EARTHQUAKES

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The History and Geography of Earthquakes.

The terrifying effects of earthquakes have made a deep impression upon the human mind, for from the earliest times we have had handed down the traditions of primitive peoples, which clearly are based upon earthquake phenomena.

When, with the advance of civilization, the art of writing was developed, more accurate accounts of earthquakes were preserved. The oldest records of this kind are those from China and Japan, where earthquakes are frequent and severe.

Other centres of ancient civilizations subject to strong earthquake shocks are those of the Mediterranean region, such as Italy, Greece and Palestine. In the latter country one of the greatest earthquakes occurred in the reign of King Uzziah, and is recorded in the Bible.[1] This earthquake made such a profound impression on the Jews that for many years afterwards historic events were stated to have occurred so many years after the earthquake.

Those earthquakes, which are strong enough to destroy buildings, are called destructive earthquakes, and these are frequently attended by loss of life. It is not, however, the actual shock experienced by the movement which is fatal, but the loss of life which arises indirectly from the earthquake. The fall of masonry, bricks and heavy beams used in large buildings is the chief source of danger, and next to this comes the risk of fire from the domestic hearths, which are fed with broken beams.

After an earthquake the disorganization of transport and social services often led to famine and disease, and these exacted a heavy toll of life as they followed in the train of the earthquake.

In some of the Italian earthquakes the loss of life has been very heavy. In the Messina earthquake of 1908 about two-thirds of the population of that city perished, while at Arezzano, which was destroyed by an earthquake in 1915, no less than ninety-six per cent. of the inhabitants were killed.

The greatest death-dealing earthquake of this century was that which destroyed Tokyo in 1923, and here the

[1] Amos. About 790 B.C.

fatalities numbered about one hundred and forty thousand, out of a total of two million inhabitants.

From records which may be relied upon as being trustworthy, it has been estimated that more than three million people have been killed by earthquakes.

The earthquake history of a country can, however, be read easily enough from its surface features or physiography, without any reference to the written or traditional history of its people.

Earthquakes are invariably associated with mountainous countries, and in these the physiographic effects of earthquakes are most pronounced.

I was greatly impressed in Japan and New Zealand, both of which are earthquake regions, by the numerous scars which defaced the forested mountain slopes. These were caused by landslides which had been set in motion by severe earthquake shocks.

In the mountains near Tokyo the slopes are very steep, as, for example, near Hakone. Here, also, the rocks are soft and unstable, because they are composed of the fragmental rocks or tuffs ejected from recent volcanoes.

When a landslide occurs in this country, the freshly exposed rock and soil is quickly replanted with pine forests by the Japanese, so as to protect the surface from further destruction by rainfall. This proves a very effective method of preservation.

While in the Murchison district of New Zealand some years ago, I had occasion to study the geology of a part of the Buller River and its tributaries, and here the recency of a number of landslides gave one a rather uncomfortable feeling, while spending a few nights in a small cottage beneath the towering cliffs flanking a deep gorge of this river system. It was therefore with little surprise that one read a few years later of the great earthquake which caused so much damage in this district. Here one large valley was completely blocked by a great landslide, and the river was held up by the fallen rock débris to form a lake.

The effects of landslides, however, are soon obliterated, and the geologist must rely upon other surface features of the earth in order to work out its earthquake history. The most eloquent testimony is furnished by the characteristic staircase-like profile which flanks the growing mountain ranges of to-day.

The steps are formed by dislocations in the rocks of the earth's crust (which are known as faults), and it is the movement along such faults which causes an earthquake. Such surface features are readily recognized by geologists ;

and from the study of these alone the earthquake activity of a region could be estimated. In regions which have been occupied by civilized man for a few centuries only, as in North America and Australia, such geological evidence is of great value, and may contribute much to the safety of communities which for economic reasons become established in earthquake zones: for the study of earthquakes has made it clear that they have a zonal distribution of a simple character.

The statistical investigation of earthquakes has shown that more than ninety per cent. of all earthquakes occur in two great belts which encircle the earth. The first and greatest of these is the Pacific girdle, which follows the borders of the Pacific Ocean from Cape Horn northwards to Alaska, and thence southwards along the coast of Asia into the East Indies, after which it continues through New Guinea to New Zealand.

