Although work on the trityl group is preliminary, it has already demonstrated wide applicability and high selectivity. We expect that reactions comparable to those of enzymatic systems will be achieved by modifying the catalyst.

Conclusions

Organic chemistry has developed to the extent that it is possible, by a combination of experimental and computing methods, to design molecules having specific functions that can store information. To construct these useful molecules, it will be necessary to develop efficient synthetic reactions based on new and novel concepts. For this purpose, the use of computers will be helpful; however, organic chemistry remains essentially an experimental science, and human intuition and observation based on experiments will continue to be essential to its development.

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Recent Earthquake Prediction Research in Japan

KIYOO MOGI

Japan has experienced many major earthquake disasters in the past. Early in this century research began that was aimed at predicting the occurrence of earthquakes, and in 1965 an earthquake prediction program was started as a national project. In 1978 a program for constant monitoring and assessment was formally inaugurated with the goal of forecasting the major earthquake that is expected to occur in the near future in the Tokai district of central Honshu Island. The issue of predicting the anticipated Tokai earthquake is discussed in this article as well as the results of research on major recent earthquakes in Japan—the Izu earthquakes (1978 and 1980) and the Japan Sea earthquake (1983).

IN RECENT YEARS A SPATE OF SERIOUS EARTHQUAKE DISASTERS has occurred in Japan and around the world. Major earthquakes that occur without warning can take the lives of many people and destroy cities in a matter of minutes. People living in countries subject to major earthquakes look forward to the day when it will be possible to predict when and where major earthquakes will occur, so that damage can be minimized. Located in the circum-Pacific seismic belt, Japan is one of the most earthquake-prone countries in the world. This fact has led to great interest in earthquake prediction ever since seismological studies were begun in Japan a century ago. Omori (*1*), Imamura (*2*), and other Japanese seismologists carried out pioneering research on the periodicity of great earthquakes and on seismic gaps and other subjects. Their research was limited, owing to the level of observations and the inadequacy of data in those days; however, their work contained the beginnings of the important methods used in earthquake prediction today.

Earthquakes occur when stress that has been applied to the earth's crust reaches a limit and a sudden fracture (the sudden slip of a fault) occurs at part of the earth's crust. In general, brittle materials fracture suddenly, and it is difficult to predict this fracture accurately. Earthquakes take place at intervals of 100 or more years, but

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practical prediction requires that earthquakes be forecast on the order of days. This raises the question of whether such highly accurate prediction is actually possible.

Fortunately, ruptures of the earth's crust do not happen without warning in most cases. As stress on the earth's crust increases, crustal changes proceed by degrees, and various phenomena occur immediately before the principal rupture. The earth's crust is very complex in mechanical terms (for example, in heterogeneous strength distribution), and ground water exists in the pores of the earth's crust. These properties of the earth's crust are truly propitious for earthquake prediction. If researchers focus on this process and are able to adequately trace it, long-term and short-term predictions are possible.

A wide variety of precursory phenomena have been observed, including anomalous crustal movements, anomalous seismic activity, changes in geomagnetism, geoelectric resistivity, and earth potential, and changes in the level, temperature, and chemical components of ground water. In most cases these changes are slight, and the manner in which they appear is complex. This does not mean, however, that they transpire in a completely random manner. Earthquakes have a marked regionality and a tendency to recur in the same region. These facts are particularly favorable for practical earthquake prediction. At this stage no single precursory phenomenon that is a common deciding factor in all cases has been determined. Hence, the procedures involved in earthquake prediction are (i) recording a variety of weak signals from the depths of the earth as clearly and exhaustively as possible, (ii) extracting effective data from these signals, and (iii) comprehensively assessing these data and forecasting the occurrence of earthquakes. Developing a dense, highly precise observation network and obtaining effective data on precursory phenomena are prerequisites for achieving these goals.

In the early 1960's, Japanese seismologists gathered to discuss how earthquake prediction could be promoted, and they compiled a report entitled "Prediction of Earthquakes—Progress to Date and Plans for Further Development" (*3*). In 1965 the earthquake prediction program was inaugurated as a national project, and since then it has been carried out as proposed in the report.

This program is supported by observation and measurement data accumulated over almost 100 years. In 1883 the Geographical Survey Institute carried out nationwide geodetic surveys (leveling and triangulation); these surveys have been repeated at regular intervals since then and whenever a major earthquake has occurred. In addition, the Japan Meteorological Agency (JMA) has made efforts since its early stages to make uniform seismic observations throughout Japan and has performed instrumental observations for more than 100 years. No other country in the world has carried out such basic observations and measurements of crustal activity over such a long period and on such a uniform nationwide scale. The Japanese data and the results obtained from them enable seismologists today to discuss earthquake prediction from a fundamental standpoint (*4*).

