8/17	Mindanao, Philippine
1977/3/18	21:43	M7.2	Mw7.2	16.741	122.246	30.0	1977/3/19	
1977/8/19	6:08	M8.3	Mw8.3	-11.164	118.378	25.0		
1978/3/23	3:14	M7.6	Mw7.6	44.207	148.982	35.0		
1978/6/12	8:14	M7.6	Mw7.6	38.195	142.0269	45.0		
1978/7/23	14:42	M7.2	Mw7.2	22.232	121.414	25.0		
1979/9/12	5:17	M7.5	Mw7.5	-1.667	135.984	20.0		
1980/6/18	17:14	M6.9	Mw6.9	-5.1369	152.218	51.0		
1982/1/11	6:10	M7.1	Mw7.1	13.864	124.375	31.8		
1983/5/26	3:00	M7.7	Mw7.7	40.425	139.184	15.1		Nihonkai-chubu
1985/8/23	12:42	M7.0	Mw6.9	39.367	75.333	30.0		
1986/8/14	19:39	M7.5	Mw7.5	1.882	126.515	32.3	1986/8/15	
1986/11/14	21:20	M7.4	Mw7.3	24.043	121.802	35.0	1986/11/15	
1987/10/16	20:48	M7.3	Mw7.3	-6.22	149.145	45.0	1987/10/17	
1988/2/24	3:52	M7.2	Mw7.2	13.488	124.606	28.1		
1989/12/15	18:43	M7.5	Mw7.5	8.387	126.606	27.5	1989/12/16	
1990/4/18	13:39	M7.6	Mw7.6	1.239	122.853	36.6		
1990/7/16	7:26	M7.7	Mw7.7	15.664	121.154	24.4		Baguio, Luzon
1991/6/20	5:18	M7.5	Mw7.5	1.199	122.768	30.0		
1991/12/22	8:43	M7.6	Mw7.6	45.545	151.076	25.3		
1992/5/17	10:15	M7.2	Mw7.2	7.202	126.725	30.0		
1992/12/12	5:29	M7.7	Mw7.7	-8.53	121.858	28.0		
1993/7/12	13:17	M7.7	Mw7.7	42.824	139.229	20.0		
1993/8/8	8:34	M7.8	Mw7.7	12.994	144.752	59.0		Guam
1994/1/21	2:24	M7.0	Mw6.9	1.052	127.718	19.2		
1994/6/2	18:17	M7.8	Mw7.8	-10.51	112.872	18.0	1994/6/3	
1994/10/4	13:23	M8.3	Mw8.3	43.851	147.167	30.0		Hokkaido toho-oki
1994/12/28	12:19	M7.7	Mw7.7	40.4769	143.397	24.8		Sanriku haruka-oki
1995/4/21	0:34	M7.2	Mw7.1	12.085	125.603	24.1		
1995/5/16	20:12	M7.7	Mw7.7	-23.043	169.93	23.6	1995/5/17	
1995/5/27	13:03	M7.0	Mw7.0	52.605	142.87	12.9		Neftegorsk, Sakhalin
1995/8/16	10:27	M7.7	Mw7.7	-5.7859	154.181	25.0		
1995/12/3	18:01	M7.9	Mw7.9	44.655	149.266	28.3	1995/12/4	
1996/1/1	8:05	M7.9	Mw7.9	0.741	119.963	33.5		
1996/2/17	5:59	M8.2	Mw8.2	-0.946	136.941	20.0		
1996/4/29	14:40	M7.2	Mw7.2	-6.525	155.0209	35.0	1996/4/30	
1996/6/11	18:22	M7.1	Mw7.1	12.712	125.22	31.7	1996/6/12	
1996/7/22	14:19	M7.0	Mw7.0	1.027	120.458	28.4		
1997/11/8	10:02	M7.5	Mw7.5	35.109	87.396	20.0		
1998/5/3	23:30	M7.5	Mw7.4	22.491	125.473	20.0	1998/5/4	
1998/10/28	16:25	M6.5	Mw6.5	0.902	125.848	35.0	1998/10/29	
1998/11/29	14:10	M7.7	Mw7.7	-1.924	124.818	25.0		
1999/3/4	8:52	M7.1	Mw7.1	5.281	121.835	15.0		
