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EARTHQUAKE PREDICTION STUDY IN JAPAN

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SUMMARY

In Japan there are three different types of shallow earthquakes. They are the earthquakes along or off the Pacific coast, inland earthquakes, and the earthquakes off the coast of the Japan sea. The recurrence intervals of most of the Pacific coast earthquakes are about 100 years; those of inland earthquakes are 1000 to 10000 years. The recurrence intervals of the Japan Sea earthquakes are more than several hundred years. The most fundamental characteristic of earthquakes is their recurrence cycle. If we able to observe the whole process between two successive earthquakes, including long-term and short-term precursors, it should be possible to predict the second earthquake.

SHALLOW EARTHQUAKES

The Japanese islands form a typical island arc. Both shallow and deep earthquakes occur frequently. The deep earthquakes are important from the viewpoint of geophysical science, but they do not cause much damage; therefore I would like to skip over them here.

Shallow earthquakes that occur in Japan are of three different types, some of which are disastrous. The three types are classified by the areas where they occur: first, earthquakes along or off the coast of the Pacific Ocean; second, inland or intraplate earthquake; and third, earthquakes off the coast of the Japan Sea. These three types of earthquakes are correlated with geological categories.

In the last 188 years, 74 large earthquakes have been recorded. Of these large earthquakes 19 were of the Pacific Coast type, 52 were inland earthquakes, and 3 occurred in the Japan Sea.

One of the striking features of the earthquakes that occur along or off the Pacific coast is their very large magnitudes. Of the 20 Pacific Coast earthquakes, 8 had magnitudes over 8: the rest registered magnitudes from 7.5 to 7.9, except for one whose magnitude was 7.4. Another feature of these earthquakes is their short recurrence intervals. In most places the recurrence interval is about 100 years. The recurrence intervals of those with smaller magnitudes may be shorter, and some large earthquakes like the Kanto earthquake of 1923 may recur at intervals of 200 to 300 years.

Inland earthquakes are intraplate earthquakes. Their magnitudes are generally smaller than 7.4. But if one of these earthquakes occurs close to a city, it can cause major damages and casualties in spite of its relatively small magnitude. Typical examples are the Zenkoji earthquake of 1847 (8600), the Tokyo Shitamachi (Downtown) earthquake of 1855 (about 10000), the Tottori earthquake of 1943 (1083), the Mikawa earthquake of 1945 (1961), and the Fukui earthquake of 1948 (3895). The numbers in parentheses are the number of lives lost in each earthquake. The magnitudes of these earthquakes were all smaller than 7.3. The most distinctive feature of inland earthquakes is their very long recurrence intervals.

Only three major earthquakes centering in the Japan Sea have been recorded in almost two centuries. They occurred in 1833, 1964 and 1983. The recurrence intervals of these Japan Sea earthquakes thus seem to be more than several hundred years (Fig. 1).

During the years following the sudden release of stress in the earth's crust in the form of an earthquake, the stress accumulated again, building up to another earthquake in the same region. This pattern is called the recurrence cycle.

The large earthquakes along the Pacific Ocean coast are of the underthrust type, and their recurrence cycle takes the following form. When an earthquake occurs, the ground or the ocean floor upheaves suddenly, for a period of several tens of seconds; after the earthquake the ground subsides, but stress continues to build up until the next earthquake occurs. The rate of subsidence is generally about 3 to 6 mm per year.

RECURRENCE CYCLE

The recurrence intervals of inland earthquakes are very long, usually from 1000 to 10000 years. Some of the faults along which inland earthquakes move are of the strike-slip type, and in these cases a dislocation occurs along the fault only at the time of the earthquake. The fault itself does not slip during the period between two successive earthquakes. Slips accumulate and finally form a geographical feature called an active fault. Aerial photography clearly reveals the the topographic features of active faults, of which Japan has a good many.

In the case of the underthrusting type of earthquakes, stress accumulates and strain increases during the recurrence interval between earthquakes. But in the case of the strike-slip type of earthquake, while stress accumulates, strain does not increase during the recurrence interval. Toward the end of this process, when the level of stress in the crust approaches the point beyond which fracture will occur, the nature of the crustal material is believed to begin to change, the phenomenon known as dilatancy of the rock which causes various types of precursory phenomena(BRACE et al., 1966). These precursory phenomena may continue for years, sometimes decades. The length of long-term precursors seems to depend on the magnitude of the earthquake. The relation between the logarithm of the length of the precursor and the magnitude M is approximately linear, although the scattering of the plots is very large.

The nature of the crust is very complicated, and an example of the complexity is the existence of many different types of long-term precursors. Some of the very clear examples are seismicity gaps (UTSU, 1972), changes in the rate of crustal movement (DAMBARA, 1973), and changes in the seismicity of the surrounding areas. As there are many papers discussing other types of long-term precursors, I will not dwell on them here.