The earthquake prediction program that began in 1965 is now in its fifth 5-year program (*5*). During these years the expansion of the earthquake observation network and the modernization of data analysis methods have been striking. Other networks for observing crustal movements and geomagnetism have also been improved. In 1969 the Coordinating Committee for Earthquake Prediction was established to gather and examine the data on a regular basis and to investigate long-term prediction. The 30 members of the committee, which meets four times a year, are mostly university staff and government officials who participate in the earthquake prediction program. Two subcommittees meet whenever necessary to examine specific areas and urgent issues.

The possibility of a large earthquake in the Tokai region was first pointed out in 1969 (*6*). It became a major social issue in 1976, because a disaster of serious consequence is expected if an earthquake occurs (*7*). In 1978 the Large-Scale Earthquake Countermeasures Act was enacted. Under this law the prime minister is to issue a public warning, and government and private organizations are to respond immediately by adopting effective procedures. As a result, observed data are transmitted to JMA in Tokyo and constantly monitored. If any anomalies are observed, the Earthquake Assessment Committee, which consists of six university professors, is to meet immediately and assess the data (*8*). This is an important national experiment aimed at minimizing the disaster by predicting the earthquake, and it is the first sure step toward practical earthquake prediction.

Several major earthquakes have occurred since the start of the earthquake prediction program. Although there have been successful examples of prediction on the basis of seismic gap theory, as for the 1973 Nemuro-Hanto-oki earthquake (*9*), there have been no cases in which all three elements of earthquake prediction—place, magnitude, and time—have been successfully forecast. However, reliable data on precursory phenomena are being steadily accumulated (*10*), and several cases suggest the feasibility of earthquake prediction. For example, before the medium-sized earthquake of magnitude (*M*) 5.6 along the Yamasaki fault in western Japan on 30 May 1984, clear anomalies in electric resistivity and earth potential were observed near the epicenter (*11*).

The 1978 Izu-Oshima-kinkai Earthquake and the 1980 Izu-Hanto-toho-oki Earthquake

No major earthquakes occurred on or in the vicinity of the Izu Peninsula, located approximately 100 kilometers southwest of Tokyo, for about four decades after a period of activity around 1930. Then, in 1974, the Izu-Hanto-oki earthquake (*M* 6.9) occurred, and it was followed by the Izu-Oshima-kinkai earthquake (*M* 7.0) in 1978 and the Izu-Hanto-toho-oki earthquake (*M* 6.7) in 1980. All of these earthquakes were the strike-slip fault type. As Fig. 1 shows, these large earthquakes successively migrated in a northeastern direction from the tip of the Izu Peninsula. This series of large

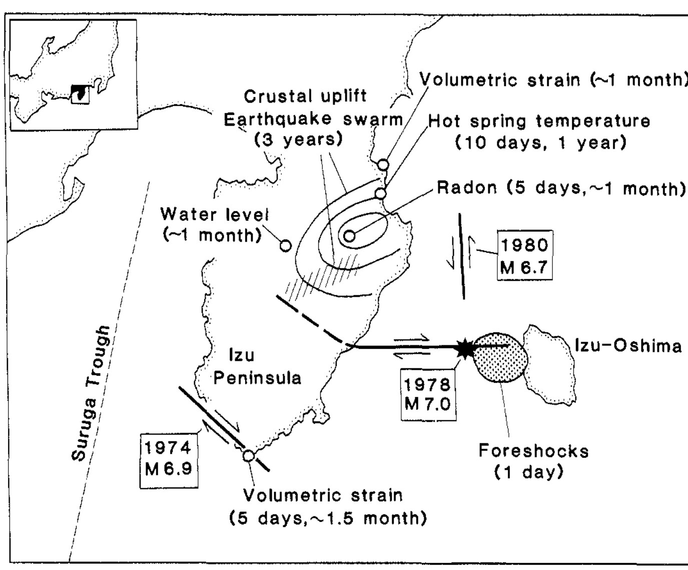


Fig. 1. Locations of the large shallow earthquakes of 1974, 1978, and 1980, in and around the Izu Peninsula, and locations where precursory phenomena before the 1978 Izu-Oshima-kinkai earthquake occurred or were observed.

