5. Earthquake Prediction Technology —The Present State and Future Development

HAMADA. Kazuo

Visiting Research Officer,
National Research Center for Disaster Prevention

EARTHQUAKE PREDICTION TECHNOLOGY---THE PRESENT STATE AND FUTURE DEVELOPMENT

Kazuo HAMADA*

1. ABSTRACT

A national program of earthquake prediction was launched in 1965 with financial support from the government in Japan. Science and technology related to the prediction have been rapidly progressing since then. The state of the art has reached a level where there is a consensus that an impending large-scale earthquake in the Tokai region can be predicted by the present modern, dense network of instruments covering the Tokai region, although no quantitative formulae or methods for the prediction have been established yet. These are still in the developmental stage.

The most important information in the prediction of earthquakes is the observational data, particularly, that on the precursory candidates, which may be the real precursors to an earthquake. For further development, new methodology and technology are required, which would include a stringent experiment involving a prediction prior to the main shock and application of space-born technology or deep-down-hole measurement techniques.

---

* Visiting Research Officer,

National Research Center for Disaster Prevention, Japan

2. INTRODUCTION

The present efforts of earthquake prediction in Japan started in 1961, when the publication "Earthquake Prediction----Progress to Date and Plans for Future Development"(Tsuboi et al., 1961) was issued by an earthquake prediction research group consisting of Japanese seismologists. This planning drew much attention throughout the world, especially from the United States. As a result, the first Japan-United States Conference on research related to earthquake prediction was held in 1964. This conference continues to be held every four or five years. Recently, the UJNR(U.S.-Japan Cooperative Program in Natural Resources) Panel on Earthquake Prediction Technology was established and the first joint meeting of the Panel was held in 1979. Following joint meetings have been held approximately every two years with increasing cooperative works.

A national program of earhquake prediction was launched in 1965 with financial support from the government. The funding and planning of the program have been in five-year increments (the first segment was an exceptional four years). The program is now in the middle of the fifth 5-year segment and thus will be 22 years old by the end of fiscal 1986. The 1986 budget is approximately 6 billion yen. If the budget for salaries, some facilities and equipment are included, the total budget reaches to about 10 billion yen. About 400 government employees are directly connected with the national program.

The Large-Scale Earthquake Countermeasures Act(LSECA) was put in force in December, 1978. This act allowed adequate countermeasures to be adopted by law in advance of an impending earthquake, when an "Earthquake Warning Statement" was issued by the Prime Minister. With this, the chances of mitigating disasters was increased and a new phase in earthquake prediction seen.

Under the LSECA, the Tokai region was designated as an area where a

"Large-Scale Earthquake" could possibly occur and where "Intensified Measures Against Earthquake Disasters" were to be taken. A long-term prediction has, in fact, already been issued.

Presently, primary efforts are being placed on the short-term prediction of the expected "Large-Scale Earthquake(M=8 or greater)" in the Tokai region, and on research into predicting M=7 class earthquakes inland.

3.THE STATE OF THE ART

With the recent development of earthquake prediction technology and social needs, the state of the art of predicting earthquakes in Japan has reached a level where there is a consensus that an impending large-scale earthquake(M=8 or greater) along the Suruga trough in the Tokai region can be predicted by the present modern, dense network of instruments distributed in the Tokai region, although no quantitative formulae, methods, or techniques for predicting earthquakes have been established yet. These techniques are still in the developmental stage. The observation in the Tokai region is one of the best in the world, including telemetry networks and data processing facilities. The main data from the stations are telemetered to Japan Meteorological Agency(JMA) in Tokyo through telephone lines. The results are monitored by special staffs at JMA.

However, even in the Tokai region, the density of the stations is not sufficient enough to detect the precursory phenomena of magnitude 7 earthquakes, whose energy is about 1/30 that of magnitude 8 earthquakes.

3.1 Observation and Research Items

Precursory phenomena to an earthquakes were found in many geo-science fields: geodesy, seismology, geo-electromagnetism, and geo-chemistry. Recently, even unusual behavior or the responses of animals or plants before earthquakes have been reported. From features of an earthquake itself, research on precursory phenomena were inherently stressed in geodesy, seismology and geo-electromagnetism. However, recent discoveries of geochemical, precursory phenomena in the Soviet Union and China have influenced the Japanese program. Due to this, observations and research on geochemical phenomena have been incorporated in the program since the third 5-year segment(1974-1978).

The present items of research and observation relevant to the prediction are as follows, according to the classification in the fifth 5-year program(1984-1988) proposed by the Geodesy Council.

(1) Observation and research items relevant to long-term prediction. Long-term predictions are based on our understanding of long-term changes of the crustal activity combined with regional characteristics of earthquakes occurrence; they are used as the basis for accurate short-term prediction. Nation-wide observation and research, and regional works in specified areas are simultaneously carried out to elucidate the regional nature with aims of developing the ability for quantitative estimation of long-term crustal activity and further accuracy of location and magnitude of earthquakes.

1. Observation and reserch items throughout Japan.
   - 1-1 Geodetic survey(Fig.1 and 2).
   - 1-2 Seismic observation(Fig.3 and 4).
2. Observation and research items in specified areas.
   - 2-1 Accurate and frequent geodetic survey.
   - 2-2 Seismic observation and others by mobile parties.
   - 2-3 Seismic observation and others at the sea bed.
3. Fundamental examination.
   - 3-1 Examination of active faults and foldings.
   - 3-2 Seismological examination of historical documents.

(2) Observation and research items relevant to short-term prediction. The short-term prediction is very important from the viewpoint of the practical use. Detection of the precursory phenomenon to an earthquake and

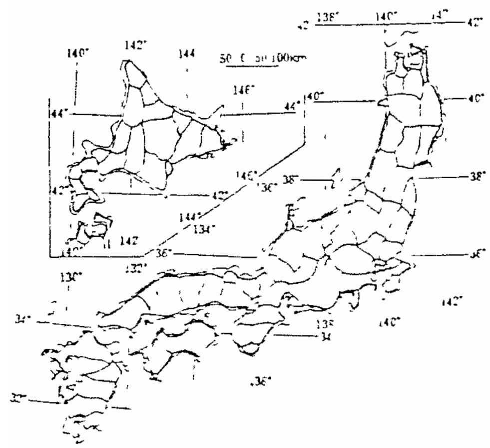

Fig. 1 Nationwide first-order levelling routes 20,000 km in total length.

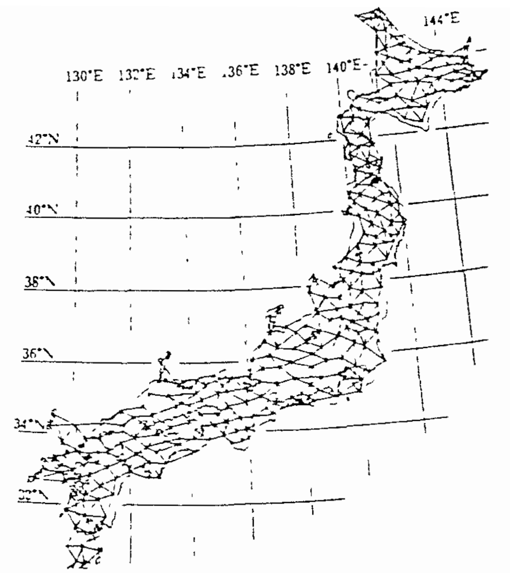

Fig. 2 Nationwide network of the first-order triangulatiion.