The duration of long-term precursors can be about 30 years for earthquakes with M 8, and less than several days for microearth-

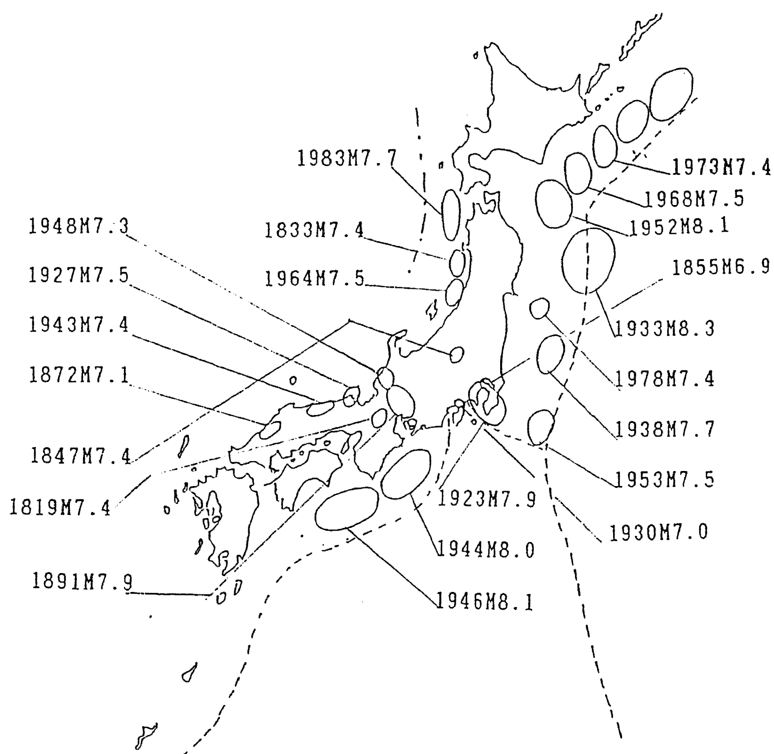

Fig. 1. Major inland and offshore earthquakes. The circle identifying each earthquake is its aftershock area, the size of which is approximately proportional to its magnitude. The magnitudes of the Pacific coast earthquakes are greater than those of inland earthquakes; however, they cause less damage. The numbers of casualties in the offshore earthquakes of 1944 and 1946 were 998 and 1432, respectively; in contrast, 142,707 casualties resulted from the 1923 inland quake. The 1933 Sanriku-oki earthquake caused a loss of 3000 lives because of the large tsunami that accompanied it.

quakes with M 1 or 2. This is the reason why a logarithmic scale is more suitable than a linear scale in a graph showing the relation between the length of the precursors and the magnitude (RIKITAKE, 1979). I think that these long-term precursors do exist, but I am not sure whether or not the relation between M and the logarithm of the length of precursors is simple.

The study of earthquake prediction and the deployment of a network for observation of precursors began about 25 years ago in Japan. However, a period of 25 years is quite inadequate for the detection of long-term precursors of large earthquakes, and this is one reason we have not had many examples of such long-term precursors.

PRECURSORS

We have had more success in observing short-term precursors. Even before the advent of precision instrumentation, many reports were made of easily observable precursors, usually changes in the coastline due to ground upheaval. Such dramatic precursors usually appeared just 1 or 2 hours before the occurrence of an earthquakes.

Among short-term precursors which have been observed with scientific methods, perhaps the best known is the change in ground tilt observed one day before the 1944 Tonankai Earthquake (M8) (MOGI, 1985). The change in tilt, measured by a team of researchers from the Geographical Survey Institute using leveling techniques, was more than 1 sec of arc over a span of several hours -- a large enough tilt to be recorded quite clearly by a modern precision tiltmeter.

This change in tilt was one of the most distinct precursors ever recorded. Another good example is the change in the concentration of radon in underground water (WAKITA, 1984) and crustal strain at the time of the 1978 earthquake close to Izu Oshima (M7). Data taken by the borehole strainmeters installed by the Japan Meteorological Agency showed that anomalous changes had begun 2 or 3 months before the earthquake. The radon concentration has been measured at 8 sites in the Izu Tokai area for 13 years. The borehole strainmeters have been collecting data at 30 sites for about 10 years on the average.

The above two are the only precursors recorded during a total of more than 100 working years. It may safely be said that these changes in the radon concentration and in the strain in the crust are anomalous. It must also be pointed out, however, that such distinct precursors are associated only with a small fraction of earthquakes with magnitude about 7.

Examples of scientifically observed short-term precursors have been reported by many authors. However, most of them are not so clear as the examples I have mentioned. There is no established theory about why short-term precursors occur before an earthquake. Some seismologists think that a small part of the fault plane of an earthquake moves slowly just before the earthquake takes place.

Some large earthquakes are preceded by foreshocks. foreshocks are among the most distinct precursors; however, it is difficult to decide whether or not a swarm of earthquakes is a group of foreshocks. During the period 1961 to 1980, about 250 earthquakes with magnitude greater than 6 were located by the JMA network; of these, 12 were preceded by foreshocks.