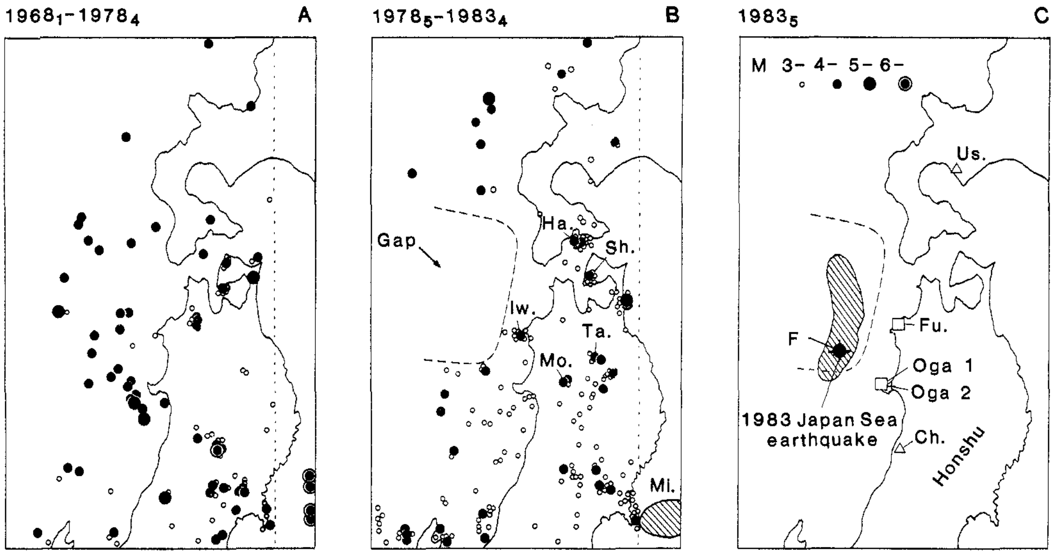
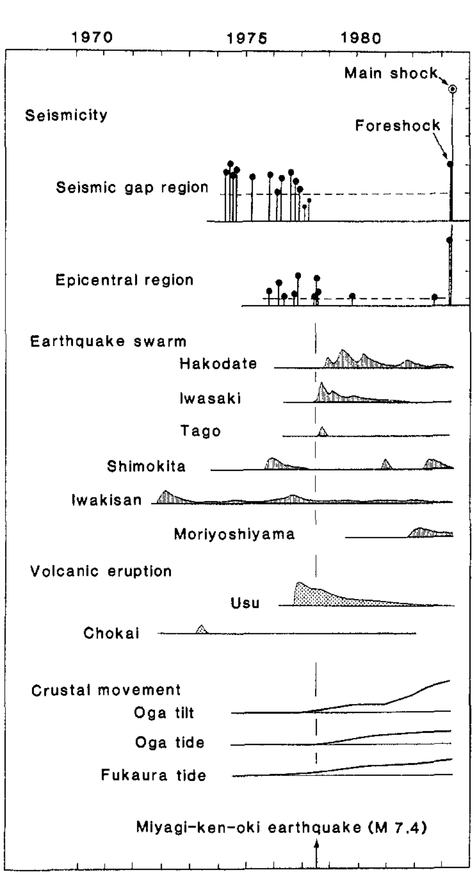


Fig. 2. (A and B) Seismicity before the 1983 Japan Sea earthquake. Mi indicates 1978 Miyagi-ken-oki earthquake (M 7.4); subscripts to the years denote the months. (C) The epicenters of the foreshock and the main shock of the Japan Sea earthquake and its aftershock region. F indicates the foreshock that occurred at the epicenter of the main shock (*22*). Ha, Hakodate; Iw, Iwasaki; Ta, Tago; Sh, Shimokita; Mo, Moriyoshiyama; Us, Usu; Ch, Chokai; Oga 1, Oga (tide station); Oga 2, Oga (tilt observatory); Fu, Fukaura. Magnitudes of the earthquakes are indicated by circles given in (C).

earthquakes was preceded by anomalous seismic quiescence in the Izu Peninsula and the surrounding area for several years (*12*).

The 1974 earthquake took seismologists by surprise. But in early 1975, uplift of as much as 15 centimeters was observed in the eastern Izu Peninsula (*13*), and earthquake swarms began (*14*), so it was suspected that these activities might be the precursor of a large earthquake. In the midst of intensive observations, the 1978 earthquake occurred. Hence, many more types of precursory phenomenon were observed than in the past. However, it was not possible to predict this $M = 7.0$ earthquake. Before the subsequent earthquake in 1980, it had been recognized that the area of activity was gradually migrating northward, and marked earthquake swarms had begun to occur repeatedly in the area adjacent to where this earthquake eventually took place. It occurred as various intensive observations were in process.

Precursory seismic activity occurred near the epicenters of both the 1978 and 1980 earthquakes. This activity began about 15 hours before the 1978 earthquake, peaking 2 or 3 hours before, and then abating temporarily until the main shock occurred. This was typical foreshock activity. Precursory activity began 4 days before the main shock of the 1980 earthquake and was of a type that cannot be distinguished from normal earthquake swarms, so it was concluded



