GEOLOGICAL CATASTROPHES

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Contents

Summary

All types of geological disasters listed in this topic are generated by one and the same cause; i.e., the transition of rock mass from the stable equilibrium to the unstable state. This transition is accompanied by a catastrophically rapid release of enormous amounts of energy that were stored up in the Earth in the course of the many centuries-old history of evolution. Mankind still inadequately assesses the forms and scale of the energy life of our planet. The energy is accumulated and redistributed by convective flows of semi-melted matter at large depths, by the movement of the Earth's crust plates, by the gravity and electromagnetic influence of the Sun, by the radioactive decay of elements and the chemical and electrochemical reactions, by the phase transitions of one type of minerals into other minerals, and by the technical activity of people.

Relaxation of the accumulated energy can occur by the evolution of the plastic flow of rock masses and a gradual transfer of heat from hot masses to cooler ones. But since the structure of the Earth's interior is heterogeneous both in mineral composition and in physical properties, there invariably appear areas with an excessive amount of accumulated energy, including high mechanical stresses reaching the limit of durability of rocks. Relaxation is caused by the destruction of rocks, which results in an

earthquake, a rock shock, or a magma outflow onto the Earth's surface in a volcano funnel. Tsunami waves can be caused by an earthquake or a volcanic eruption on the sea floor.

1. Introduction

This article discusses the geological hazards of endogenic origin; i.e., events caused by processes developing in the Earth's interior; these phenomena are initiated by continuously active differentiation processes in the Earth's matter and by convective flows of rock mass in the unstable state of both density and temperature. This unstable state is a consequence of the Earth's evolution as a planet and of its warming by the radioactive decay of elements. Four types of the most dangerous geological catastrophes can be indicated: earthquakes, tsunami waves, volcanic eruptions, and rockbursts.

2. Earthquakes

An earthquake is a consequence of a rupture of rocks (a gigantic fracture) in the depth of the Earth. After a few seconds, the elastic waves, radiated by the moving banks of the rupture, reach the Earth's surface and, in strong earthquakes, cause the destruction of buildings and loss of human lives. The present-day geological and seismological knowledge testifies that earthquakes appear as a result of sudden discharges of mechanical stresses that accumulate in the Earth.

The first to reach the Earth's surface are the compression-extension waves (longitudinal waves) that propagate in rocks at the rate of 6-8 km per second. They are followed by the transversal waves, the velocity of which, on the average, is 1.7 times less. Then, along the upper roof of the Earth, the surface waves propagate, which during strong earthquakes can run several times around the Earth's globe with slowly attenuating amplitude. In 1920s the earthquakes started to be registered by many instruments (seismographs) and since then it has been noted that different observation stations record the anti-polar directions of the first arrivals of longitudinal waves. It was established that the sign of the first arrival (positive or negative) corresponds to the arrival of the phase of compression or extension of rocks. Further research revealed a quadrant distribution of the anti-polar signs on the Earth's surface. This phenomenon is observed practically during all earthquakes and is evidence that the banks of the rupture, causing the earthquake, move in such a way that the normal component of their relative movement is much less, than the displacement component. If the earthquakes were caused by the source of volumetric expansion of the material (the explosion type), then the first arrivals of the longitudinal waves at all observation points should have the same sign. Consequently, it was irrevocably established that earthquakes are caused by shear ruptures. This should be kept in mind when evolving any hypothesis about the character of a given natural calamity. The ruptures of most of the dangerous (strong) earthquakes appear at depths of the first tens of kilometers from the Earth's surface; i.e., within the so-called Earth's crust.

2.1. The earthquake source

The earthquake source is a rupture, or a system of ruptures, that appear in the Earth's crust during an earthquake. The release of the accumulated elastic energy during the movement of the banks of the rupture occurs as a result of deformation. The energy in the course of an earthquake attenuates and is redistributed in a certain volume of rocks surrounding the rupture. But the boundaries of this volume, strictly speaking, cannot be defined, and practically they largely depend on the structure and the stress-deformation state of the Earth's crust. Not every rupture necessarily radiates elastic waves in the frequency spectrum studied in seismology (10^{-3}–10^{2} Hz), but only that whose velocity of sides relative displacements is very high and actually exceeds several kilometers per second.

During very strong earthquakes, the ruptures that have caused them sometimes reach the Earth's surface. In such cases the source is said to have emerged on the surface.

Figure 1. The rupture of the December 7, 1988 Spitak Earthquake.

The length of the ruptures of the strongest earthquakes can be several hundreds of kilometers. The relative displacements of the banks of the rupture on the Earth's surface, vertical and horizontal, reach several meters. The point in the Earth's interior, at which the movement was started by the rupture causing the earthquake, is called the hypocenter of the earthquake, whereas the projection of this point on the surface is called the epicenter.

