THE NATURE OF EARTHQUAKES

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Contents

Summary

The principal features of the geological environment are described, as well as the forces and tectonic structures responsible for producing an earthquake. The following topics are presented: data distribution of earthquakes on Earth, the reasons for the occurrence of shallow earthquakes (in the Earth's crust), kinds of seismogenerating faults, types of the Earth's lithosphere and the main theses of Plate Tectonics, types of seismic waves, measurements of the intensity of an earthquake, the seismotectonic models of earthquake source, the nature of deep (in mantle) earthquakes, and the results of study into earthquake recurrence interval. Essentially, the modern ideas and knowledge about an earthquake origin and nature are discussed.

1. Distribution of earthquakes on the Earth

An **earthquake** is an abrupt, rapid shaking of the Earth produced by the release of tectonic energy stored in geological rocks. This energy can be built up and accumulated for many years and then discharged in short time (seconds or minutes). Many earthquakes are so weak that humans can not feel them. Some, on the other hand, have caused enormous destruction and have killed many hundreds or thousands of people. The dots on the world's map above indicate the regions of earthquake activity (Figure 1).

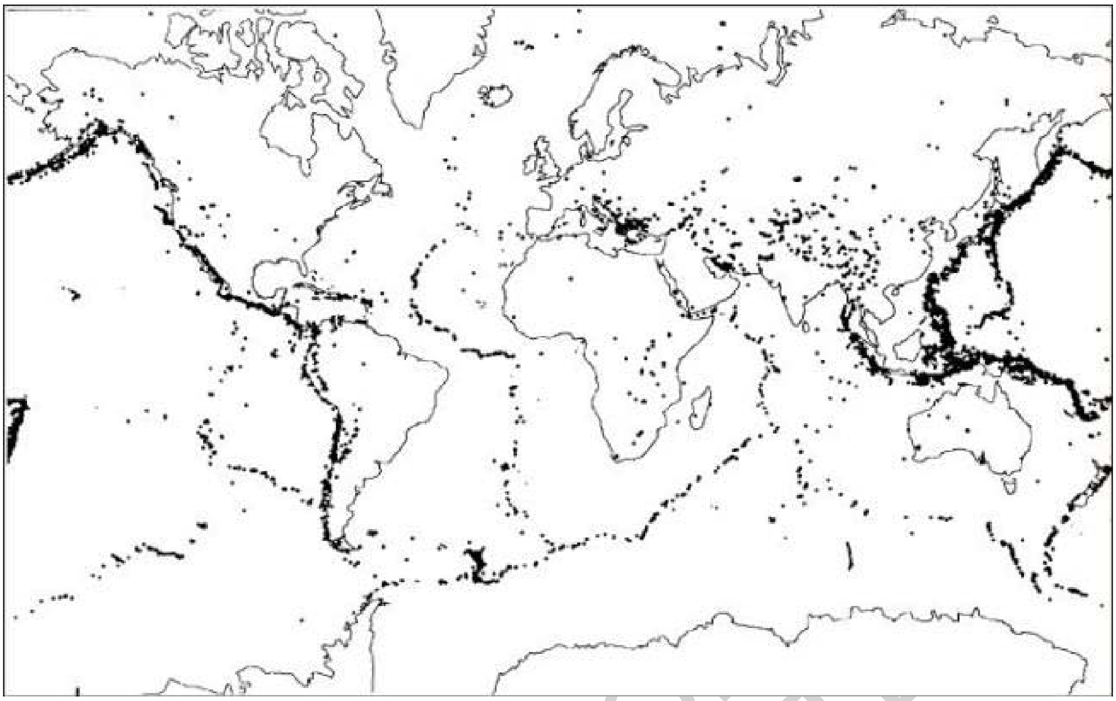

Fig. 1. Distribution of epicenters of shallow (lithosphere) earthquakes (<50 km) with magnitude more and equal than 5.5, for the period 1965-1989 on the Earth. Seismological data have taken from NEIC (National Earthquake Information Center) catalog.