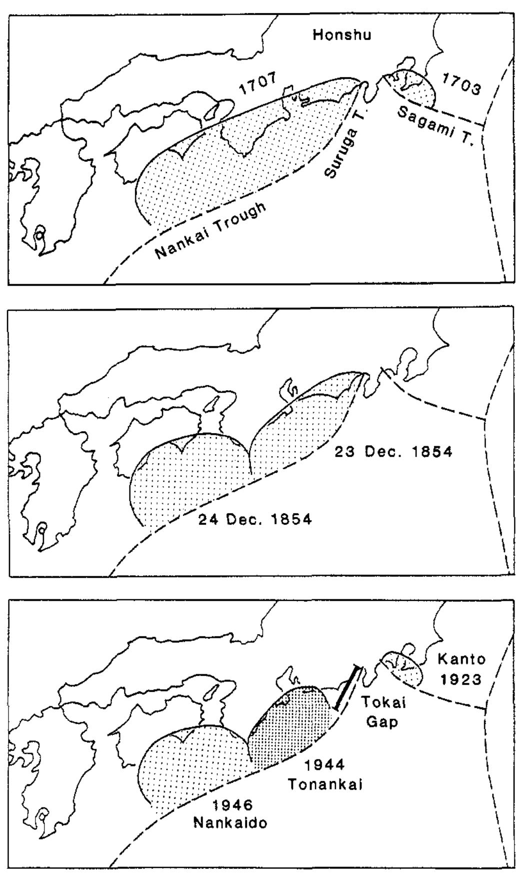


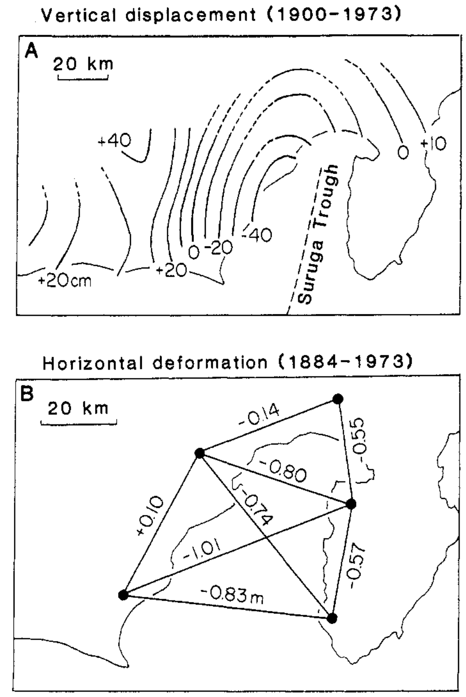
Fig. 3 (left). Summary of precursors of the 1983 Japan Sea earthquake (*22*). Fig. 4 (right). Rupture zones of great shallow earthquakes along the Nankai-Suruga and Sagami troughs in successive periods. The Tokai region along the Suruga Trough is a seismic gap of the first kind.

that these swarms probably triggered the large earthquake. Several methods have been proposed for judging in advance whether a sudden increase in small earthquakes will end as a mere swarm or whether it constitutes the foreshocks of a large earthquake, but at this stage no conclusive method has been found. Without doubt, however, foreshocks are one of the most vital precursory phenomena, and sometimes, as with the 1975 Haicheng earthquake in China, they are the decisive factor in earthquake prediction. The Izu region is prone to foreshocks, thus earthquake prediction is facilitated there. Earthquake swarms also occur there frequently, however, so any forecasts based solely on data on small earthquakes risk being off the mark.

Figure 1 shows the types of precursory phenomenon observed for the 1978 Izu-Oshima-kinkai earthquake and where they occurred or were observed (*15–19*). The figure also indicates how long before the earthquake these anomalies were observed. In this case, much of the data was not telemetered to Tokyo, and the monitoring setup did not enable a constant grasp of the whole situation, so it was not possible to predict this earthquake. Some seismologists are of the opinion, nevertheless, that this earthquake could have been forecast to a certain extent from the amount of data that were available in advance. However, the location of the epicenter at sea, where there were no observation stations, was a major drawback.

As stated earlier, the 1980 earthquake (*M* 6.7) occurred when a northward migration of activity was anticipated after the 1978 earthquake. When the precursory seismic activity began several kilometers off the eastern coast of the Izu Peninsula, my assistant and I boarded an observation vessel bound for this area and monitored the high-frequency seismic wave with a hydrophone on board the ship (*20*). The $M = 6.7$ earthquake on the following day occurred right below our observation vessel. However, the observations were interrupted just before the main shock by foul weather conditions, and we were unable to record any precursory changes, but we did obtain valuable data on the aftershocks. The temperature of an artesian hot spring on the eastern coast of the Izu Peninsula rose sharply 2 days before this earthquake but, on the whole, fewer precursory phenomena appeared in 1980 than had been evident before the 1978 earthquake. Intermittent earthquake swarms also occurred off the city of Ito on the east coast of the Izu Peninsula after the 1980 earthquake, and measurements continue to be taken in and around the northern area adjacent to the focal region of this earthquake.

Fig. 5. Recent vertical (A) and horizontal (B) crustal movements in the Tokai region (*33, 34*).