1999/9/20	17:47	M7.6	Mw7.6	23.834	120.813	25.0	1999/9/21	
1999/12/11	18:03	M7.2	Mw7.2	15.809	119.75	40.0	1999/12/12	
2000/5/4	4:21	M7.5	Mw7.5	-1.12	123.551	30.0		
2000/6/4	16:28	M7.9	Mw7.8	-4.605	102.056	35.0		
2000/6/18	14:44	M7.9	Mw7.9	-13.926	97.402	15.0		
2000/8/4	21:13	M6.8	Mw6.8	48.7299	142.387	15.0	2000/8/5	
2000/11/16	4:54	M8.0	Mw8.0	-4.011	152.254	30.0		New Ireland, Papua New Guinea
2000/11/17	21:01	M7.8	Mw7.8	-5.535	151.94	37.4	2000/11/18	New Ireland, Papua New Guinea
2001/1/1	6:57	M7.4	Mw7.4	6.875	126.624	36.0		
2001/10/19	3:28	M7.5	Mw7.4	-4.1	123.951	15.0		
2001/11/14	9:26	M7.8	Mw7.8	35.964	90.549	10.0		Kunlunshan, China
2002/3/5	21:16	M7.5	Mw7.5	5.966	124.176	25.0	2002/3/6	
2002/9/8	18:44	M7.6	Mw7.6	-3.353	143.014	13.0	2002/9/9	
2002/10/10	10:50	M7.6	Mw7.5	-1.683	134.2829	20.0		
2002/11/2	1:26	M7.2	Mw7.2	2.9009	96.114	28.1		
2003/5/26	19:23	M6.9	Mw6.9	2.343	128.893	31.0	2003/5/27	
2003/9/25	19:50	M8.3	Mw8.3	41.898	143.916	30.0	2003/9/26	Tokachi-oki
2004/11/11	21:26	M7.5	Mw7.5	-8.167	124.823	13.0	2004/11/12	
2004/12/26	0:58	M9.1	Mw9.1	3.331	95.952	30.0		Sumatra
2005/3/28	16:09	M8.6	Mw8.6	2.092	97.154	30.0		Nias
2005/10/8	3:50	M7.6	Mw7.6	34.451	73.649	15.0		
2006/7/17	8:19	M7.7	Mw7.7	-9.328	107.323	25.3		
2006/12/26	12:26	M7.0	Mw7.0	21.823	120.609	10.0		
2007/1/21	11:27	M7.5	Mw7.5	1.127	126.285	22.0		
2007/4/1	20:39	M8.1	Mw8.1	-8.389	157.092	15.0	2007/4/2	
2007/9/12	11:10	M8.5	Mw8.5	-4.407	101.502	34.0		
2008/5/12	6:28	M7.9	Mw6.9	30.98	103.396	10.0		Wenchuan, China
2008/11/16	17:02	M7.4	Mw7.3	1.29	122.077	34.0	2008/11/17	
2009/1/3	19:43	M7.7	Mw7.6	-0.502	132.738	30.0	2009/1/4	
2009/2/11	17:34	M7.1	Mw7.1	3.811	126.541	25.0	2009/2/12	
2010/4/6	22:14	M7.8	Mw7.8	2.347	97.0819	20.0	2010/4/7	
2010/4/13	23:49	M6.9	Mw6.9	33.1719	96.656	15.0	2010/4/14	
2010/10/25	14:42	M7.8	Mw7.8	-3.545	100.066	17.6		
2010/12/21	17:19	M7.4	Mw7.4	26.879	143.812	20.0	2010/12/22	
2011/3/11	5:46	M9.0	Mw9.0	38.2849	142.546	20.0		E off Tohoku, Japan
2012/4/11	8:38	M8.6	Mw8.6	2.327	93.063	20.0		
2012/4/11	10:43	M8.2	Mw8.2	0.802	92.463	25.1		
2012/8/31	12:47	M7.6	Mw7.6	10.811	126.638	28.0		
2013/10/15	0:12	M7.1	Mw7.1	9.8796	124.1167	19.0		
2015/3/29	23:48	M7.5	Mw7.4	-4.7294	152.5623	41.0		
2015/4/25	6:11	M7.8	Mw7.9	28.2305	84.7313	8.2		Gorkha, Nepal