A seismological map of the Earth (Figure 1) reveals the epicenters of earthquakes are for the most part located on long arcing bands - the seismological belts that circumscribe the globe. These seismological belts mark the convergence, divergence and transform boundaries that define the lithosphere plates of the Earth. A lot of the active seismological belts lie close to or are underneath heavy populated areas of human habitation.

There are two major regions of earthquake activity *in continents and continental margins.* One is the circum-Pacific belt, which surrounds the Pacific Ocean, and the other is the *Alpine* belt, which slices through Europe and Asia. The circum-Pacific belt includes the West coasts of North America and South America, the Kuril-Kamchatka island arc, Japan, Taiwan and the Philippines. The Alpine belt contains the Mediterranean Region, the Alps, the Carpathians, the Caucasus, the Pontides, the Zagros, the Elburz, the Kopet-Dag, the Himalayas, and the Arakan Yoma. Many earthquakes are also registered outside these belts in the activated areas of ancient tectonism, i.e.rift and orogenic zones of Central Asia, Eastern Africa, South of Northern America and in China.

Rift systems are the long, linear (in plan) zones of horizontal extension in the Earth's crust. In the upper parts of the crust-rift system one or more narrow linear grabens may be found and connected to them are block structures. All blocks in the rift system are bordered or separated by active faults: mainly by normal faults or combined normal faults plus strike-slips. Rift length is usually measured as several hundreds of thousands of kilometers. Rifts are dozens of kilometers in width. A Rift in the relief of the Earth's surface usually appears as a deep, narrow linear valley with steep slopes. In an active period of development rift systems are producing shallow, relatively strong seismicity and high heat flow. There are three types of rift system, according to the deep structure of the crust: intracontinental, intercontinental and oceanic.

Over one million earthquakes may happen each year on the Earth. Most shocks last only seconds, but some large quakes can last minutes. About 90% of all earthquakes are produced at plate boundaries where two plates collide, spreading apart, or sliding past each other. When these plates move quickly, they release an incredible amount of energy being changed into seismic wave movement. Earthquake waves are similar to sound and water waves in the way they move. They are the waves that run through the Earth's crust causing building collapse, bridge snap, mountain rise, soil fall, and in some cases they make the ground open up into huge cracks.

2. Reasons for earthquakes in the Earth's crust

Scientists believe that the movement of the Earth's plates (Figure 2) curves and compresses the rocks at the edges of those plates. Sometimes the bending and squeezing brings great pressure strokes. Rocks are somewhat elastic; they can be bent without crashing. It's as if a rubber band is stretched; if you increase the tension too much, the rubber band will break. Rock layers act in somewhat the same way; if the pressure becomes too great the rock layer cracks and shifts. When it happens the layers move along a fracture in the Earth's crust called a fault, or the delivery of energy causes a new breach to be produced. This rupture of the rocks and the resulting displacement of the geological material are the reasons for an earthquake. A fault is a thin area of crushed earth material between two rock blocks, and can be of any length, from centimeters to thousands of kilometers. It is a fracture in the Earth's crust along which rocks on one side have moved, relative to those on the other side. Most faults are the result of repeated movements over a very long period of geological time.

The plate names: AF - African; AN - Antarctic: AR - Arabian; AU - Australian; AU, Australia; CA, Caribbean; CO, Cocos; EU, Eurasian; IN, Indian; NA, North American; NZ, Nazca; OK, Okhotsk; PA, Pacific; PH, Philippine Sea; SA, South American; SM, Somalia; SC, Scotia Sea. Arrows, with the length of the arrows show plate velocities equal to the predicted displacement for the next 25 million years. Plate convergence rate shown by arrows with solid arrowhead on underthrust plate pointing toward overthrust plate. Gordon, R.G.& Stein, S. calculated these values in 1992. Shaded pattern identifies mainly subaerial regions where deformation is inferred from earthquakes and evidence of active faulting.

Three different kinds of faults (Figure 3) are as follows;

(a) **Normal, dip-slip fault.** The fault plane of a normal fault dips away from the risen hard block. Faulting occurs in response to near-horizontal extension.
(b) **Reverse (thrust, overthrust), dip-slip fault.** The fault plane of a reverse fault dips beneath the risen brittle block. Faulting occurs in response to near-horizontal compression.

