SEISMOLOGY AND VOLCANOLOGY

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Contents

1. Seismology
1.1. History and Development
1.2. Main Problems and Trends
1.3. Earth’s Earthquake Activity
1.4. Elasticity and Seismic-Wave Equations
1.5. Seismic Waves within Earth
1.6. Earthquake Sources
1.6.1. Conventional Source Models
1.6.2. Magnitude, Seismic Moment, Energy, and Intensity
1.7. Earthquake Prediction
2. Volcanology
2.1. Historical Notes, Development, and Trends
2.2. Some Principal Terms and Definitions
2.3. Volcanic Activity on Earth
2.4. Types of Volcanic Eruptions
Appendices
Glossary
Bibliography
Biographical Sketch

Summary

Seismology and volcanology are sciences investigating two excessively interesting and disastrous natural phenomena—earthquakes and volcanoes. Among the disasters on Earth, earthquakes should be classified as the most unfavorable ones. Approximately a quarter of Earth’s dry land is in active earthquake zones along the main seismic belts. Seismology is the study of earthquake sources, the seismic waves propagating through Earth, and the resulting unfavorable impacts on the surface. Seismological studies and results are the basis for the present ideas about the deep structure and physical properties of our planet. The practice of earthquake prediction is related not only to its pure scientific importance but also to humankind’s need for effective protection from earthquake disasters. Regarding the prediction problem, humankind owes much to seismology. Volcanic eruptions are spectacular phenomena that have piqued human curiosity since ancient times. They can cause great harm, but on the other hand they can also be of benefit to man. Periods of extreme volcanic activity can influence the climatic
conditions and the evolution of flora and fauna. Volcanic eruptions and deposits are a remarkable source of fertile lands, of mineral resources, and of the formation of continents themselves.

1. Seismology

Seismology is the study of earthquakes. The name comes from the Greek *seismos* (earthquake) and *logos* (science). Seismology can be considered an ancient and at the same time a modern science. Ancient, because from antiquity, the impacts of earthquakes have drawn attention, and modern because only since the middle of the nineteenth century has it been possible to study earthquake phenomena more comprehensively from a scientific and methodological point of view. Seismology has its own object of study, methods, tools, and instrumentation. The object is borrowed from geology, the methods are physical, the basic tools are mathematical, and the instrumentation is mainly mechanical and electronic.

1.1. History and Development

Earthquakes have played an important role in the geological history of our planet. The first descriptions of earthquakes come from China and refer to 3000-2000 BC. In world histories, the strongest events since 2000 BC are dated. Considerations on the nature of the phenomena also appeared early. Thales of Milet (ca. 700-600 BC) thought Earth was a sphere floating in water and high seas caused earthquakes. Heraklit (ca. 600-500 BC) thought fire was at the root of everything and assumed volcanoes caused earthquakes. Aristotle (ca. 400 BC) considered earthquakes were the result of “dense air and vapors” within Earth. The Chinese mathematician and astronomer Chan Hen constructed the first seismoscope in AD 132.

Many centuries of accumulation of knowledge in all fields of natural sciences passed. In the second half of the seventeenth century, the English scientist Robert Hook published the fundamental law of the elasticity theory (1678). The development in mechanics and mathematics during the first half of the nineteenth century stimulated progress in seismology. In 1828, the Frenchman S.D. Poisson predicted theoretically the existence of longitudinal and transverse elastic waves. In the period 1828-1831, Poisson and the Russian scientist M. Ostrogradski wrote the first works on general methods for integrating the equations of the elasticity theory. In England in 1837, J. Green introduced the elastic potential and determined that 21 elastic modules characterized the anisotropic bodies. The Englishman G.G. Stocks presented the first mathematical model of earthquake sources. The German scientist G. Kirchoff gave the solution of the wave equation in 1855. The Irish researcher Robert Mallet used the accumulated knowledge in studying the strong earthquake of 1857 in Naples, Italy and realized the first attempt of applying the physical principles for explanation of the earthquake impacts. In this sense, he is probably the founder of the physics of earthquakes. It is impossible herein to mention all the results obtained, so a short chronological list is given below:

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
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<tbody>
<tr>
<td>1879-</td>
<td>A group of English scientists constructed seismographs in Japan.</td>
</tr>
<tr>
<td>1880</td>
<td></td>
</tr>
<tr>
<td>1883</td>
<td>The 10-grade macroseismic scale of Rossi-Forel was developed.</td>
</tr>
<tr>
<td>1885</td>
<td>Lord Rayleigh (England) theoretically predicted the existence of surface waves.</td>
</tr>
</tbody>
</table>
1887 Seismological stations were installed in California.
1889 The first distant earthquake (in Japan) was recorded in Potsdam, Germany, on April 17.
1892 In Japan, the English scientist J. Milne constructed a seismograph suitable for the creation of a worldwide network of stations.
1897 R.D. Oldham (England) showed that records of distant earthquakes consisted of three waves: first and second “preliminary” (now P and S) and “large” (now surface) waves.
1898 In Japan, F. Omori constructed seismographs which became widely used in the world.
1900 Omori created the first version of the Japanese severe-grade macroseismic scale.
1901 Wiechert constructed the “Wiechert” astatical seismograph.
1903 The International Seismological Association (now IASPEI) was founded; E.H. Love, England, developed the theory of point sources.
1904 H. Lamb (England) set forth the theoretical fundamentals of wave propagation in a layered medium.
1906 B.B. Galitzin (Russia) constructed the first electromagnetic seismograph which revolutionized seismological recording; H.F. Reid (USA) created the elastic rebound theory of earthquake source studying the April 18 disastrous earthquake in California (published 1910).
1909 The Croatian scientist A. Mohorovičić discovered the boundary between the crust and mantle, now known as Moho discontinuity.
1910 L. Geiger (Germany) created a method for determining the earthquake hypocenter parameters.
1911 Love worked out the theory of the horizontally polarized surface waves.
1912 The Mercalli-Cankani-Sieberg (MCS) 12-grade macroseismic scale was created.
1913 B. Gutenberg (Germany) determined the radius of Earth’s core.
1918 The first volume of the International Seismological Summary (ISS) was published.
1922 H.H. Turner (England) suspected the existence of deep-focus earthquakes. (Their existence was confirmed by K. Wadati [Japan] in 1928.)
1923 The Great Kanto earthquake occurred in Japan, demolishing Tokyo and Yokohama; the Earthquake Research Institute (ERI) was established.
1925 The Wood-Anderson short-period torsion seismograph was constructed in the USA.
1931 Wood and F. Neuman created the Modified Mercalli Scale (MM) for USA.
1935 Ch. Richter (USA) published the magnitude scale for nearby earthquakes.
1936 Inge Lehmann (Denmark) proved the existence of a solid inner core.
1940 H. Jeffreys (England) and K.E. Bullen (Australia) published the contemporary seismological travel times tables.
1945 Gutenberg published the teleseismic magnitude scales; Gutenberg and Richter introduced the earthquake recurrence law.
1948 G.A. Gamburtsev (Russia) suggested the establishment of earthquake prognostic sites.
1951 The European Seismological Commission (ESC) was established.
1952 H. Honda (Japan) published the methodology for determining the earthquake mechanism.
1960 Earth’s free oscillations were recorded after the strong Chile earthquake.
1964 The International Seismological Center started publishing the ISC bulletin; the 12-grade macroseismic scale of Medvedev-Sponheuer-Karnik (MSK) was published.
1965 The large aperture seismic array (LASA) in Montana (USA) was put into operation.
1966 K. Aki, Japan, introduced the seismic moment.
1967 Global seismicity and earthquake generation was connected with plate tectonics.
1970 NASA sent a seismograph to the Moon and obtained the first moonquake records.
1975 The strong earthquake of 4 February in China was successfully predicted.
1979 The IASPEI Manual of Seismological Observatory Practice was issued.
1985 The Norwegian regional mini seismic array (NORESS) was put into operation.
1990 The International Decade for Natural Disaster Reduction (IDNDR) was launched.

1.2. Main Problems and Trends

So far, there is not any generally adopted scheme concerning the main problems, branches, and trends of seismology. Taking into consideration the known views a synthesized generalization has been attempted.