The second great earthquake belt can be traced from the East Indies westwards along the southern margin of Asia through Burmah, the Ganges Valley, Persia, and Palestine, whence it then passes along the Mediterranean Sea and, crossing southern Spain, continues across the floor of the North Atlantic Ocean by way of the Azores to the West Indies, and intersects the Pacific zone in the Panama region.

There is also a third well marked zone of earthquake activity along the Great Rift Valley of Africa. This region forms a narrow trough in which the great lakes of Africa are situated, and this has been found to continue northwards into the Red Sea and the Jordan Valley, where it joins the Mediterranean belt.

It will be seen from this account of the distribution of earthquakes that Australia lies at a safe distance from these disturbed regions.

Movements of the Earth during Earthquakes.

In a severe earthquake the shaking may be so violent as to produce nausea and, to make it impossible for people to walk about or even to stand. Sometimes heavy blows are experienced on the soles of the feet due to a sharp upward movement of the ground. Still more uncanny is the movement of visible waves in the ground, which have been described as resembling waves in water. These waves may raise the earth a foot or more above its stationary position. Such earth waves are, however, very rare, and occur only where there is a deep layer of soil.

The actual number of vibrations per second varies greatly, and may range from as few as five per second to

more than forty per second. In those earthquakes where the frequency is fifty or more per second, the vibrations in the air give rise to a low rumbling sound. Such sounds are very common during earthquakes. When the acceleration of the ground reaches seventeen millimetres per second per second the motion can be felt by most persons, but there are many earthquakes with a smaller acceleration which pass unnoticed by people carrying on their daily occupations, although these shocks are well recorded on seismographs. On the other hand, the acceleration may sometimes reach thousands of millimetres per second per second, and even occasionally have a vertical component exceeding the acceleration due to gravity (about nine thousand eight hundred millimetres per second per second). In such cases rocks lying loosely on the earth's surface have been projected into the air for some feet, and sometimes have been overturned before reaching the earth.

During a great earthquake in Iceland several persons lying on the ground of a cliff were hurled over its edge by the earthquake shock.

The water in tanks may be set in motion so violently that the tanks are overturned. In strong earthquakes the motion of the ground has sometimes been so great that trees have swayed to and fro until their higher branches lashed the ground. Even in light earthquakes, hanging bodies, such as chandeliers and pictures, are set swinging to and fro ; and the pendulums of clocks are often stopped during an earthquake.

In addition to these vibrations there are, in strong earthquakes, large movements of the ground which result in permanent displacements. These may be either vertical or horizontal movements.

The horizontal displacements were very noticeable in California after the earthquake which destroyed San Francisco in 1906. Here, in some places, the earth's surface was sheared horizontally to give a displacement of about twenty feet. As a result of this movement the front gardens of some houses were moved along parallel to the street, and were placed in front of the adjoining houses.

The same movement cut across fences and displaced them, so that an owner following his own fence, and keeping it on his left, would suddenly find himself in his neighbour's block, with their common fence on his right. Roads were offset by this horizontal movement of the ground, and the railway tracks and water and gas mains were dislocated in the same way.

The largest vertical movement known to have been caused by an earthquake occurred along the shores of Alaska at Yakutat Bay in 1899. Here, for some miles, the shore rose suddenly to a height of forty-seven feet, carrying with it indisputable evidence of the movement in the zone of shell fish and barnacles still attached to the rocks which were formerly within the tidal range.

While the displacements just mentioned are the largest known to have occurred on the land during the time of man, much larger displacements have been measured on the floor of the sea. Of these, the largest and best authenticated are those measured by the Japanese in Sagami Bay, after the great Tokyo earthquake of 1923. The magnitude of these movements is remarkable, and this is accentuated by the fact that the greatest vertical movement of the land along the shores of this bay was an uplift of about seven feet.

The floor of Sagami Bay had been carefully surveyed about ten years before the earthquake. When it was found, from the study of the seismograph records, that the earthquake originated in this bay, a resurvey was undertaken. The result of this work, which covered an area of about two thousand five hundred square miles, was based upon more than eighty thousand soundings. These showed that an area of about two hundred and seventy square miles had subsided to an average depth of over two hundred feet, while in one part the sinking of the floor amounted to more than fifteen hundred feet. The movement of elevation affected only ninety square miles, and the greatest elevation was about eight hundred feet.

Some Great Earthquakes.

Many great earthquakes have, unfortunately, occurred in the densely populated regions ; so that a great deal of information is available for their study from such sources.