(c) **Strike-slip fault**. Crustal blocks slide along each other. The slip can be left lateral (sinistral) or right lateral (dextral). This example shows both left-lateral and right-lateral strike-slip faults.

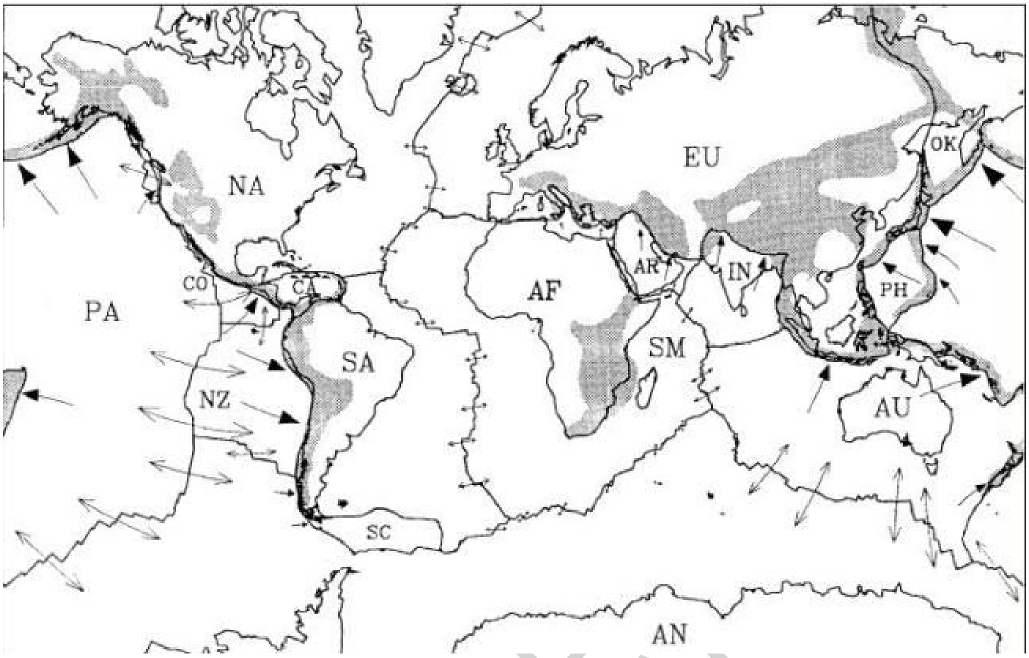

Fig. 2. Map of the world with the main lithosphere plates distribution.

Earthquakes occur at faults. When the rock on one side of the fault quickly slips with respect to the other one an earthquake happens. The fault surface can be vertical, horizontal, or at some angle with the surface of the earth. The slip direction can also be at any angle. Strike-slip earthquake occurs at an approximately vertical fault plane as the rock on one side of the fault slide horizontally along the other. Dip-slip earthquake occurs on an inclined fault. Such fault is at an angle to the Earth's surface and the movement of the rock is up or down.

It's known that an active fault exists: (1) if the earthquake has left surface evidence, such as surface ruptures or fault scarps (cliffs made by earthquakes); (2) if, in the past, a large earthquake has broken the fault (since instrumental recordings began in 1932); (3) if the fault produces small earthquakes, which modern seismographic network can record (since 1970s); and (4) if the fault demonstrates slow geological movements (creep).

Surface rupture occurs when movement in a seismic source at a fault situated deep in the Earth's interior breaks through to the surface. Not all earthquakes result in surface rupture. Fault rupture nearly always follows well known, preexisting geological faults, which are zones of weakness in the Earth's crust. Rupture may occur suddenly during an earthquake and aftershock sequence or slowly in the form of fault creep. Sudden displacements are more damaging because they are accompanied with shaking. Fault creep is the slow movement of faults in the earth's crust. Examples of creep are well known along the Upper Pil'tun Fault in Northern Sakhalin Island long before the Neftegorsk, 1995 (Ms=7.6) destructive earthquake, where the boreholes crossing the fault were destroyed by slow fault displacement without any earthquake.