![Diagram of Main branches of seismology](image)

Figure 1. Main branches of seismology

The following main problems can be considered: (1) the study of earthquakes as a manifestation of contemporary geological activity; (2) clarification of the nature and properties of earthquake sources; (3) investigation of Earth’s wave field, and the kinematic and dynamic parameters of seismic waves; (4) a solution to the direct and inverse problems concerning Earth’s structure and internal properties; (5) elaboration on the theoretical basis of seismic sources and waves; (6) data recording, processing,
storage, and distribution of realized seismic events; (7) improved methods and instrumentation for recording seismic waves; (8) evaluation of seismic hazard and risk; (9) better prediction of earthquakes.

The main branches and trends of seismology are schematically given in Figure 1. The classical branches as well as the newly formed ones, such as the experimental or the extraterrestrial seismology, are included. The main branches are presented on the right of the diagram.

1.3. Earth’s Earthquake Activity

Earthquakes are not evenly and randomly distributed on Earth. They are concentrated along the so-called seismic belts, which coincide with the contact zones between the largest geostructures: the tectonic plates (see Tectonic Processes). The main ones are the Pacific, Eurasian, American, African, Indian, Arctic, Nasea, and Philippine plates. The contact zones are formed by three types of boundaries: constructive (divergent, spreading), destructive (convergent, colliding) and transform faults. The oceanic ridges along which the plates move apart from one another (spreading zones) and form the new oceanic crust are constructive zones. The spreading velocity along the mid-Atlantic ridge varies between 1 and 10 cm per year, and in the Pacific the velocity is, on average, 5 cm per year. The destructive boundaries are the result of collisions between opposing plates, which the subduction (Wadati-Benzioff) zones in the oceans. The transform faults are regulators of the relative horizontal movements and displacements between lithospheric plates. The reasons for the relative movements of the plates are connected with the convective fluxes in the mantle under conditions of an active lithosphere, i.e., with the behavior of heavy solid bodies or plates “floating” on a plastic or partially melted astenosphere.

The strongest earthquakes are associated with collision zones and transform faults. According to the source depth, the earthquakes are divided into three groups: shallow (surface to 70 km), intermediate (70–300 km), and deep events (300–700 km). Deep earthquakes are typical for subduction zones, their depth increasing from the contact line between the plates in the direction of sinking of one plate.

There are two main earthquake belts—the Pacific Ocean belt (PO) and the Alpo-Himalayan belt (AH). The PO belt almost completely encircles the Pacific in the transition sections towards the land. The AH belt passes from the Atlantic through the Mediterranean Sea, Minor and Middle Asia, the Himalayas, China, and Indo-China (divided into northern and southern branches) and ends on the Pacific coast. The secondary belts are the Atlantic, Indian, and South African belts. The dominant annual portion of the earthquake energy is realized along the PO belt (75–80%) and the AH belt (15–20%), while only about 5% is attributed to all other belts.

An assessment of earthquake frequency can be obtained from the recurrence law of Gutenberg-Richter, expressed by the relation

\[ \log N = a - bM \]
where $N$ is the annual number of earthquakes of magnitude $M$ with a mean recurrence period $T = 1/N$ (measured in years) and $a$ and $b$ are empirical coefficients. An approximate evaluation of these coefficients for Earth is $a = 7.8$ and $b = 0.9$ ($a = 6.7$, $b = 0.9$ for shallow events with $M \geq 6$).

The mean annual sum of realized earthquake energy is almost a constant and is of the order of $1–2 \times 10^{18}$ J. In Table 1 the mean parameters for the different earthquake categories are given. Earthquakes with $M \geq 5$ can cause unfavorable consequences. It is seen that the first two categories—the great and major events—form the annual sum of the realized earthquake energy. The seismological stations in the world record annually more than 100,000 earthquakes, most of which are very small.

<table>
<thead>
<tr>
<th>Category</th>
<th>Magnitude ($M$)</th>
<th>Energy ($E$)</th>
<th>Mean annual events ($N$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great</td>
<td>$&gt;8$</td>
<td>$&gt;10^{17}–10^{18}$</td>
<td>$1–2$</td>
</tr>
<tr>
<td>Major</td>
<td>7–8</td>
<td>$10^{16}–10^{17}$</td>
<td>15–20</td>
</tr>
<tr>
<td>Strong</td>
<td>6–7</td>
<td>$10^{15}–10^{16}$</td>
<td>100–150</td>
</tr>
<tr>
<td>Moderate</td>
<td>5–6</td>
<td>$10^{14}–10^{15}$</td>
<td>750–1000</td>
</tr>
<tr>
<td>Light</td>
<td>4–5</td>
<td>$10^{13}–10^{14}$</td>
<td>5000–7000</td>
</tr>
<tr>
<td>Minor</td>
<td>$&lt;4$</td>
<td>$&lt;10^{11}$</td>
<td>$&gt;100$ 000</td>
</tr>
</tbody>
</table>