One of the best known of the European earthquakes is that which, in 1755, destroyed the city of Lisbon. The earthquake was heralded for a few seconds by a deep rumbling sound, after which the blow fell with appalling suddenness and the city lay in ruins. Many people were killed outright by the falling buildings ; others were injured and imprisoned, and condemned to the further torture of a fire that fiercely swept through the streets and completed the ruin.

Those that escaped from the horrors of the first few minutes hurried for safety to the waterside and congregated on the great marble quay which had recently been built. This, however, sank without warning, and many

thousands of people were drowned. More destruction was effected by a rapid sinking of the sea itself, carrying off into a maelstrom, the shipping of the port. Finally, the sea returned in a great wave—the greatest known in connection with an earthquake—sweeping all before it and destroying not only what remained of the city, but the coastal villages in its neighbourhood.

The greatest of known earthquakes is that which devastated the Province of Assam in 1897. Here the earthquake shock was felt over nearly two million square miles of the earth's surface, and over about one-tenth of this area the towns and villages were razed to the ground. Fortunately, the area of greatest damage was not densely populated, so that the loss of life was not great.

In this earthquake the ground was severely twisted, with a motion akin to the coiling and uncoiling of a clock spring, and there was, in addition, a very strong vertical movement. Where the soil was of a sandy nature, fence posts were driven into the ground by this movement, and around the bottoms of the posts were small depressions, as if the posts had been violently screwed into the ground. Houses on sandy soil were buried in sand to their eaves.

Over large areas fountains of water spurted through the surface soil, forming funnel-shaped depressions as the water drained away. This torrent of water carried with it, in many places, enormous quantities of sand, which were swept over and buried arable land, destroying its agricultural value. So much of the underground water was forced to the surface that the Brahmaputra River was flooded, and flowed on as a great wave ten feet in height.

A great number of small lakes were formed by the warping of the earth's surface, which blocked the drainage. These were found to be arranged like beads on a string, being actually along a line of fracture or fault reaching the earth's surface.

Considerable movements of the ground of a permanent nature occurred, for at many places distant ranges of hills came into view, which were previously obscured by nearer objects.

Another great earthquake closed the nineteenth century, for in September 1899 a large area on the southern shores of Alaska was shaken very severely. The greatest disturbance centred about Yakutat Bay, into which many great glaciers discharge their melting streams. Little information is available about the immediate effects of the earthquake, as the region is practically uninhabited.

A scientific expedition made by two American geologists in 1905 yielded important results. It was found

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that even six years after the earthquake the raised shore still retained intact the remains of barnacles and other shell fish firmly attached to the rock, about forty-seven feet above sea-level. Other raised beaches of still more ancient date, and at higher elevations, showed that earthquake activity had long been in progress in this district. The earthquake of 1899 was attended by a huge sea wave which uprooted and destroyed great forests forty feet above sea-level.

Of the twentieth century earthquakes, the best known are the San Francisco earthquake of 1906, and the great Tokyo earthquake of 1923.

The city of San Francisco lies near a great fault which extends for more than two hundred miles along the coast of California. Although not actually on this great line of fault, San Francisco is cut by a cross fault, which branches off the main coastal fault zone. A notable feature of this great earthquake was the number of open fissures which were formed. In one part of the city more than three hundred such fissures were counted in a distance of one mile in the streets of the city.

Although the city was badly damaged, the loss of life was small, for the earthquake occurred about 5 a.m., before the city became thronged with people. Far more damage was done by the fire which swept the city following the collapse of the buildings, than by the earthquake itself.

This earthquake awakened the citizens of the United States to the risk of earthquakes, and very active investigations were made into the cause of this earthquake, and into the problem of mitigating the effects of any subsequent shock.

The rebuilding of San Francisco was carried out with architectural designs much better adapted to withstand earthquakes.

In September 1923 the greatest earthquake disaster of modern times, and one of the greatest known, overtook the city of Tokyo. The city lies at the head of a long arm of the sea, which opens into Sagami Bay, where the earthquake centre was situated.

It was almost at noon on the first day of September that the first shock occurred. Slight at first, it grew stronger in the few precious seconds which enabled many persons to escape from their homes into the streets. Then for half a minute the destructive shocks rocked the city, and buildings crashed to the ground. Within a few minutes the horrid spectre of fire raised its head, and licked with its red and greedy tongue the fragile wooden and paper houses of the populace. The water mains were shattered

by the shock and rendered useless. Gas mains were broken, and fed the hungry flames to further the destruction. The electric cables, too, torn from their stanchions, added to the dangers and fury of the fires that now, fed by the rising wind, swept so remorselessly through the doomed city. In a few minutes a million souls were homeless and without food. The courage, the resourcefulness, the energy and organization of the Japanese people under this blow were amazing.