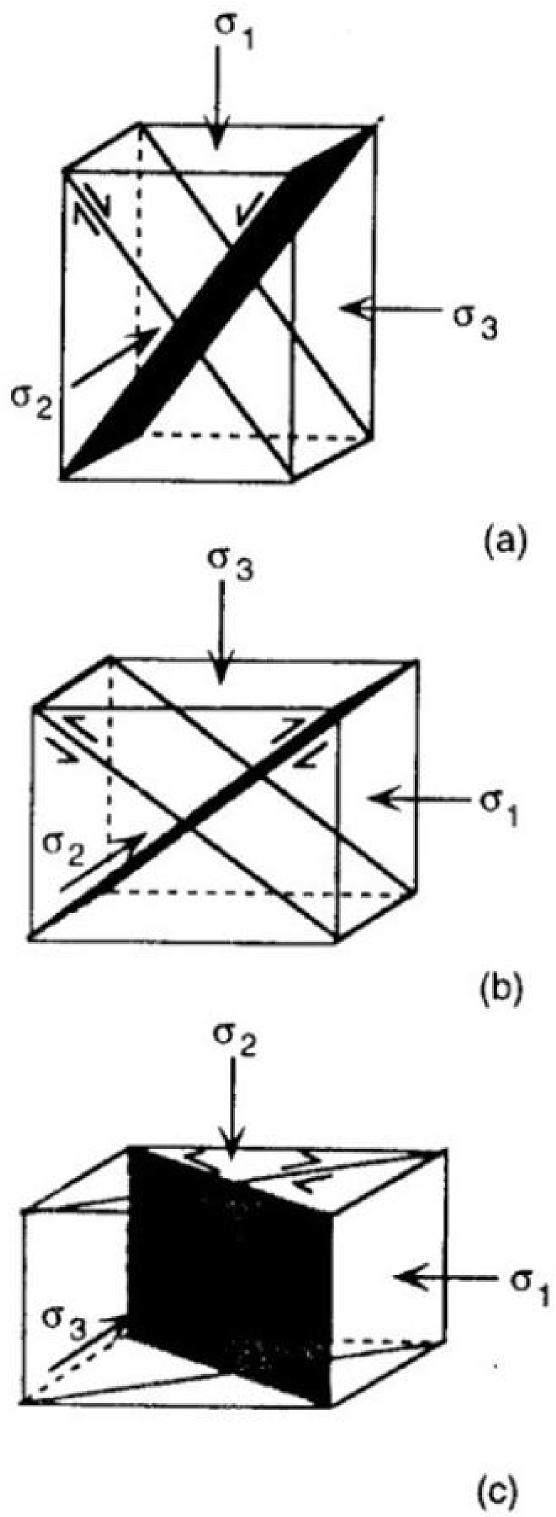

Fig. 3. Orientation of conjugate fault planes (shaded) with respect to principal stress directions (σ1, σ2, σ3) in isotropic rock for (a) normal faults, (b) reverse faults, (c) strike-slip faults. The fault planes are shown as block diagrams.

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Biographical Sketch

Eugene A. Rogozhin, Professor of Geology, was born in 1947. Since 2001 he has occupied position of Deputy Director of United Institute of Physics of the Earth , Russian Academy of Sciences. Since 1996 he has been Director of the Russian Federal Center for Earthquake Prediction of Geophysical Survey of Russian Academy of Sciences, and from 1993 is Head of Seismotectonic Lab. of Institute of Physics of the Earth, Russian Academy of Sciences. In 1971 he graduated from the Geological Department of Moscow State University. In 1971-1974 was a post-graduate student of Institute of Physics of the Earth, USSR Academy of Sciences (supervisor - Prof. V.V. Beloussov). Rogozhin defended his Ph.D. (candidate) theses in 1974 and Full Doctor (Professor) theses in 1990. Major fields of activity include: tectonics, structural geology, modern geodynamics; seismotectonics, tectonics of strong earthquake sources; earthquake prediction, seismic hazard assessment, seismic zoning. E. Rogozhin is author of 200 publications in the field of tectonics, seismotectonics and geophysics.