Fig. 3 Nationwide seismic network of JMA.

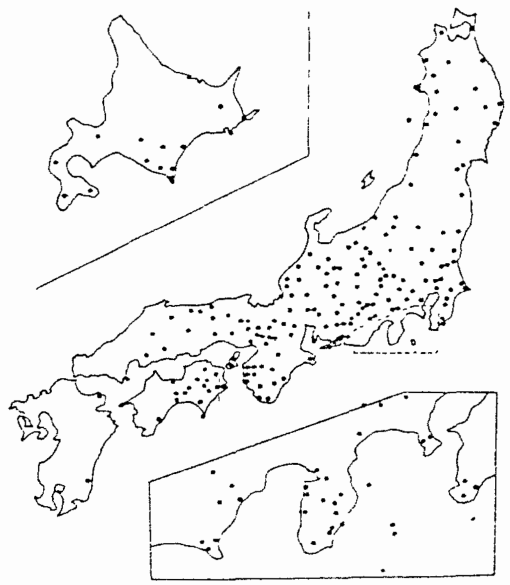

Fig. 4 Microearthquake observation stations.

its change with time is substantially important in the making of an accurate short-term prediction. It had been made clear that the pattern in which the precursory phenomenon appear is quite complicated. Therefore, a synthetic technology is stressed. based on a variety of observation items.

1. Continuous observation of the crustal deformation(Fig.5).
   - 1-1 Borehole-type volume strainmeters.
   - 1-2 Tiltmeters and strainmeters.
   - 1-3 Continuous observation of tidal difference(Fig.6).
   - 1-4 Various observations of the crustal activity along "observation lines."
2. Survey of gravity change.
3. Seismic observation(Figs.3 and 4).
4. Geo-electromagnetic observation(Fig.7).
   - 4-1 Geomagnetic observation.
   - 4-2 Observations of earth resistivity change and others.
5. Observations of groundwater and gas(Fig.8).
6. Instrumental development for the prediction in the capital area and other urban communities.

(3) Research items for elucidation of the focal process. To attain a prediction of high accurracy, fundamental research to elucidate the focal process including the precursory phenomena is important and must be carried out along with the long-term and short-term prediction works.

1. Research to elucidate the mechanism of the precursory phenomena.
   - 1-1 Experiments on rock failure.
   - 1-2 Composite experiments and observations in the test field.
2. Fundamental research to understand the precursory phenomena.
   - 2-1 In-situ stress measurements.
   - 2-2 Examination of underground structure.
   - 2-3 Observation and research on seismic-wave velocity change.

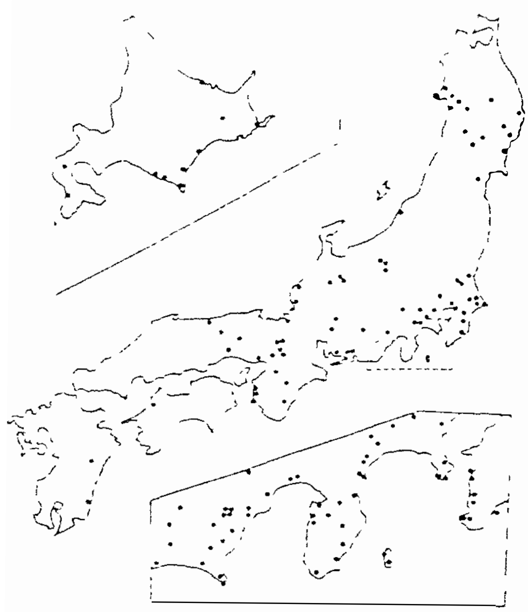

Fig. 5 Crustal-movement observation stations.

Fig. 6 Tide-gauge stations.

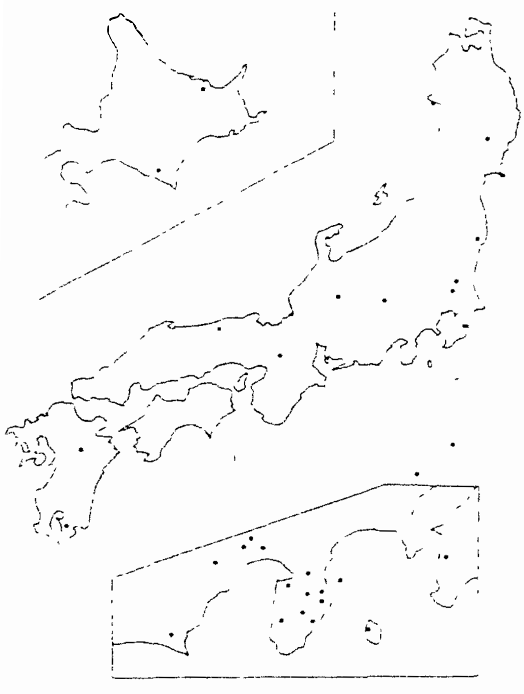

Fig. 7 Stations for geo-electro-magnetic observation.

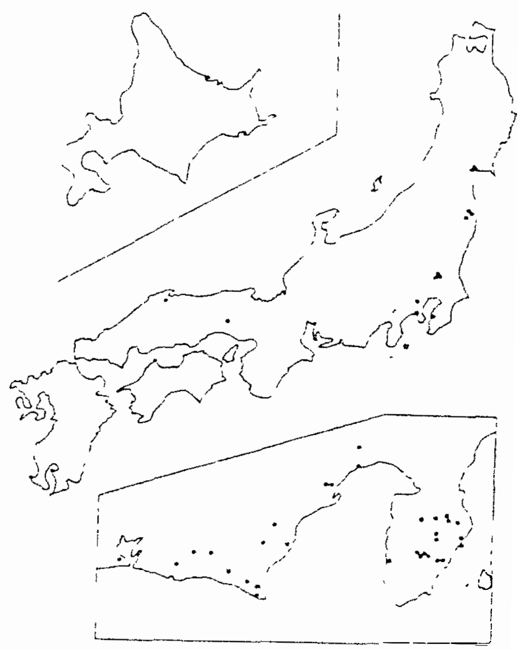

Fig 8 Stations for groundwater-related observation.

5.2 Precursory Phenomena to an Earthquake

Precursory phenomena based on the seismic observation of earthquake which occurred in and around Japan in the period 1872 through 1985 have bee examined. The total number of precursory phenomena reached 529 in these 11 years. Two-hundred and seven cases out of them were obtained in the 1 years since 1976. That is, intensified seismic observation through th earthquake prediction program in Japan has been obtaining the desire results.