The 1983 Japan Sea Earthquake (*M* 7.7)

At noon on 26 May 1983 a large earthquake (*M* 7.7) occurred on the floor of the Japan Sea off the western coast of Aomori and Akita prefectures in northern Honshu. This was the largest earthquake to have occurred on the Japan Sea side of the country, and its focal region covered an area 120 km long and 40 km wide, extending from south to north (*21*). This focal region was located 100 km out to sea, away from the observation network on land. The Japan Sea is far less active than the Pacific side of Japan, so the monitoring setup there was incomplete. Hence it was not possible to forecast this earthquake on either a long-term or short-term basis. If absolutely no precursory phenomena could be recognized, even after the earthquake, the outlook for earthquake prediction would indeed be grim. Thus the results of investigations after earthquakes are an extremely important indication of the possibility of predicting future earthquakes on the Japan Sea side of Japan and inland, where there is little seismic activity.

Figure 2 shows epicentral distribution of earthquakes that have occurred in recent years in and around northern Honshu (*22*). The data are from JMA. These data reveal that seismic activity had declined in quite a wide area including the focal region for about 5 years before the main shock. This indicates that a seismic gap of the second kind [meaning a precursory seismic quiescence; a seismic gap of the first kind refers to an unruptured area in the seismic belt (*23*)] had appeared. This pattern emerges clearly when the lower limit of the earthquake magnitude is denoted as 4.0. The appearance of a seismic gap of the second kind is regarded as the most universal long-term precursory phenomenon known; the fact that it was also recognized in the case of the Japan Sea earthquake provides us with further valuable data. To my knowledge, Inouye (*24*) was the first to point out the existence of seismic gaps of this type.

At the end of 1978 active earthquake swarms occurred at Iwasaki (western coast of Aomori prefecture) and Hakodate (in Hokkaido). The heightened earthquake-swarm activity in recent years in northern Honshu, including these two areas, had attracted the attention of many researchers (*25*). The regions where these earthquake swarms took place frequently lay right around the focal region of the Japan Sea earthquake. That frequent earthquake swarms surround the focal region of a forthcoming major earthquake was also recognized after the 1983 Coalinga earthquake in California (*M* 6.5) (*26*). Such swarms are now regarded as long-term precursory phenomena.

Data in Fig. 3 relate a seismic gap appearing in mid-1978 and the various changes that occurred around the focal region (*22*). Frequent earthquake swarms (*25, 27*), the eruption of active volcanoes, and uplift and tilting of the ground along the Japan Sea coast (*28, 29*) occurred around the focal region during the same period. (The crustal movements at Oga and Fukaura along the Japan Sea coast had attracted the attention of some researchers before the earthquake.) Though various kinds of long-term precursory phenomena were observed, the only changes that could be described as short-term precursory phenomena were the foreshocks that occurred for 12 days before the main shock, including one of *M* 5.0 (*21*). The location of the hypocentral region out to sea with no observation stations nearby could be a major reason no other precursory phenomena were observed immediately before the main shock.

As described above, a seismic gap and other precursory phenome-

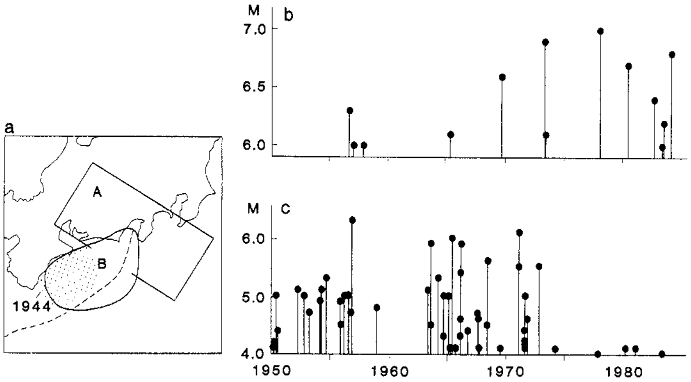


Fig. 6. (a) Reference map. Dotted area indicates the focal region of the 1944 Tonanki earthquake (*39*). (b) Temporal variation in seismic activity in region A. (c) Temporal variation in region B.

na appeared after mid-1978. At the same time, the Miyagi-ken-oki earthquake (*M* 7.4) occurred off the Ojika Peninsula on the Pacific Ocean side of Japan (Figs. 2 and 3). Recently I suggested that the Miyagi-ken-oki earthquake may have triggered many long-term precursory phenomena of the Japan Sea earthquake (*30*).

Though the Japan Sea earthquake occurred out to sea quite distant from the observation network on land, various kinds of precursory phenomena were observed. This suggests that if careful and appropriate monitoring is carried out, it will be possible to forecast to a certain extent a large earthquake of this magnitude.

Earthquake Prediction in the Tokai Region

There are two reasons a major earthquake is expected in the Tokai region in the near future: (i) Large earthquakes have often occurred in this region in the past, but none for many years, and (ii) crustal strain has steadily increased here for a long time.