The first problem was the fire. The firemen, of whom twenty-two lost their lives, and more than a hundred were injured, fought with improvised hoses stretched out to distant canals, and after two days finally subdued the fire; but not, alas, until incalculable damage had been done. Priceless art treasures and literature, so valued by the Japanese, were irrevocably lost, and this was a blow felt far more keenly than the material damage of nearly four hundred million pounds.

But saddest of all was the cruel suffering of a homeless people, who were still tortured for hours after the first destructive shock, by a train of after-shocks of great intensity. Refugees sought the open spaces of the parks and the bridges crossing the canals for safety. One by one the bridges caught fire and, collapsing, carried their victims to a double death.

A terrible scene occurred near the Military Clothing Depôt, where about forty thousand people had congregated on an open piece of ground adjoining the depôt. Here they seemed safe, as the fire was moving away from this centre. But as darkness fell a hurricane change of wind bore the burning torches from a thousand homes towards the depôt, and the haven which seemed so secure was soon surrounded on all sides by a wall of flame. Not a soul escaped. Visiting this spot some three years later I stood bareheaded, with a heavy heart, before the simple memorial commemorating this, one of the saddest events in Japanese history.

But amid all this suffering and terror the Japanese authorities worked with clear minds and cool heads at a plan for relieving suffering.

Communications with the outside world were cut off—all telegraph lines were down, all telegraphic equipment put out of order, and the railway tracks heavily damaged.

The immediate problem was to provide food and shelter for the people. Shelters were soon provided in the public parks, and warships were converted into record-breaking commercial vessels weighted with food supplies.

They also acted as passenger ships, carrying all who could leave the city for homes elsewhere. All foreign warships within reach joined in the rescue work.

By frantic efforts the water services were sufficiently restored within twenty-four hours to avert a water famine. Eight days after the earthquake, a free distribution of milk to invalids and children was available. Within a week train and tramway services were partly restored, and telegraph and telephone communications were in use; and electric light services were in operation.

The work of restoration thenceforth went steadily forward, and a new and greater Tokyo has since arisen from the ashes. This modern Tokyo need never fear such another disaster, for the buildings are constructed upon earthquake-proof designs, worked out by a long series of investigations, and based upon great experience.

The earthquake cost the Japanese some hundred thousand lives. The fire burned about four thousand acres of the city—an area ten times as large as that destroyed by the great fire of London.

The Cause of Earthquakes.

The rise of seismology, as the study of earthquakes is called, is a very late development in scientific study.

The ancients sought for causes in the supposed activities of some subterranean monster which shook the earth by its movements. Thus, in China and Japan, a giant catfish or a monstrous mole was blamed for these disturbances. The Greek philosophers put forward the more reasonable theory that earthquakes were caused by winds and vapours imprisoned within the earth. This view, in a modified form, invoking the pressure of steam in volcanic regions, survived into the present century, although the true cause had been gradually ousting this theory for some decades previously. It has now been established beyond all doubt that earthquakes are due to the movement of the great rock masses of the earth's crust along fractures or faults, and that the vibrations set up by such movements constitute the earthquake shocks.

Earthquakes are known to occur along such lines of fracture, and their greatest intensity is along such fractures.

The contributions made by instrumental seismology are immense, and have furnished most valuable information about the constitution of the earth's interior. But this is another story—one to be expounded by a physicist rather than a geologist.

Earthquake Prediction.

At present it is not possible to predict accurately the time of occurrence of earthquakes, although some general predictions as to the place of occurrence have been made successfully by geologists and seismologists. There are, however, several lines of research which are being actively followed, in the hope that earthquakes may be predicted with sufficient accuracy to give a warning of value to peoples living in earthquake lands.

Meanwhile much may be done to mitigate the sufferings of such peoples by geological work, for thus the danger zones may be accurately marked out, and so avoided in building new cities.

Furthermore, the principles now established for constructing earthquake-proof buildings are becoming more and more recognized in earthquake lands, and in time should lead to a high degree of safety, even in the most unfavourably situated countries.