The collected precursory phenomena have been classified and are shown in Table 1. The majority of the phenomena are foreshocks, being 57% out of the total 529 cases. The precursor times of foreshocks from the commencement of the precursor to the main shock are independent of the magnitude(M) of the main shock. About 40% of them ar within 1 day, 70% are within 10 days, and 90% are within 30 days. Th empirical probability function and observed results for foreshocks are give in Fig. 9.

Table 1 Seismological precursors to an earthquake in the period 1872 through 1985

Kind of precursors	Number of precursors
Foreshocks	301
Anomalus seismic activity	72
Pattern change of seismic activity	35
b value change	27
Seismic gap and quiescence	24
Microearthquake activity	16
ν value change	14
Velocity change of seismic waves	13
Utsu's criterion for foreshocks	11
Change of seismic wave form	8
Ground rumbling	5
Attenuation change of seismic waves	2
Change of focal mechanisms	1
Total	529

Logarithms of the precursor times of anomalous seismic activit increase with the M of the main shock, corresponding to Rikitake's firs kind precursor as illustrated in Fig. 10. Precursor times of anomalousl small ν values, which show the successive features of earthquake occurrence are independent from the M of the main shock and 90% of them are within 1(days. Precursor times of the other phenomena do not seem to show clea dependence on the M of the main shock and are distributed in a wide rang between 0 and several thousand days.

Non-seismological, precursory phenomena to an earthquake are reporte

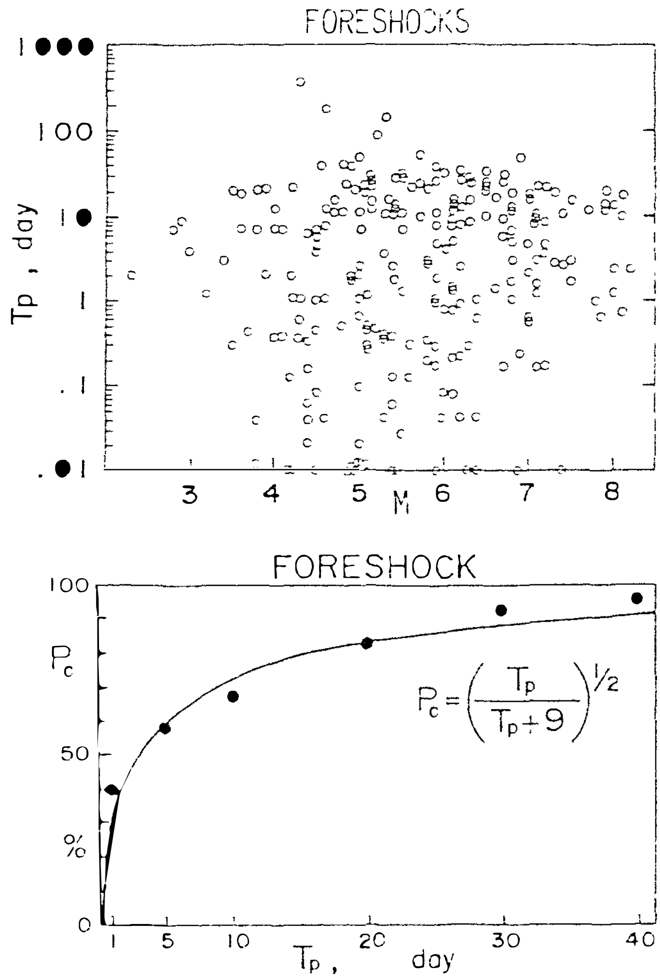

Fig. 9 Above: Precursor time(Tp) vs magnitude(M) of the mainshock. Below: Empirical formula of probability function Pc and observed results(black circles). Pc is the probability of mainshock occurrence within Tp days after the commencement of foreshocks.

from the Earthquake Disaster Countermeasures Section of the Shizuoka Prefectural Office as given in Table 2. Ninety-two out of the total 163 precursory phenomena were obtained after 1974. Therefore, intensified observation according to the national program of the prediction has also been producing the intended effect in the fields of geodetic survey, continuous measurements of crustal movement, geo-electromagnetism, and geochemistry.

Rikitake(1979) examined the relationship between the logarithmic

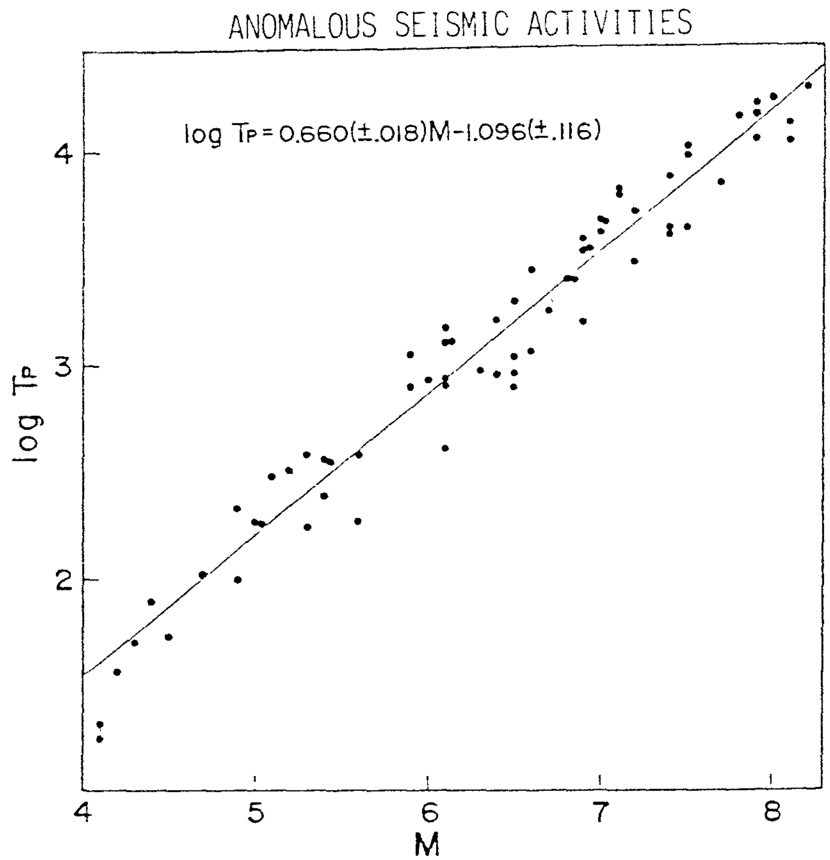

Fig. 10 Logarithm of precursor times(Tp) vs. magnitude(M) of the mainshock.

precursor time and the M of the mainshock for various precursors which were collected from many countries of the world. He found two groups of precursor times; one cluster around the straight line of the empirical relationship logT=0.60M-1.01 and the other cluster around logT=-1. The former is magnitude dependent and called first kind of precursors and the latter is independent of magnitude and called the second kind precursors. The former is useful for long-term prediction and the latter for short-term prediction.

3.3 Synthetic Diagnosis for the Prediction

Prediction of earthquakes should specify the time, magnitude, and location with the probabilities, based on precursors to an earthquake.