Table 1. Categories of Earth’s earthquakes and the parameters that define them

Some historical earthquakes that left enduring traces in the memories of eyewitnesses and deserved the specialist’s attention should be noted. One example is the Lisbon earthquake of November 1, 1755, with an epicenter in the Atlantic Ocean. Lisbon and vicinity were almost completely ruined, and because of the high tsunami waves, the casualties were about 50000. The earthquake of October 28, 1891, in Mino-Ovari, Japan, left strong traces on Earth’s surface. After the earthquake, a fault of 100 km was formed with relative horizontal and vertical displacements up to 4 m and 7 m, respectively. About 197 000 buildings were demolished and casualties were over 7000. The most stupendous and well documented historical earthquake is that in Assam (India) of June 12, 1897. Destruction was observed over an area of 350 000 km², and in the epicentral zone, over 75 000 km², everything manmade was demolished. People observed Earth waves with amplitudes of about 30 cm. In the epicentral zone, strong changes in the landscape were observed and the faults had amplitudes up to 12 m.

Information on more recent earthquake activity after 1900 can be obtained from Table 2, where some data on the most destructive events are listed. In the number of casualties, two events stand out, the first one in Japan in 1923 and the second one in China in 1976.

<table>
<thead>
<tr>
<th>Date</th>
<th>Magnitude</th>
<th>Deaths ($10^6$ USS)</th>
<th>Damage ($10^6$ USS)</th>
<th>Region</th>
</tr>
</thead>
</table>
Table 2. Some significant earthquakes after 1900

Earthquakes are some of Earth’s worst disasters. Statistically, after 1970 earthquakes dominate with about 35% of the world’s damage and casualties, while floods and tropical cyclones each account for 20%. The annual risk for casualties is evaluated to be $2–3 \times 10^{-6}$, while the risk of flu or car accidents is significantly larger, about $2 \times 10^{-4}$. The high consequences of earthquakes are explained by two main factors. The first one is connected with the environmental conditions and socio-economic development. Approximately a quarter of dry land falls in active seismic zones. Such zones cover the most climatically and geographically favorable regions with a significant concentration...
of human and material resources, and therefore, a higher risk when seismic events occur. The second factor is determined by the still limited efficiency of earthquake resistance measures, and in some cases, by underestimation or neglect of the real danger from earthquakes. From this viewpoint, humankind owes much to seismology, earthquake engineering, and some socio-economic sciences.

Bibliography


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Biographical Sketch

**Ludmil Christoskov** was born in 1936 in Sofia, Bulgaria. He is a graduate of the Mining and Geology University, receiving his master’s degree in Geophysics in 1959. He has worked more than 40 years in the section of Seismology at the Geophysical Institute of the Bulgarian Academy of Sciences. His major interests cover the problems of regional seismology, geodynamics and natural hazard evaluations, investigation and modeling of the geophysical media, etc. He gained his PhD degree in 1972, became Associate Professor of Seismology in 1973, received a DSc in Physical Sciences in 1984, and became Professor in Seismology in 1986. Since 1977, Professor Christoskov has been a titular lecturer in Seismology in the Meteorology and Geophysics Department of Sofia University. He is a member of the International Association of Seismology and Physics of the Earth’s Interior, the European Seismological Commission, the Bulgarian Geophysical Society, the International Students Institute–Tokyo and was the Chairman of the Expert Council for seismic risk evaluation at the National Coordinating Council of the Permanent Government Commission of Natural Disasters in 1991. Since 1995 he has been Corresponding Member of the Bulgarian Academy of Sciences. Professor Christoskov is author or co-author of over 250 publications and 10 monographs published in Bulgaria and abroad. The main topics of the publications are quantification of the earthquakes, seismological networks and data processing, seismicity and seismic zoning, seismic sources modeling and identification, prognostic approaches in seismology, etc. A textbook on seismology authored by Professor Christoskov is in press.