The focal regions of the large thrust-type earthquakes of *M* 8 class that have occurred along the troughs in western Japan since 1700 are shown in Fig. 4. In the area from the Nankai Trough to the Suruga Trough, earthquakes have transpired at regular intervals of 100 to 150 years. In the earthquakes in 1707 and 1854, the ruptures covered the whole area along these troughs; but in the 1944 and 1946 earthquakes, the ruptures were confined to part of the Nankai Trough, and the area along the Suruga Trough at the eastern end remained unruptured (*7, 31, 32*).

Figure 5 shows the results of geodetic surveys of the Suruga Bay region where the Suruga Trough reaches northward (*33, 34*). Figure 5A depicts the vertical ground movements from 1900 to 1973 and reveals that marked subsidence occurred along the western coast of Suruga Bay. Recent leveling surveys show that this subsidence is continuing. The results of triangulation surveys (recently trilateration surveys) (Fig. 5B) indicate that the distance across the Suruga Trough has shortened by about 1 m over a period of 100 years.

The hypocentral distribution of microearthquakes and the results of seismic prospecting of underground structures suggest that in this region the Philippine Sea Plate subducts westward from the Suruga Trough at an angle of approximately 20° (*35*). The subsidence and horizontal contraction shown in Fig. 5 are proceeding, which

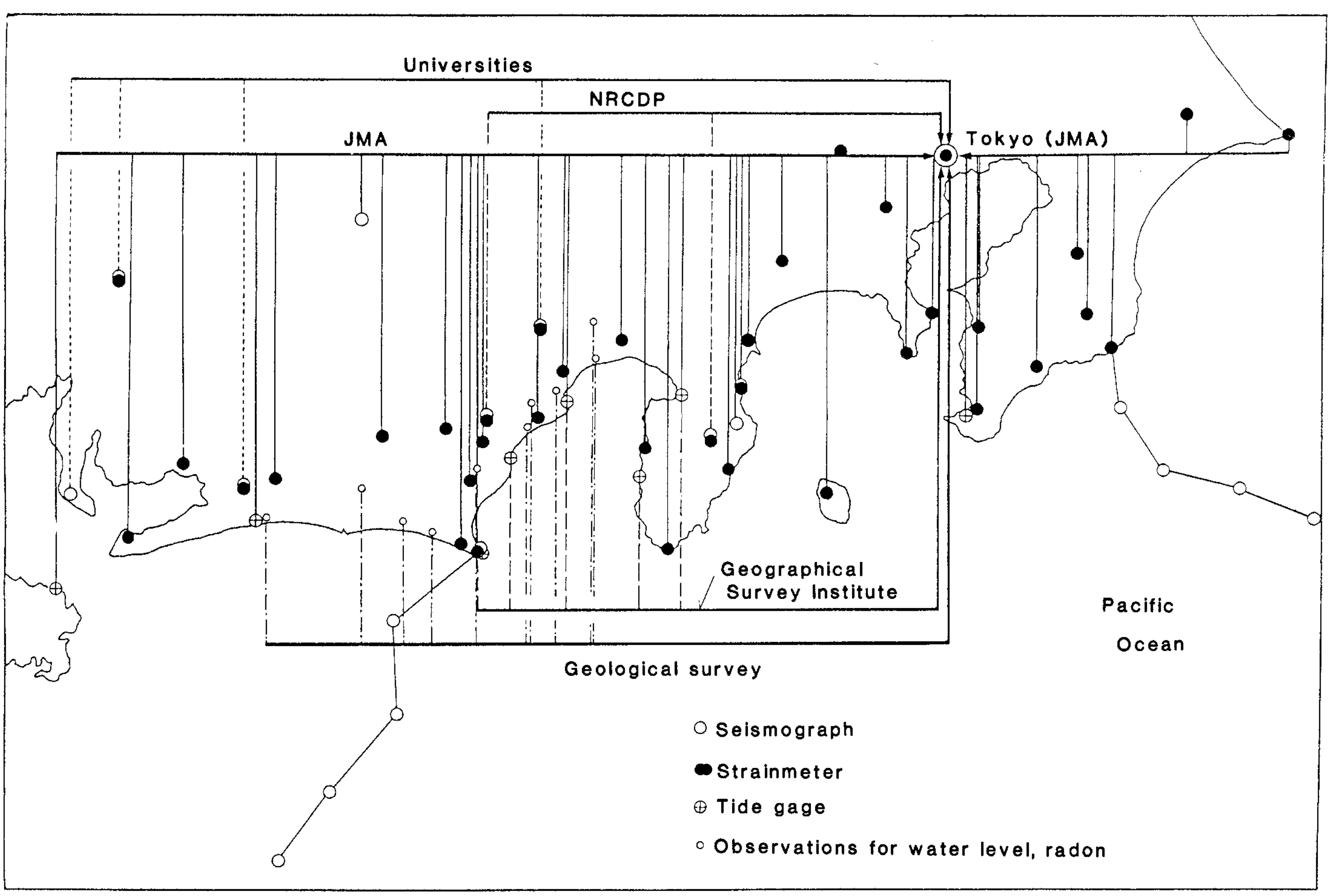


Fig. 7. Earthquake precursor monitoring system in the Tokai region. JMA, Japan Meteorological Agency; NRCDP, National Research Center for Disaster Prevention.

suggests that considerable elastic strain energy has accumulated in this region as the result of this subduction. When this strain energy reaches its limit and a sudden slip occurs on the upper surface of the subducted plate, the upper plate should rebound and the Tokai earthquake should occur (*36*). If the whole unruptured area along the Suruga Trough ruptures, the earthquake could be of *M* 8. The structure of the Suruga Bay area is quite complex, however, so the possibility of a partial rupture also exists, in which case the earthquake would be of a smaller magnitude.