There are more than ten kinds of precursory phenomena, including seismological, geodetic, geo-electromagnetic, geo-chemical, and so forth. However, for short-term predictions from several minutes to several days prior to the occurrence of the earthquake, there so far seem to be no deterministic precursors to the earthquake. Precursors do not seem to always appear, but the probability of their occurrence is related to characteristics of the earthquake and the region. Also, there are noises apparently similar to real precursors, which come from differt sources.

Table 2 Non-seismological, precursory phenomena to an earthquake in the period 1923 through 1985(Earthquake Disaster Counter-measures Section of Shizuoka Prefectural Office, 1985)

Kind of observations	Number of precursors	
Geodetic Survey	rhombus base line	1
	levelling	13
	triangulation	1
	tide gauge	9
	gravity	1
Continuous measurements of crustal movement	pendulum tiltmeter	15
	water-tube tiltmeter	10
	strainmeter	16
	volume strainmeter	14
Geo-electro-magnetism	geo-magnetism	5
	earth current	10
	resistivity,	
	Yamazaki-type	30
	others	9
	radio waves	7
Geo-chemistry	Radon	14
	groundwater level etc.	8
Total		163

Therefore, many observations from different disciplines and overall synthetic judgement concerning the occurrence of earthquakes based on those varieties of observations are a realistic and practical approach to the prediction. Unfortunately, there is not really an established method for such an overall, comprehensive judgement yet, but one is being developed. Previous investigators e.g. Rikitake(1969,1976a,b), Utsu(1977,1979,1982), Aki(1981), Anderson(1982), Hamada(1983) have already proposed several techniques to accomplish this end.

Hamada(1983) proposed a probability model for earthquake prediction, where formulae for total probability of earthquake occurrence based on some precursory candidates to an earthquake are derived under the assumption of a very simple probability model. Applied results to the 1978 Near Izu-Oshima earthquake(M7.0) are introduced here.

The Izu area has been seismically active since the 1974 Izu-Hanto C earthquake(M6.9) which occurred near the southern end of the I peninsula(Fig. 11). An earthquake swarm has been observed in the centr part of the peninsula since October, 1975. Unusual uplift in the easte part of the peninsula has also been observed. The Coordinating Committ for Earthquake Prediction issued a statement in May, 1976 concerning t unusual uplift and seismic activities in the Izu area and emphasiz intensification of all kinds of observation from the viewpoint earthquake prediction. Surveys and observations for prediction we intensified thereafter. The 1978 Near Izu-Oshima earthquake(M7.0) occurr beneath the sea near Izu-Oshima Island at 12:24 Japan Standard Time January 14, 1978. Modern instruments detected more than 10 precurso candidates to that event, such as an unusual uplift, foreshocks and chang in strain, groundwater level, radon concentration and geo-electromagnet anomalies.

To apply the probability model, the following assumptions were mad and three groups, A,B,C, of independent precursory candidates were included.

1. The area under consideration is the Izu peninsula and its vicinity.
2. Earthquakes mean those with a magnitude greater than $6\frac{1}{2}$.
3. The probability of successful prediction for each single precursory item is obtained when the basic probability of earthquake occurrence was once

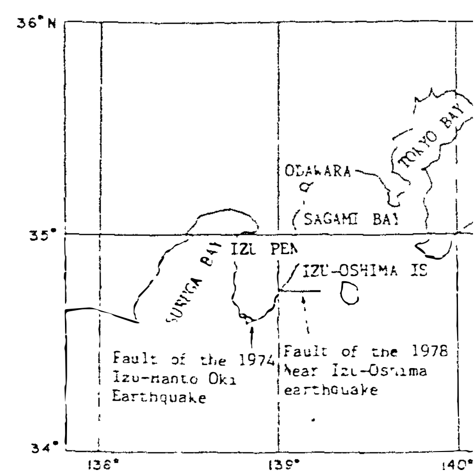

Fig.11 Locality of the Izu peninsu and its vicinity with the earthqua faults of the 1978 Near Izu-Oshi earthquake M=7.0(Shimazaki, 1978) a the 1974 Izu-Hanto Oki earthqual M=6.7(Matsuda and Yamashina, 1974).

per 100 years and 30 years.

4. (A) Unusual uplift was confirmed in August, 1975. The probability that an earthquake would occur within 5 years thereafter was 1/3. If it did not occur in that period, the uplift would be regarded as noise.

5. (B) Unusual changes were observed in strain, radon emanation, level of groundwater, etc. The probability of earthquake occurrence within one month thereafter was 1/10. If there was no earthquake in that period, these unusual changes would be classified as noise.

6. (C) Unusually high seismic, foreshock-like activities were recognized around 10:00 in the morning of January 14, 1978. The probability of earthquake occurrence in the 3 days thereafter was 1/35. If there was no earthquake in that period, those would not be foreshock activities.

The probabilities of earthquake occurrence for each single precursor were taken from a paper by Utsu(1979).

Figure 12 shows the total probabilities calculated under the above assumptions. A,B,C indicate the times of confirmation for the unusual precursory phenomena described above. There are two cases in the figure where the basic probabilities of earthquake occurrence are different. Taking into account the wider area including Odawara, Izu-Oshima, the southern end of the Izu peninsula, the

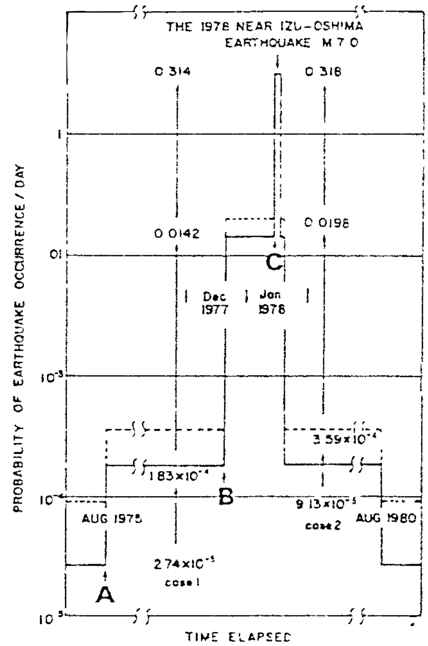

Fig. 12 Application of the probability model to the case of the 1978 Near Izu-Oshima earthquake——the total probability with time elapsed. Numerals show the probability amplified by the appearance of precursory candidates A,B, and C.

calculation in the 2nd case was made.

Although the probabilities of earthquake occurrence adopted at t initial phase in case 1 and 2 differ from each other by threefold, t maximum total probabilities per day of 0.314 for case 1 and 0.318 for case are almost the same. These probabilities are close to that of 0.96 in c 1 for 3 days calculated by Utsu(1979).

Consequently, the total probability of the earthquake occurrence w calculated to be 0.94 for the three days immediately after the observat of the foreshock-like activities near the Izu-Oshima island on the morn of January 14; the main shock took place at 12:24 on January 14, 1978.

It was clearly shown that, when many precursory candidates appear pr to the main event, the total estimation resulting from these precurs candidates is a powerful tool for overall diagnostic judgement concern the earthquake occurrence. However, the rate of successful prediction quite small when each precursory candidate is used alone.