横幅18cm

Table 2. List of disastrous earthquakes in Japan.

Date (yyyy.mm.dd)	name	M	Number of deaths and missing	Reference
2011.03.11	Tohoku	9	21,839 (S:60,T:18,378,L:30, O:3,331)	Fire and Disaster Management Agency, Reconstruction Agency, Kahoku shinpo (local newspaper), National Police Agency of Japan
1995.01.17	Kobe	6.9	6,437 (S:5075,L:40, F403,O:919)	#Include 3 missing
1948.06.28	Fukui	6.8	3,728 (S, F)	
1946.12.21	Showa Nankai	8.1	1,443 (S:860, T:583)	Kawasumi & Sato (1947), Kanai et al. (1947), Cabinet office
1945.01.13	Mikawa	6.8	2,306 (S)	Iida (1978), Cabinet Office
1944.12.07	Showa Tonankai	7.9	1,230 (S:779, T:451)	Iida (1977), Tsunami Digital Library, Cabinet office
1943.09.10	Tottori	7.2	1,083 (S)	
1933.03.03	Showa Sanriku	8.4	3,064 (T)	
1927.03.07	Kita-Tango	7.3	2,925 (S)	
1923.09.01	Kanto	7.9	105,385 (S:12,591,T:325, L:688,F:91781)	Moroi & Takemura (2004), Cabinet office
1896.06.15	Meiji Sanriku	8.4	21,959 (T)	
1891.10.28	Nobi	8.0	7,273 (S)	
1855.11.11	Ansei Edo	7.1	10,000 (S:6,000, F:4,000)	Nakamura ?
1854.12.24	Ansei Nankai	8.4	3,000 (S,T)	
1854.12.23	Ansei Tokai	8.4	3,000 (S,T)	
1847.05.08	Zenkoji	7.4	8,600 (S,L)	

Causes of the fatalities (S: Structure, T: Tsunami, L: Landslide, F: Fire and O: Other related death)

横幅8cm

Table 3. List of disastrous earthquakes in China.

Date (yyyy.mm.dd)	name	M	Number of deaths and missing	Reference
2010.04.13	Qinghai	6.9	2,200 (S)	NOAA
2008.05.12	Wenchuan	8.0	87,210 (S:67,210, L:20,000)	Huang & Fan
1976.07.28	Tangchan	7.8	242,419 (S)	NOAA, USGS
1975.02.04	Haicheng	7.0	2,000 (S)	NOAA
1974.05.10	Zhaotang	7.0	20,000 (S)	NOAA
1970.01.04	Tonghai	7.5	15,621 (S)	NOAA
1966.03.07	Ningjin	7.0	1,000 (S)	NOAA
1933.08.25	Maowen	7.5	9,300 (S:6,800, L:2,500)	EERI
1931.08.10	Fuyan, Xinjiang	8.0	10,000 (S)	NOAA
1927.05.22	Gulang	7.6	40,900 (S)	NOAA
1925.03.16	Talifu	7.0	5,800 (S)	NOAA
1923.05.24	Lohuo, Sichuan	7.3	3,500 (S)	NOAA
1920.12.16	Haiyuan	7.8	273,400 (S)	NOAA
1917.06.30	Daguan	7.5	1,800 (S)	NOAA
1911.01.03	Kebin	7.7	450 (S)	NOAA
1556.01.23	Shaanxi	8.0	830,000 (S)	NOAA
1303.09.25	Shanxi	8.0	200,000 (S)	NOAA

Causes of the fatalities (S: Structure, L: Landslide)

横幅8cm

Table 4. List of the tsunami events.

Tsunami event name	Date	Cause	Approx. fatality	Approx. maximum runup height (location)
1. Meiwa (Yaeyama)	24 Apr. 1771*	Earthquake and submarine landslide?	12,000	30 m (Ishigaki Island, Japan)
2. Unzen	21 May 1792*	Debris avalanche by volcanic earthquake	10,000	50 m (Nagasaki, Japan)
3. Krakatau Volcano	27 Aug. 1883*	Volcanic eruption	36,417**	42 m (Sunda Strait, Indonesia)
4. Moro Gulf (Mindanao)	16 Aug. 1976	Earthquake	Over 8,000**	4 m (Moro Gulf, Philippines)
5. Sea of Japan	26 May 1983	Earthquake	103	15 m (Akita, Japan)
6. Papua New Guinea	17 Jul. 1998	Earthquake and submarine landslide	Over 2,200**	15 m (Sandaun, Papua New Guinea)
7. Indian Ocean	26 Dec. 2004	Earthquake	290,000**	51 m (Banda Ache, Indonesia)
8. Japan Tohoku	11 Mar. 2011	Earthquake	18,378	40 m (Iwate, Japan)

* Local date

**Total fatalities in the event

横幅8cm

Table 5. Frequency of VEI of Holocene eruption occurred in East and Southeast Asia excluding Russia and United States from Smithsonian Global Volcanism Program (2013).