The main issue is when this earthquake will occur. In view of the periodicity of large earthquakes along the Nankai Trough, some researchers believe the Tokai earthquake will occur in the near future. However, periodicity covers a broad range, and a detailed discussion of this issue is not possible here. The question of whether this periodicity can be applied to the Tokai earthquake that is expected to occur in the Suruga Trough is also a problem. Since earthquakes occur when crustal strain reaches a certain limit, attempts have been made to estimate the time of occurrence of this earthquake from the accumulated strain (*37*). Estimates of this "ultimate" strain differ widely, however, and are only an approximate yardstick. Naturally, then, seismologists are forced to estimate the time of this earthquake by observing changes regarded as long-term or short-term precursory phenomena.

Before a major earthquake occurs the focal region of the coming earthquake tends to become inactive (appearance of a seismic gap of the second kind) and, simultaneously, the wide-ranging area surrounding this tends to become active (appearance of the doughnut pattern whereby an area of seismic quiescence is surrounded by a seismically active area) (*38*). Figure 6 shows the results of an examination of seismic activity in the Tokai region from this viewpoint (*39*). Region A in Fig. 6a is the area surrounding the assumed focal region of the Tokai earthquake. Region B is the Suruga Trough and the part of the Nankai Trough that is joined to the Suruga Trough on the west; region B includes most of the focal region of the possible Tokai earthquake. The Tonankai earthquake occurred in the western half of region B in 1944; the reason for including this area in region B is that the activity here is similar to that in the Suruga Trough area, so this area is an effective model of the changes in activity in the Suruga Trough region. Changes in activity in region B can be regarded as representing changes in the Suruga Trough area [a similar method was also effective in the case of the successful long-term prediction of the 1978 earthquake in Oaxaca, Mexico (*40*)].

Figure 6, b and c, shows temporal variations in seismic activity in regions A and B, respectively. In region A, earthquakes of *M* 6.5 and larger have been occurring since about 1970, whereas region B, the Suruga Trough area, has been inactive since about 1973. This inactivity in the focal region and the contrasting activity in the surrounding region suggest the appearance of the doughnut pattern mentioned earlier. If this contrast signifies the appearance of a precursory seismic gap or a doughnut pattern, a major earthquake should occur in the not too distant future. Since the number of earthquakes is few, this pattern may be merely an apparent one; but the situation demands great caution. At this stage, no other changes that could be regarded as long-term or short-term precursory phenomena have been observed.

Observation stations are densely located from the Tokai region to the southern Kanto district, and currently 76 data sets are telemetered to JMA in Tokyo (Fig. 7), where they are monitored 24 hours a day. If any anomalies are discovered, the Earthquake Assessment Committee will be convened. Will this result in the prediction (in terms of days) of the Tokai earthquake? That depends on whether precursory phenomena are observed immediately before the earthquake.