3.4 Detection Capability of the Precursor

The most important information in predicting earthquakes is t observational data, particularly, that on the precursory candidates wh may be the real precursors to an earthquake. Therefore, intensifi observation of natural phenomena relevant to earthquake prediction is t most important tool. The author systematically examined the effect intensified seismic observation in Japan which is one of the m components of the national program for prediction.

Figure 13 shows the number of seismological, precursory phenomena per years reported in the past. These are also given in Table 1. There is very clear trend of increase in the number of precurosrs, and particularly drastic increase after 1976.

Figure 14 shows detection capability of seismological, precurs phenomena to disastrous earthquakes which are defined as ones which caus damage in Japan and of which magnitude is 7 or greater. Such earthquakes

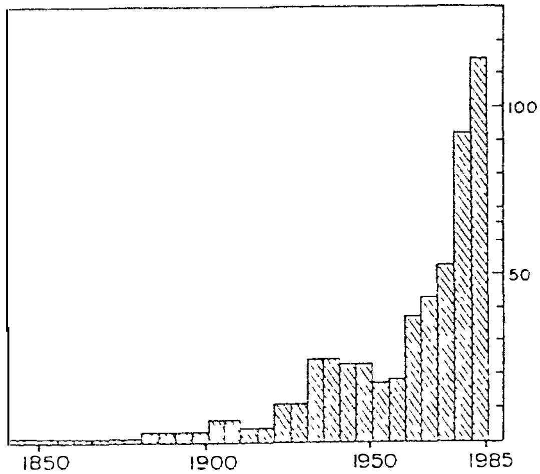

Fig. 13 Number of seismological, precursory phenomena per 5 years.

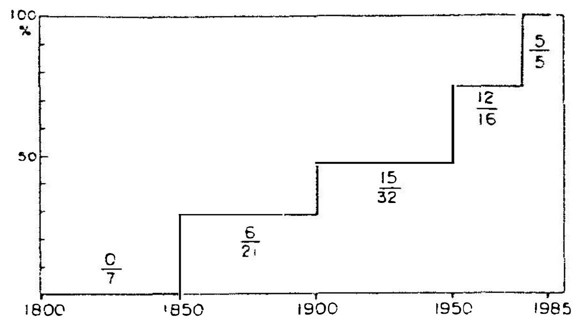

Fig. 14 Detection capability of seismological, precursory phenomena to disastrous earthquakes.

were selected from the list of disastrous earthquakes in the publication of "1986 Rika Nen-pyo"(Chronological Table of Science). There is a very obvious trend of increase in the detection capability as we can see in the figure. Recently, most of the disastrous earthquakes were preceded by at least one precursory phenomenon. However, it must be noticed that almost all precursory phenomena were recognized and reported after the main shock. Therefore, Fig. 14 demonstrates the great possibility of predicting earthquakes, however, this might be possible only when predicting disastrous earthquakes with a magnitude of 7 or greater. Figures 13 and 14 suggest the importance of analitical methods in finding out the precursor prior to the occurrence of the main shock.

4. FUTURE DEVELOPMENT

4.1 New Methodology and Technology of the Prediction

Utsu(1977) has already proposed two kinds of probabilities connection with earthquake prediction. One is that a prediction will successful and the other is that an earthquake will be predicted. former is a ratio of the number of successful predictions to the t number of predictions issued. The latter is a ratio of the number earthquakes which were successfully predicted to the total number earthquakes in space-time domain under consideration.

Prediction research should be expanded into a new area w probabilities of the successful prediction and the predicted earthqu will be examined by a stringent experiment in which the prediction will made, prior to the main shock, based on a preset procedure of processing. Only by doing such an stringent experiment can the useful of each precursory phenomenon and usefulness of algorithm or procedure identify the precursor be examined in the strictest sense. Research w or precursory phenomena after the occurrence of the event are s important and necessary; however, such research alone will not sufficient. This kind of prediction experiment requires a consider amount of work on data processing and that work must be systema Consequently, technological developments in data processing, such automatic determination of hypocenter of the shock, automatic eliminatio noises or automatic calculation of monitoring parameters will increasingly stressed.

4.2 Analyzing System for Precursors of Earthquakes

A prediction-oriented computer system, named the Analyzing System Precursors of Earthquakes(APE), is now under development at the Natio Research Center for Disaster Prediction(NECDP). Figure 15 illustrates target of the APE at the final stage of the development. This system is oriented to establish a basic technique contributing to practical earthquake prediction by providing online monitoring of crustal activities, automatic detection of anomomalous phenomena, and diagnosis of an earthquake occurrence.

Since 1978, the NRCDP has expended its efforts to construct a dense observational network of crustal activities covering the Kanto and Tokai area, central Japan. As of 1986, about 70 stations have been distributed in these areas; the observational items include microearthquakes, crustal tilt

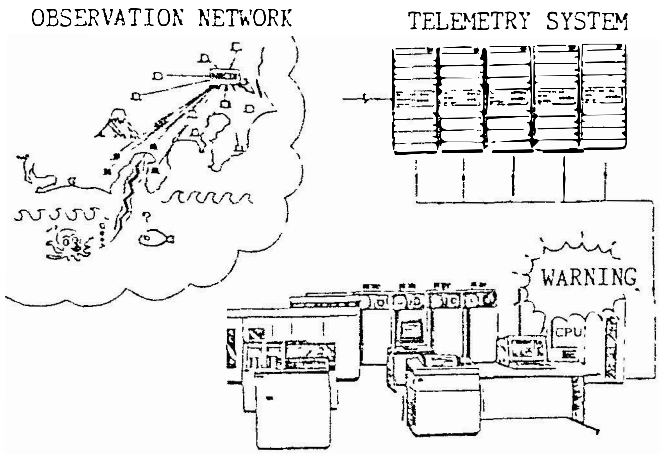

Fig. 15 Illustration of the target of the APE at the final stage of the development.

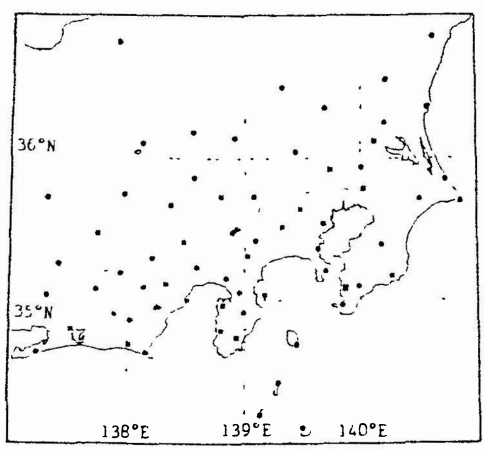

Fig. 16 Location of observation stations of the NRCDP.

and strain, groundwater, and acoustic emission. Figure 16 shows stat distribution of the Kanto and Tokai observational network of the NRCDP. these data are constantly being transmitted through telephone lines to NRCDP in Tsukuba Science City. The APE is dirctly connected to t observational network.