If we are able to observe the whole process between the Nth earthquake and the N+1st earthquake, including long-term and short-term precursors, it should be possible to predict the N+1st earthquake. However, a successful earthquake prediction is, of course, not so easy. Very dense nationwide networks for observing various phenomena are necessary for short-term prediction; however it is almost impossible to establish such nationwide networks. Practical earthquake prediction involves several steps: (1) identification of

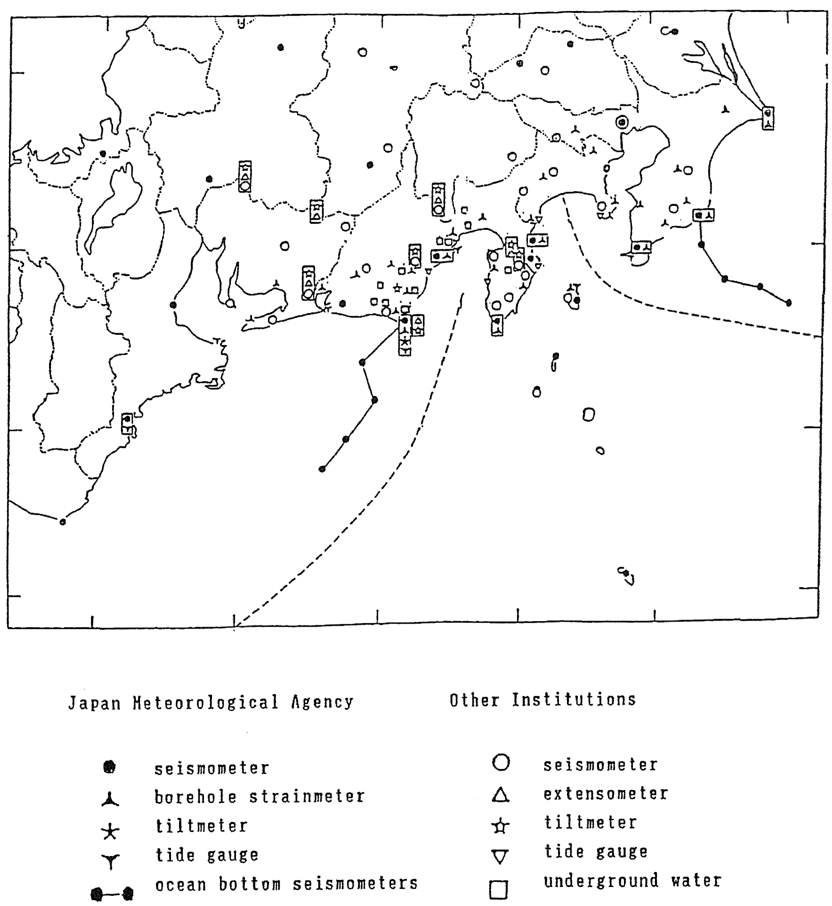

Fig. 2. Networks of various types of sensors in the Tokai area. Their outputs are telemetered to the Japan Meteorological Agency.

the areas vulnerable to destructive earthquakes, (2) deployment of networks for recording precursors in these areas, and (3)adoption of administrative measures when precursors are identified.

Of these three steps, the most difficult is identifying the inland areas that may experience destructive earthquakes in the near future. This is because the recurrence intervals for inland earthquakes are so long, usually more than 1000 years.

Only 6 inland earthquakes have occurred twice in the same place during all of historical time in Japan. Active faults, especially those for which there are no historical records of destructive earthquakes, should be identified a possible future sites of large earthquakes. However, we may have to wait hundreds of years for the next large earthquakes at these sites.

In the area around the western half of Suruga Bay, or the Tokai area, there have been no earthquakes since the one which occurred in 1854. This is the only place along the Pacific coast where no large earthquake has occurred in the past 100 years (ISHIBASHI, 1981). In all other areas along and off the Pacific coast that are known to be earthquake-prone, earthquakes with magnitudes of 7.5 or greater have occurred in recent decades, so they are not expected to recur in the foreseeable future. Even if a big quake occurs some where off the Pacific coast, the Japan Meteorological Agency's tsunami warning system will be able to prevent major damage on land. Accordingly, a Tokai earthquake is the only one which is expected to cause a major disaster. In this area the coast is subsiding continuously, and the total subsidence has reached a considerable level.

As a Tokai earthquake is expected to have a magnitude of about 8, most Japanese seismologists believe that major short-term precursors such as those that appeared before the 1944 Tonankai earthquake will be recorded. Networks of tiltmeters, borehole strainmeters, and sensitive seismometers for microearthquakes have been set up in the Tokai area (Fig. 2).

The Japanese Government has prescribed large-scale Earthquake Countermeasures, and has designated the Tokai region as one of the Areas Under Intensified Measures Against Earthquake Disaster. The output of all the instrument networks around the Tokai area is displayed at the Japan Meteorological Agency. If very distinct precursors are observed, the Agency's Assessment committee will advise the Director-General of the Agency that the occurrence of a Tokai earthquake is likely.

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