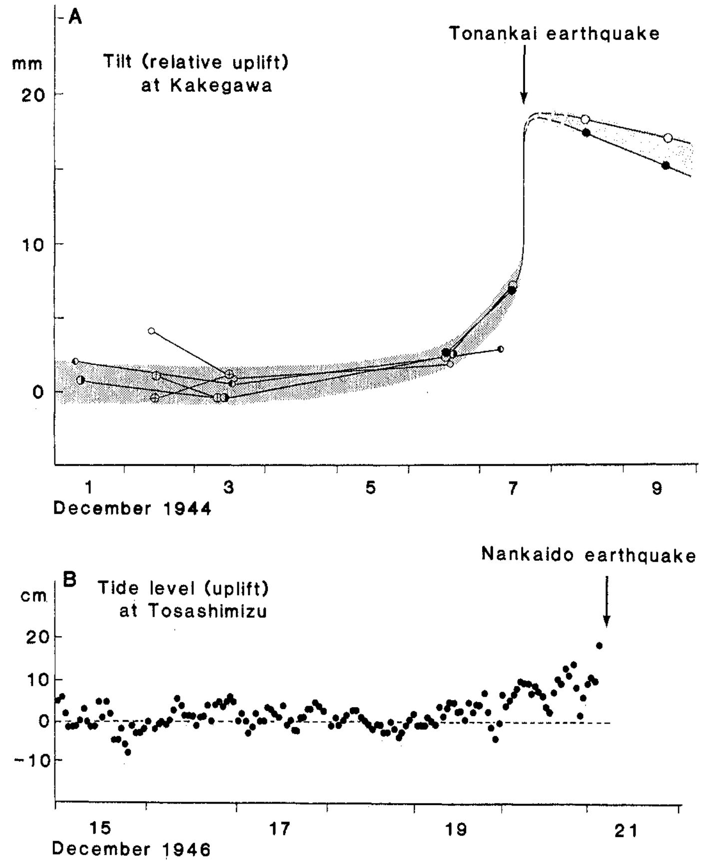


Fig. 8. Temporal variations of crustal deformation before the 1944 Tonankai (A) and the 1946 Nankaido (B) earthquakes along the Nankai Trough (*42, 43*).

Since precursory phenomena normally have a marked regional character, the type of phenomena that preceded the Tokai earthquake of 1854 should herald the occurrence of the next one. Unfortunately, there are virtually no reliable data available from 1854. However, the Tonankai earthquake (1944) and the Nankaido earthquake (1946) occurred adjacent to the Tokai region. They could be described as tectonically related to the future Tokai earthquake and thus should provide valuable information. As shown in Fig. 8, in both of these earthquakes the trough side began to uplift a day or two before they occurred (*41–43*). Before the Nankaido earthquake, marked anomalies were also reported in the wells and hot springs along the coast. Consequently, if similar phenomena occur before the Tokai earthquake, the changes should be sufficiently marked to be recorded by the present network of highly sensitive observation stations in that region.

Earthquakes are a kind of rupture phenomenon, and forecasting their occurrence is intrinsically difficult. However, since the possibility of prediction exists, active efforts must be made to minimize the expected disaster by forecasting the earthquake.

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Brownian Motion and Nonequilibrium Statistical Mechanics

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This article is a personal reflection of the branch of nonequilibrium statistical mechanics called the linear response theory that has as its heart the fluctuation-dissipation thereom, which states that irreversible processes in nonequilibrium are necessarily related to thermal fluctuations in equilibrium. Its origin lies in the Einstein relation for the diffusion constant and the mobility of a Brownian particle. The short history of the fluctuation-dissipation theorem is described. Then the linear response theory is briefly summarized and the meaning of stochastization is considered. The Langevin equation approach and its extensions are reviewed.

MUCH OF MY WORK IS CONCERNED WITH THE NONEQUILIBRIUM theory of statistical mechanics that aims to establish a theoretical framework to treat a macroscopic system in nonequilibrium dynamic states from a microscopic standpoint. In contrast to equilibrium statistical mechanics, which is the microscopic foundation of thermodynamics, nonequilibrium statistical mechanics is far from complete. The concept of nonequilibrium is perhaps too broad to be unified by a few principles. In spite of this there has been great progress in our understanding of this field in the last few decades.

The nonequilibrium aspect of statistical mechanics is not new, but rather the origin of statistical mechanics more than 100 years ago. In 1872, Ludwig Boltzmann published the Boltzmann equation for gaseous systems (*1*). This equation determines the evolution of the distribution function of gaseous molecules. For equilibrium states it derives the Maxwell-Boltzmann distribution of molecular velocities. For nonequilibrium states, where mass and heat flows are present, it gives the macroscopic laws with the kinetic coefficients (for example, the viscosity coefficient or the heat conductivity) in terms of the intermolecular forces governing collisions between molecules. If the function $f(\mathbf{r}, \mathbf{v}, t)\, d\mathbf{r}d\mathbf{v}$ is the number of molecules to be found at time t in the elementary volume $d\mathbf{r}d\mathbf{v}$ with the spatial coordinate $\mathbf{r}$ and the velocity $\mathbf{v}$, the equation is expressed in the form

$$\frac{\partial}{\partial t} f(\mathbf{r}, \mathbf{v}, t) = -\mathbf{v} \cdot \frac{\partial}{\partial \mathbf{r}} f - \frac{\mathbf{K}}{m} \cdot \frac{\partial}{\partial \mathbf{v}} f + \Gamma(f) \qquad (1)$$

where the first two terms on the right are the drift terms representing the change of f by the free motion of each molecule, $\dot{\mathbf{r}} = \mathbf{v}$, and $\dot{\mathbf{v}} = \mathbf{K}/m$. $\mathbf{K}$ is the force acting on a molecule and m is the molecular mass. The last term $\Gamma(f)$ is the collision term representing the change of f by collisions between molecules. Boltzmann wrote this equation by intuition, making the Stoss-Zahl Ansatz assumption for collisions taking place in a random fashion. This may be justified in the limit of a dilute gas and in the scale of time and space much larger than the mean free time and mean free path. Derivation of the Boltzmann equation and its extensions to denser systems remain outstanding problems even today.

The Boltzmann equations are commonly used not only for gases

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