The APE has three fundamental functions, each of which is performed a powerful computer. The first is data acquisition. The second is c processing on the routine basis, and construction of a data base. third, which is the essential element of this system, is realtime automa monitoring of crustal activities. On the basis of the data process monitoring is performed for various observational items of seismicity, ti strain, radon emission, etc., the anomalous changes of which are possi related to an earthquake occurrence. It is thought that the monitoring multiple items by computers makes it possible to provide object information about earthquake prediction, and to evaluate the reliability the prediction. Figure 17 illustrates schematic diagram of the APE.

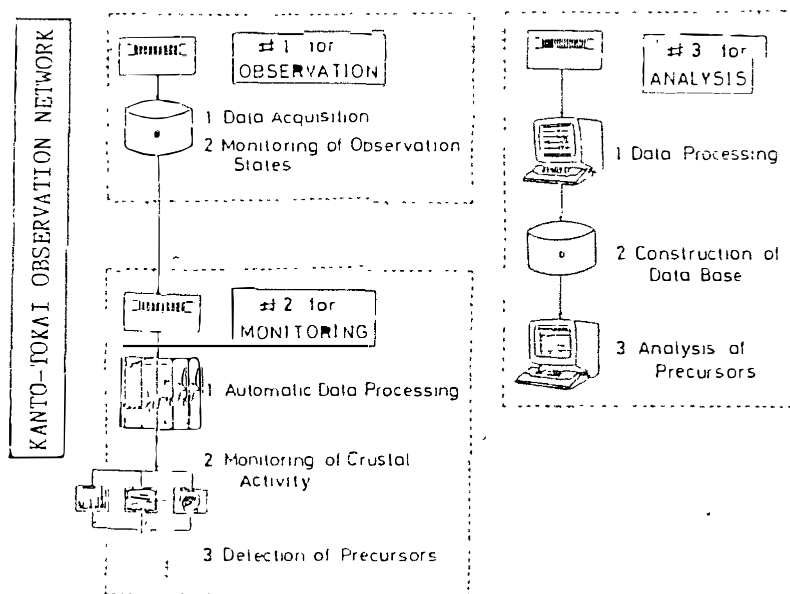

Fig. 17 Schematic diagram of the APE.

4.3 Application of Space Technology

The NASA Geodynamics Program was originally structured to support the Earthquake hazard Reduction Act of 1977 in the United States(NASA, 1983). This act called for federal-agency collaboration in research activities in order to further the understanding of the processes responsible for causing earthquakes. The ultimate goal of this act was the predicting earthquakes and therefore alleviating the danger associated with this phenomenon. The following are the main technology applicable to accurate measurements of crustal movement for eartnquake prediction.

VLBI Development With the development in the late 1960's of extremely precise clocks such as the hydrogen maser, very-long-baseline or independent clock interferometry became possible. In VLBI, incoming stellar radio signals are received simultaneously by antennas that can be separated by very great distances. The signals are recorded at both receiving stations and then cross-correlated at a later time at a central analysis facility. Figure 18 illustrates astronomic radio interferometry techniques. Figure 19 shows the recent achievements in VLBI measurements. The standard deviation of differences from a mean is only 3 cm for a distance of about 4,000 km.

Laser Ranging A laser ranging station(Fig.20 consists of a laser, transmitting telescope and receiving telescope set up on either a permanent or temporary site at a location. The laser is aimed towards a satellite equipped with optical cube corners, which then reflects back the incident laser pulse to the laser receiver located at the station. This process is controlled by the station computer which automatically starts and stops the laser firing and pulse counter. The laser firing is repeated at a rate of one pulse every few seconds. The pulse duration depends on the laser design and may vary from a few nanoseconds to a few hundred picosecond. The distance from laser station to satellite is calculated using measured one-way time interval and the velocity of light. Figure 21 shows recent achievements by satellite laser ranging(SLR).

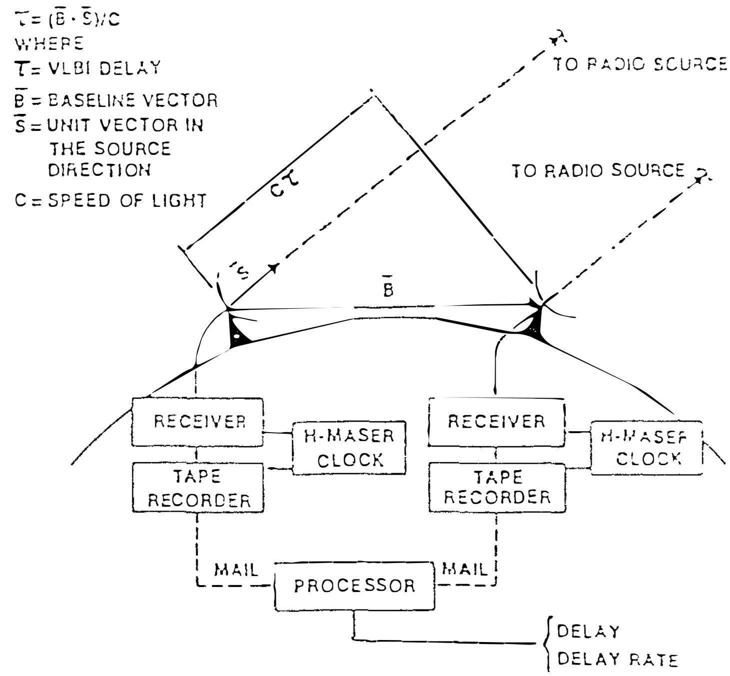

Fig 18 Astronomic radio interferometry techniques.