VEI	Number
8	0
7	4
6	19
5	37
4	144
3	384
2	1,728
1	534
0	88
not mentioned	508

横幅5cm

Table 6. List of pyroclastic fall eruption shown on this map.

Volcano	Age	VEI	Reference
Tambora	1815AD	7	Self et al. (2004), Zollinger (1855), Kandlbauer and Sparks (2014)
Rinjani	1257AD	7	Lavigne et al. (2013)
Changbaishan	936AD	7	Machida and Arai (2003), Wei et al. (2013), Horn and Schmincke (2000)
Kikai	7 ka	7	Machida and Arai (1978), Machida and Arai (2003)
Pinatubo	1991AD	6	Paladio-Melosantos et al. (1996)
Krakatau	1883AD	6	Verbeek (1885), Simkin and Fiske (1983)
Dakataua	800AD	6	Silver et al. (2009), Neall et al. (2008)
Rabaul	540AD	6	Walker et al. (1981), Nairn et al. (1995), Nairn et al. (1989)
Witori	3.4 ka	6	Machida et al. (1996)
Mashu	7.6 ka	6	Katsui et al. (1975), Kishimoto et al. (2009)
Ulreung	8.8 ka	6	Lim et al. (2008), Machida (1990), Machida and Arai (1983)
Moekeshi	9.4 ka	6	Nakano et al. (2001), Nakagawa et al. (2013)
Pleistocene well-documented eruptions for comparison			
Aira	30 ka	7	Machida and Arai (1988), Machida and Arai (2003), Kawai and Miyake (1999)
Aso	90 ka	7	Machida et al. (2003), Machida and Arai (2003)
Toba	74 ka	8	Ninkovich at al. (1978), Self (2006), Lee et al. (2004)

横幅12cm

Table 7. List of large-scale ignimbrites shown on the map

Ignimbrite	Age	Source	Volume (km^3)	VEI	Region, Country	Reference
Ito	30ka	Aira Caldera	350	7	Kyushu, Japan	Aramaki (1984), Machida and Arai (2003)
Aso 4	90ka	Aso Caldera	600	7	Kyushu, Japan	Ono et al. (1977), Ono and Watanabe (1985), Machida and Arai (2003)
Hachinohe	15ka	Towada Caldera	20	6	Tohoku, Japan	Hayakawa (1983), Nakawaga et al. (1972), Machida and Arai (2003)
Toya	110ka	Toya Caldera	170	7	Hokkaido, Japan	Okumura and Sangawa (1984), Machida and Arai (2003)
Shikotsu	40ka	Shikotsu Caldera	300	7	Hokkaido, Japan	Yamagata (1992), Machida and Arai (2003)
Kussharo 4	120ka	Kussharo Caldera	>150	7	Hokkaido, Japan	Okumura (1991), Machida and Arai (2003)
Changbaishan	938AD	Tianchi (Changbaishan, Baitoushan) volcano	>100	7	Ryanggang, North Korea and Jilin, China	Wei et al. (2013), Taniguchi (2004)
Pinatubo	1991AD	Pinatubo volcano	10.4	6	Luzon, Philippines	Newhall and Punongbayan (1996)
Krakatau	1883AD	Krakatau Caldera	13.6	6	Sunda Strait, Indonesia	Sigurdsson et al. (1991)
Tambora	1815AD	Tambora volcano	100	7	Sumbawa, Indonesia	Sigurdsson and Carey (1989), Kandlbauer and Sparks (2014)
Toba	74ka	Toba Caldera	2,500-3,000	8	Sumatra, Indonesia	Timmreck et al. (2012), Aldiss et al. (1983), Acharyya and Basu (1993), Rose and Chesner (1987)
Rabaul	540AD	Rabaul Caldera	11	6	East New Britain, Papua New Guinea	Nairn et al. (1995), McKee et al. (1985), Walker et al. (1981)

VEI: Volcanic Explosivity Index (Newhall and Self, 1982)

Volume: include co-ignimbrite ash

横幅 15cm

Table 8. Worst top 25 fatalities caused by volcanic events in Japan (after 1400AD)