2.2. The strength of an earthquake

Different methods were suggested for the quantitative estimation of the earthquake's magnitude, but the most practical one is the scale of magnitudes (*M*), which allows a rather simple comparison of different earthquakes. The magnitude characterizes the value of an earthquake near its hypocenter; i.e., in the Earth's interior, and it is calculated on the basis of measurements of seismic oscillations at seismic stations. Ch. Richter was the first to elaborate the scale of magnitude for earthquakes the foci of which are located at depths of no more than 60 km and at distances from the observation stations not farther than 600 km. Later, more universal scales were also developed. The simplest magnitude for measurement of the value of strong earthquakes is the magnitude calculated from surface waves using the relationship

$$M = \lg(A/T) + B\lg\Delta + \varepsilon, \qquad (1)$$

where *A* and *T* are the amplitude and the period of oscillations in the wave respectively; Δ is the distance from the observation station to the epicenter of the earthquake, *B* and ε are the constants depending on the regional geological conditions and seismograph response. Other types of magnitudes are also applied; they are calculated using the measurements of longitudinal and shear waves from deep earthquakes, when the recording equipment is used with different amplitude-frequency ranges in the spectrum or longevity (code) of oscillations. Often in seismological practice, instead of the earthquake magnitude, the term earthquake strength is applied, thus qualifying the earthquakes as strong and causing destruction and as weak and not dangerous in themselves to population and constructions. Experience shows that destructive are the earthquakes that have magnitudes greater than 5.5, while the strongest have magnitudes of about 9. The magnitudes, calculated by various methods, differ by about 0.5 of unit. Below are the values of magnitudes calculated from surface waves, if otherwise not indicated.

The scale of magnitudes shows the relative strength of an earthquake, but it yields few data on the physical properties of the seismic source. Therefore, the total energy E, radiated by the source of elastic (seismic) waves, is calculated. As the first approximation, the energy is assumed proportional to the product of the square of *A* wave amplitude, related to period *T*, by longevity *t* of the wave passing through the registration point

$$E = C(A/T)^2 t \qquad (2)$$

The calculations take into account the geometric discrepancy and energy absorption on the path from the hypocenter to the observation station.

The correlation of formulas (1) and (2) shows that there should be no linear compatibility between the magnitude and the energy of earthquakes. An approximate evaluation of correlations between these formulas is given in Table 1.

M	*E, erg*	*M*	*E, erg*
8.5	$3.6 \bullet 10^{24}$	6.0	$6.3 \bullet 10^{20}$
8.0	$6.3 \bullet 10^{23}$	5.5	$1.1 \bullet 10^{20}$
7.5	$1.1 \bullet 10^{23}$	5.0	$2.0 \bullet 10^{19}$
7.0	$2.0 \bullet 10^{22}$	4.5	$3.6 \bullet 10^{18}$
6.5	$3.6 \bullet 10^{21}$	4.0	$6.3 \bullet 10^{17}$

Table 1. Correlation between *M* magnitude and *E* energy of earthquakes.

It follows from Table 1 that the rise of magnitude by 2 units corresponds to the increase of energy one thousand times. In order to obtain an approximately linear correlation between energy and magnitude, one can use the energy algorithm

$$\lg E(J) = aM + b \qquad (3)$$

The *a* and *b* values, adopted in modern practice, are: $a = 1.5$, $b = 4.8$.

According to the data presented by many researchers, the dependencies between the size of the source and the strength of the earthquakes are now obtained in a number of countries. The dimensions of the source, in most cases, were determined from the length of the ruptures that emerged on the surface, or from the sizes of the areas of repeated shocks (aftershocks). The boundaries of the latter form contours around the rupture areas. The generalized dependence between the length of the rupture *L* and the magnitude *M* can be represented by the formula

$$\lg L(km) = cM + d \qquad (4)$$

Into this dependence are also introduced corrections as the depth of the hypocenter requires. The length of the rupture of the earthquake with magnitudes 7 usually varies from 30 to 40 km. During the strongest earthquakes with magnitude more than 8, the ruptures several hundreds of kilometers long were observed. It should be noted that the relative displacements of the rupture banks, actually causing the seismic waves, comprise only a small portion of the total length of the rupture and are within a few meters long.

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Biographical Sketch

Gennady A. Sobolev, born on April 7 1935, graduated from the Moscow State University in 1958, geophysisist. 1963–Candidate of sciences (physics and mathematics). 1969–Head of Laboratory in the Institute of Physics of the Earth. 1976–Doctor of sciences (physics and mathematics). 1985–Professor. 1990–Member of Russian Academy of Natural Sciences (RANS). 1994–Member of Russian Academy of Sciences (RAS).

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