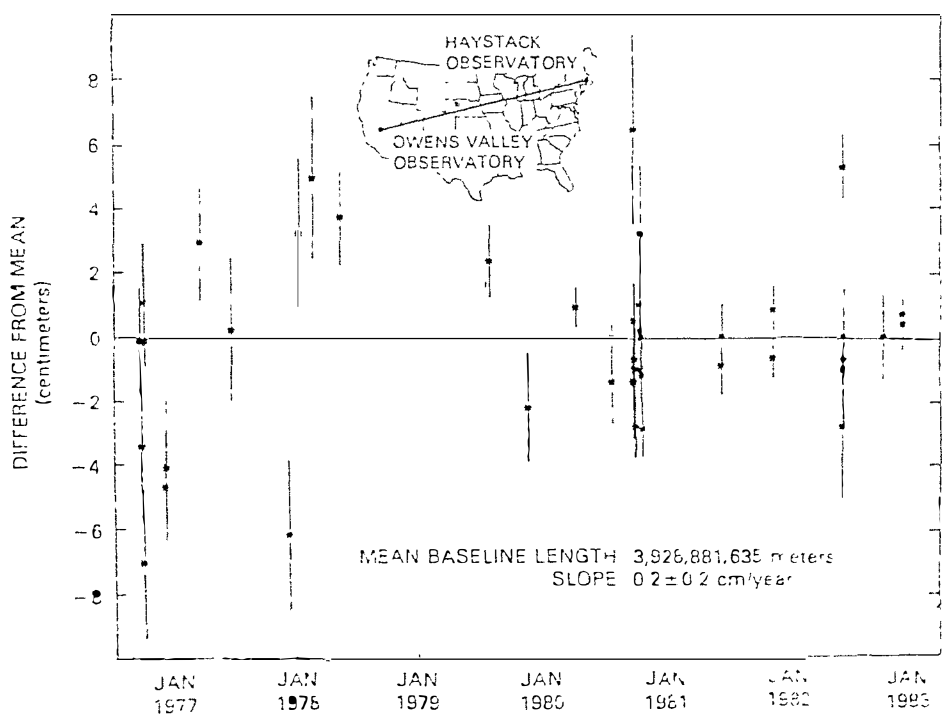

Fig. 19 VLBI measurements. North american plate stabilit

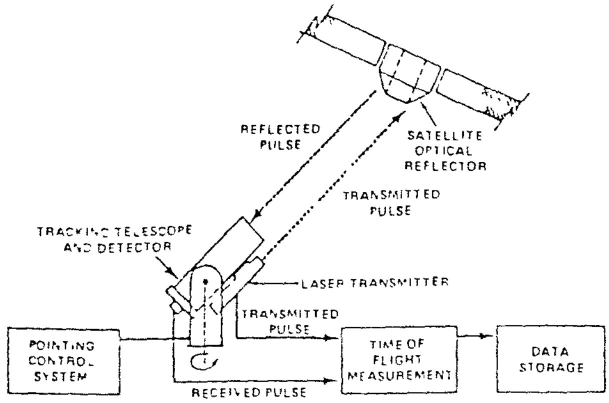

Fig 20 Satellite laser ranging(SLR) techniques.

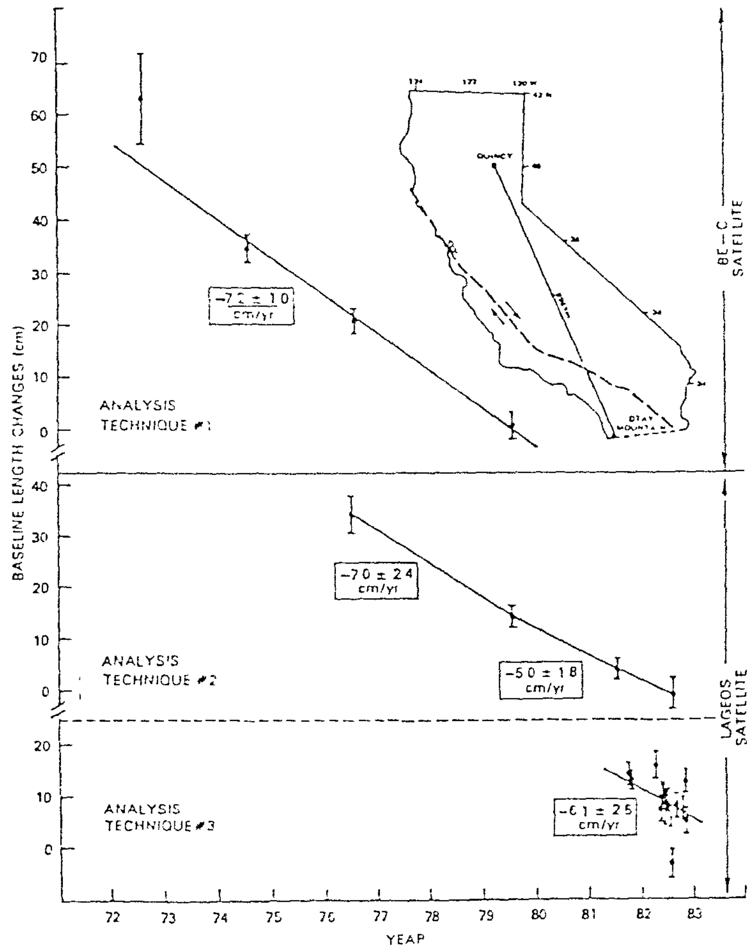

Fig. 21 SLR measurements. western north america region deformation.

Global Positioning System. The Global Positioning System(GPS) is being established by the Department of Defense in order to consolidate and improve present navigation systems. The system will include 18 satellites. Several concepts have been proposed for making use of the GPS signals to measure crustal movement. Many uncertainties still exist, although the prospects seem good that all of the GPS methods being developed will achieve at least 3 cm accuracy for the three baseline components at a high confidence level.

4.4 Deep-Down-Hole Measurements of Crustal Activity

As part of the national program of earthquake prediction, techniques for deep-down-hole measurements of crustal activity were designed and completed by the National Research Center for Disaster Prevention(NRCDP) in order to overcome artificial noises at the surface of the capital area in Japan(e.g. Hamada et al., 1979). Due to land development in urban areas, sensitive and accurate measurements of crustal activity, which are very important in the prediction of earthquakes, are becoming impossible to obtain by the use of the conventional instruments at the surface.

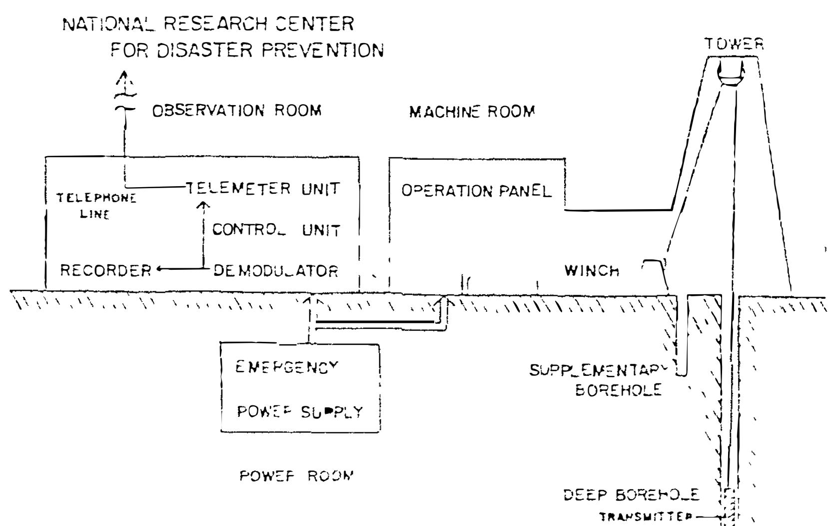

Fig. 21 Outline of the deep-borehole observatory.