Number	Volcanic Event	Year	Date	Fatalities (total)	Eruption Type	Causes and fatalities	VEI
1	Unzen Mayuyama	1792	May 21	15,000	Debris avalanche	W (10,000), D (5,000)	4
2	Asama Tenmei	1783	Aug. 5	1,491	Pyroclastic flow, debris avalanche and lahar	L (1,025), D (466)	4
3	Oshima-Oshima	1741	Aug. 27	1,467	Debris avalanche	W (1,467)	4
4	Hokkaido Komagatake	1640	May 24	700	Debris avalanche	W (700)	5
5	Akagi	1947	Sep. 16	699	Lahar	L (699)	-
6	Bandai	1888	July 15	477	Debris avalanche and phreatic eruption	D (377), P (100)	4
7	Tateyama	1958	Apr. 9	279	Debris avalanche	L (279)	4
8	Nasu	1410	Mar. 5	180	Pyroclastic flow, tephra fall, lava flow and lahar	L (180)	3
9	Sakurajima An-ei	1779	Nov. 8	153	Pyroclastic flow, lava flow and tephra fall	T (100), W (53)	5
10	Tokachidake	1926	May 24	144	Pyroclastic flow, tephra fall and lahar	L (141), T (3)	2
11	Aogashima	1785	Apr. 18	130	Pyroclastic fall and lava flow	R (130)	3
12	Izu Torishima	1902	Aug. 7	125	Phreatic eruption	P (125)	2-3
13	Usu Bunsei	1822	Mar. 23	103	Pyroclastic flow (surge)	P (103)	4
14	Adatara	1900	July 17	72	Pyroclastic flow	P (72)	2
15	Ontake	2014	Sep. 27	63	Phreatic eruption	T (63)	2
16	Sakurajima Taisho	1914	Jan. 12	63	Pyroclastic flow, lava flow and tephra fall	R (40), T (23)	4
17	Kuchinoerabu-jima	1841	Aug. 1	>50	Pyroclastic flow	P (>50)	2-3
18	Unzen Heisei	1991	June 3	43	Pyroclastic flow	P (43)	2
19	Sakurajima An-ei	1781	Apr. 11	38	Pyroclastic flow, lava flow and tephra fall	W (38)	4
20	Bayonnaise Rocks	1952	Sep. 24	31	Base surge	P (31)	2
21	Esan	1846	-	>30?	Lahar	L (>30)	-
22	Unzen	1664	Apr. 15	>30	Lahar	L (>30)	-
23	Ontake	1984	Sep. 14	29	Debris avalanche	D (29)	3
24	Hokkaido Komagatake	1856	Sep. 25	25	Debris avalanche	P (23), T (2)	4
25	Aso	1958	June 24	12	Phreatic eruption	T (12)	2

P: Pyroclastic flow and surge, T: Tephra fall and ballistics, W: Wave and tsunami, L: Lahar, D: Debris avalanche, and R: Related death

横幅 12cm

Table 9. Worst top 15 fatalities caused by volcanic events in Philippines (after 1400AD)

Number	Volcanic Event	Year	date	Fatalities	Eruption Type	Cause and fatalities	VEI
1	Mayon	1875	-	>1,500	Lahar (rain)	L (>1,500)	1-2
2	Taal	1911	Jan. 30	>1,335	Pyroclastic flow	P (>1,100), W (>235)	3
3	Mayon	2006	Nov. 30	1,266	Lahar	L (1,266)	1
4	Mayon	1814	Feb. 1	1,200	Pyroclastic flow and Lahar	P (1,100), L (100)	4
5	Pinatubo	1991	June 15	800	Pyroclastic flow and tephra fall	P (25), L (100), R (450)	6
6	Hibok-Hibok	1951	Dec. 4	>500	Pyroclastic flow	P (>500)	1-2
7	Mayon	1897	June 25	350	Pyroclastic flow and tephra fall	P (310), T (40)	4
8	Taal	1965	Sep. 28	>250	Pyroclastic flow and Base surge	P (>150), W (>100)	4
9	Mayon	1981	June 30	>200	Lahar (rain)	L (>200)	4
10	Parker	1995	Sep. 6	<100	Lahar (rain)	L (<100)	-
11	Mayon	1993	Feb. 2	77	Pyroclastic flow	P (77)	2
12	Hibok-Hibok	1950	Sep. 15	68	Pyroclastic flow	P (68)	1-2
13	Mayon	1766	Oct. 23	49	Lahar	L (49)	-
14	Mayon	1853	Sep. 13	34	Pyroclastic flow	P (34)	3
15	Mayon	1887	Mar. 9	15	Pyroclastic flow and tephra fall	T (15)	3