Table 3 Performance of the deep-borehole observatories

Observatory	Iwatsuki	Shimonsa	Fuchu
Code	IWT	SHM	FCH
Location	35°55'33"N 139°44'17"E	35°47'36"N 140°01'26"E	35°39'02"N 139°28'25"E
Altitude	-3502m	-2277m	-2707m
Temperature	85.6°C	61.9°C	82.0°C
A three-components set of velocity seismometers			
Sensitivity	1.7V/(cm/sec)	1.9V/(cm/sec)	1.7V/(cm/sec)
Frequency	1.0Hz	1.0Hz	1.0Hz
Damping	0.65	0.62	0.62
Overall ranges recordable	2μ-10m,cm/sec (1-25Hz)	5μ-70m,cm/sec (1-25Hz)	7μ-16m,cm/sec (1-25Hz)
A three-components set of accelerometers			
Sensitivity	16.1V/G	16.1V/G	1.17V/G
Frequency	50Hz	50Hz	100Hz
Overall ranges recordable	5m-30gal (0-30Hz)	5m-30gal (0-30Hz)	0.1-850gal (0-30Hz)
A two-components set of Tiltmeters			
Sensitivity	100mV/arc sec	100mV/arc sec	100mV/arc sec
Overall ranges recordable	0.01-5arc sec	0.01-5arc sec	0.01-5arc sec
Thermometers			
Sensitivity	0.2V/°C	0.2V/°C	0.2V/°C
Overall ranges recordable	85-90°C	56-68°C	76-86°C

Therefore, techniques for deep-down-hole measurements are increasingly essential in and around city areas in many countries. Figure 22 and Table 3 show a rough sketch and performance of the three deep-borehole observatories which were completed by the NRCDP. Seismic noise level at the bottom is fairly stable and low. The spectral amplitude of background noise at the bottom of the hole is from 1/30 to 1/100 compared with that at the surface, depending on the surface conditions.

REFERENCES

Aki, K., A probabilistic synthesis of precursory phenomena, in Earthquake Prediction, An International Review, Maurice Ewing Series, IV, edited by D. W. Simpson and P. G. Richards, 566-574, AGU, Washington, D.C., 1981.

Anderson, J. G., Revised estimates for the probabilities of earthquakes following observation of unreliable precursors. Bull. Seismol. Soc. Am., 879-999, 1982.

Earthquake Disaster Countermeasures Section of the Shizuoka Prefectural Office, The present state of analysis of precursors to an earthquake, pp.144, 1985, in Japanese.

Hamada, K., H. Takahashi, M. Takahashi and H. Suzuki, Deep borehole Measurements of Crustal Activities Around Tokyo, in Terrestrial and Space techniques in Earthquake Prediction Research, edited by A. Vogel, 475-500, Friedr. Vieweg & Sohn, Braunschweig/Wiesbaden, 1979.

Hamada, K., A probability model for earthquake prediction, Earthq. Predict. Res. 2, 227-234, 1983.

Matsuda, T. and K. Yamashina, Surface faults associated with the Izu-hanto-Oki earthquake of 1974, Japan, Special Bull. Earthq. Res. Inst., 14, 135-158, Univ. Tokyo, 1974.

NASA, The NASA Geodynamics Programs:An Overview, Geodynamics Program Office, 1983.

Rikitake, T., Prediction of magnitude and occurrence time of earthquakes, Bull. Earthq. Res. Inst., 47, 107-128, 1969.

Rikitake, T., Earthquake prediction, Elsevier, Amsterdam, 1976a.

Rikitake, T., A guide to earthquake prediction theory, Kyoritsu-Shuppan, Tokyo, 1976b, in Japanese.

Rikitake, T., Classification of earthquake precursors. Tectonophysics, 54, 293-309, 1979.

Shimazaki, K., Summary of the fault parameters of the Izu-Oshima earthquake of January 14, 1978, Rep. Coord. Comm. Earthquake Prediction, 20, 51-52, 1978, in Japanese.

Tsuboi, C., K. Wadati and T. Hagiwara, Prediction of earthquakes---progress to date and plans for future development, Rep. Earthquake Prediction Res. Group, Earthq. Res. Inst. Univ. Tokyo, pp.21, 1961.

Utsu, T., Probabilities in earthquake prediction, Bull. Seismol. Soc. Jap., II, 30, 179-185, 1977.

Utsu, T., Calculation of the probability of success of an earthquake prediction(in the case of Izu-Oshima Kinkai earthquake of 1978), Rep. Coord. Comm. Earthquake Prediction, 21, 164-166, 1979, in Japanese.

Utsu, T., Probabilities in earthquake prediction(the second paper), Bull. Earthq. Res. Inst., 57, 499-524, 1982, in Japanese.

KAGOSHIMA DECLARATION

1988 JULY

KAGOSHIMA INTERNATIONAL CONFERENCE
ON VOLCANOES

Kagoshima Declaration

Of all the diverse natural phenomena of our planet Earth, volcanoes have a particular! significant impact on the daily lives of their human neighbours.

While responsible for a number of disasters in world history, and seriously affectir everyday life and industry in many volcanic regions, volcanoes are one of the dramat geophysical forces that shape our environment In addition, they provide valuable benefi in the form of resources and energy.

The 5-day Kagoshima International Conference on Volcanoes was held in July, 1988, wi the general theme "Towards Better Coexistence between Human Beings and Volcanoes The Conference was sponsored by Kagoshima Prefecture, Japan, the site of seven activ volcanoes including the famous Sakurajima Volcano.

Participants from all over the world exchanged knowledge and experience in a ver wide range of volcano-related fields.

The following conclusions emerged as a result of the Conference

1. The continued development and improvement of volcanic research and monitorin systems for eruption forecasting, disaster mitigation etc are of vital importance i nations with active volcanoes.
   Because volcanic activities widely and variously influence our daily life, the furthe promotion of interdisciplinary and international cooperation in volcanic research is c the highest priority.

2. To maintain the safety and health of people living in volcanic regions and to reduc risks to our daily life and industrial activities, we will endeavor to apply the results c research and monitoring of volcanic activities and related developments in other field to administrative measures designed to mitigate disasters.
   Mutual understanding and cooperation between peoples of the world will be enhance through increased availability of more accurate knowledge and information concernin volcanoes.

3. A number of valuable studies are currently being carried out towards the fulle utilization of volcanic resources and energies.
   Important benefits to daily life will result from increased application of the lates technology, combined with practical developments, in cooperation with the academic administrative and private sectors

4. In order to stimulate the development of volcanic regions by promoting tourism and other industries drawing on their natural resources, and the establishment of communities appropriately oriented to the specific features of volcanic regions, we will intensify efforts to promulgate the exchange of practical experiences and research results between volcanic regions all over the world.

5 To achieve the above-mentioned objectives, the establishment of one or more international and comprehensive volcanic information, research and training centers is urgently required. We strongly recommend that vigorous and immediate action be taken to implement such a plan by the nations and organizations concerned

The Kagoshima International Conference on Volcanoes was the world's first meeting to focus extensive and comprehensive attention on the problems of coexisting with volcanoes, with participants attending from 30 nations throughout the world. We believe that this conference was especially symbolic and meaningful in being held just before the "International Decade for Natural Disaster Reduction" established by the United Nations and aimed at reducing the effects of natural disasters

We sincerely hope that this conference will deepen peoples' interest in volcanoes, and produce a wide range of fruitful results, thereby contributing greatly to progress and development in all of the volcanic regions of the world.

July 23, 1988

Kagoshima International
Conference on Volcanoes

KAGOSHIMA '88

INTERNATIONAL CONFERENCE ON VOLCANOES