P: Pyroclastic flow and surge, T: Tephra fall and ballistics, W: Wave and tsunami, L: Lahar, D: Debris avalanche, and R: Related death

横幅12cm

Table 10. Worst top 30 fatalities caused by volcanic events in Indonesia (after 1400AD)

Number	Volcanic Event	Year	Date	Fatalities (total)	Eruption Type	Causes and fatalities	VEI
1	Tambora	1815	Apr. 10	60,000	Pyroclastic flow and tsunami	P (11,000) and R (49,000)	7
2	Krakatau	1883	Aug. 27	36,417	Pyroclastic flow and tsunami	P (2,000), W (34,417)	6
3	Kelut	1586	-	10,000	Pyroclastic flow?	P (10,000)	-
4	Kelut	1919	May 19	5,110	Pyroclastic flow and lahar	L (5,110)	4
5	Galunggung	1822	Oct. 8	4,011	Pyroclastic flow	P (3,600), L (411)	5
6	Merapi	1672	Aug. 4	3,000	Pyroclastic flow	P (3,000)	3
7	Awu	1711	Dec. 11	3,000	Pyroclastic flow	P (3,000)	3
8	Papandayan	1772	Aug. 12	2,957	Debris avalanche	D (2,957)	3
9	Awu	1856	Mar. 2	2,806	Pyroclastic flow	P (2,806)	3
10	Makian	1760	-	2,000	Pyroclastic flow and lahar	L (2,000)	4
11	Awu	1892	June 7	1,532	Pyroclastic flow and lahar	P (1,150), L (382)	3
12	Merapi	1930	Dec. 18	1,369	Pyroclastic flow and laha	P (1,369)	3
13	Gamalama	1775	-	1,300	Pyroclastic flow (base surge)	P (1,300)	3
14	Agung	1963	Mar. 17	1,148	Pyroclastic flow, tephra fall and lahar	P (820), T (163), L (165)	4
15	Raung	1638	-	>1,000	Lahar	L (>1,000)	4
16	Awu	1812	Aug. 6	953	Pyroclastic flow and lahar	P (700), L (253)	4
17	Iliwerung	1979	July 18	539	Debris avalanche and Tsunami	W (539)	3
18	Ruang	1871	Mar. 3	400	Collapse of lava dome and tsunami	W (400)	2
19	Sumeru	1981	May 14	372	Lahar	L (372)	-
20	Merapi	2010	Oct.-Dec.	353	Pyroclastic flow	P (353)	3
21	Makian	1861	Dec. 29	326	Pyroclastic flow	P (326)	4
22	Paluweh	1928	Aug. 4	226	Explosive eruption and Tsunami	W (226)	3
23	Sumeru	1909	Aug. 29	221	Lahar	L (221)	-
24	Kelut	1966	Apr. 26	215	Pyroclastic flow and lahar	L (214), P (1)	4
25	Sorikmarapi	1892	May 21	180	Lahar	L (180)	2
26	Merapi	1872	Apr. 17	170	Pyroclastic flow	P (170)	2
27	Dieng	1979	Feb. 20	149	Volcanic gas	G (149)	1
28	Sumeru	1976	Nov. 13	133	Pyroclastic flow and lahar	L (133)	2
29	Kaba	1833	Nov. 24	126	Lahar	L (126)	2
30	Dieng	1944	Dec. 4	117	Phreatic eruption	T (117)	2

P: Pyroclastic flow and surge, T: Tephra fall and ballistics, W: Wave and tsunami, L: Lahar, D: Debris avalanche, G: Volcanic gas, and R: Related death

横幅 12cm

Table 11. Worst top 5 fatalities caused by volcanic events in Papua New Guinea (after 1400AD)

Number	Volcanic Event	Year	date	Fatalities	Eruption Type	Cause and fatalities	VEI
1	Ritter Island	1888	Mar. 13	3,000	Debris avalanche and tsunami	W (3,000)	2
2	Lamington	1951	Jan. 21	2,942	Pyroclastic flow	P (2,942)	4
3	Long Island	1660	-	2,000	Pyroclastic flow and tsunami	P (1,000), W (1,000)	6
4	Rabaul	1937	May 29	507	Pyroclastic flow and tephra fall	P (300), T (207)	4
5	Rabaul	1850	-	>500	Pyroclastic flow and tephra fall	T (>500)	4

P: Pyroclastic flow and surge, T: Tephra fall and ballistics, and W: Wave and tsunami

横幅12cm