Geoelectric Precursors to Earthquakes in China

Fuye Qian Yulin Zhao and Chun Wei

(*Institute of Geophysics, State Seismological Bureau, Beijing* 100081, *P. R. China*)

Abstract

The main results of searching for geoelectric precursors to continental strong earthquakes in China for the last 25 years are presented. Those are the continuous twenty—year resistivity record before and after the great Tangshan earthquake of 1976, spatial and temporal variation of resistivity anomalies observed at more than 6 stations whose distance from the Tangshan earthquake epicenter are within 150 km, the travel—time curve for the front of the resistivity precursor and a method of intersection for prediction of epicenter location, the behaviors of intermediate—term precursor for resistivity and empirical formulas of the relationships between the resistivity anomalies or the epicentral distances to resistivity stations and magnitudes, and identification of short—term or impending—earthquake precursory signals of resistivity and self—potential and their mechanism.

Stability and accuracy of the measurement, ability to separate "normal" variations and environmental effects from precursory signals, relationship between geoelectric precursors and strain or fluid flow, and negative cases such as aseismic variation are also discussed in brief.

1. Introduction

In 1966, at about the same of study as Japanese, Russian and American scientists (Rikitake & Yamazaki, 1969; Barsukov, 1970; Mazzella & Morrison, 1974; Fitterman & Madden, 1977; Yukutake et al., 1978), we began to search for geoelectric precursors to earthquakes in the aftershock area of the Xingtai earthquake, Hebei province (Zhao & Qian, 1969). China has consistently funded research earthquake related geoelectric phenomena for the last 25 years. The SSB of China has established a national network of over 100 geoelectric stations in major meizoseismal zones of the country (Fig. 1). Three methods of geoelectric measurement in earthquake prediction are used; one is resistivity method for intermediate or short—term prediction (Zhao & Qian, 1978), the second is self—potential, used mainly in short —term or impending earthquake predictions (Zhao & Qian, 1982) and the third is magnetotelluric method, applied to mapping subsurface conductivity structures for long—term prediction of the localities prone to earthquakes (Qin et al. , 1991;). Since we set up the first resistivity network, consisting of 14 stations, in the Xingtai earthquake area, techniques for monitoring precursory signal and separating "normal" variations and environmental effects from the signal are developed, refined and standardized (Qian et al. , 1981; Qian et al. , 1987) and continuous resistivity data with high accuracy of better than 0. 3 to 0. 5% have since been collected at the great majority stations. Almost thirty geoelectric precursors to earthquakes with magnitude greater than 6 have been measured. Of these thirty cases, the most significant precursors of resistivity were obtained before the M=7. 8 Tangshan earthquake of 1976.

In the paper, we will concentrate on intermediate and short—term or impending earthquake precursors.

2. The Intermediate—term Precursory Signal of Resistivity

Figure 2 is the continuous twenty—year resistivity record at Baodi station which is 80 km from the Tangshan epicenter. This record shows only one significantly large change over the twenty—year period, associated with the great Tangshan earthquake of 1976, the only strong earthquake to have occurred within 250 km of the station. An intermediate—term precursor, shown in Fig. 2 as a persistent decrease in resistivity, began about three years prior to the Tangshan earthquake. The amplitude (3. 1%) of the overall decrease in resistivity was over twenty times the standard deviation (0. 15%) and the mainshock occurred when the resistivity anomaly fell to about its lowest value. After the earthquake, the resistivity increased gradually to the "normal" value before the earthquake in about four years. In other periods (both in the earlier period 1968——1973 and in the period after 1981), the annual rate of change in resistivity was relatively small and no anomaly occurred.

Figure 3 shows the resistivity curves, over a period of years, for six stations around the Tangshan 7. 8 event. The curves for two mutually perpendicular arrays at each station are given, and the stations are arranged according to distance from the Tangshan epicenter. Except for the Mafang station, all stations show intermediate—term precursors, an overall decrease in resistivity appearing two to three years before the Tangshan event. This anomalous decrease begins first at the epicentral area stations of Tangshan and Changli, moving outwards to Baodi and finally to Qingguang and Zhongxingzhuang stations, as far away as 150 km from the epicenter. We suggest that the front of the resistivity precursor here emigrates from the epicenter at an apparent velocity of approximately 100 km per year.

The general decrease is such a pervasive phenomenon that the mean decrease, in percent, can be contoured on a map of the Beijing—Tianjin—Tangshan region (Fig. 4). This shows that the maximum decrease is centered over the epicenter.

Through analysis of data from the entire country for about 10 large earthquakes over the last two decades, we have obtained the travel—time curve for the front of the resistivity precursor (Fig. 5). Note that the closer one is in time to the earthquake event, the higher the emigration speed the resistivity precursor front will have. This steepening in slope may reflect an acceleration in earthquake faulting.

We have developed a method of intersection for prediction of the would — be epicenter location on the basis of our travel—time curve. Figure 6 shows the results of a test case for this method, using data from our geoelectric stations in southwest China. A predicted epicenter was established in May of 1989. The actual epicenter is shown with solid line circule in Fig. 6 for the M=6.7 Xiaojin earthquake, which occurred on Sep. 22, 1989. A deviation of only less than one degree of latitude separates these two epicenters.

By means of analysis of over 50 resistivity precursors to the earthquakes with magnitudes from 3.0 to 7.9, the following empirical relations between the duration (T), amplitude ($\Delta\rho/\rho$) or the epicentral distances (Δ) of the stations exhibiting the intermediate — term precursor of resistivity and the earthquake magnitude (M) are found (Qian, et al., 1982):

$$M = 0.50 + 2.50 \log T$$

$$M = 10.8 + 3.41 \log (\Delta\rho/\rho)$$

$$M = -1.34 + 3.40 \log \Delta$$

These empirical formulates reveal that the longer the duration is, the larger the amplitude of the anomaly is, and the wider the anomalous area is, the greater the magnitude of the earthquake will be. For great earthquakes of $M \geqslant 7$, the duration of the resistivity anomaly may be two to three years; the amplitude of the anomaly is 3—5% and the extent of the anomaly may reach a distance of 200 to 300 km.

Note that negative cases such as aseismic variation, post—shock effects and no variation before an earthquake are sometimes observed and lead to trouble with an intermediate—term prediction. The number of aseismic variation is about 45% of the total of anomalous variation and this is the main reason of a false prediction.

3. Sort—term or Impending Earthquake Precursors

On a shorter time scale, two months before the Tangshan earthquake, additional significant changes, including pulse—like periodic variations and accelerated decreases, in our resistivity and self—potential data sets were observed, which were considered as sort—term or impending earthquake precusors. Figure 7 shows the sort—term precursors of accelerated decrease in resistivity before the M 7.8 Tangshan earthquake and the M 7.2 Sungpan earthquakes. The upper curve in this Figure shows the record observed at the Wudu station (Δ=100 km) before the 1976 Sungpan earthquakes, whereas the lower curve is the record at the Changli station (Δ=70 km) before the Tangshan event. The fact that the very similar pattern of the accelerated anomalies in resistivity occurred just prior to different earthquakes may be essential to understand the mechanical process at the source.

Figure 8 is the daily observed resistivity, taken six times per day on the north—south and east — west arrays at Changli station, for the month of July, 1976. Changli station is 70 km from the Tangshan mainshock and 35 km from the magnitude 7.1 aftershock. Note the series of hachured minima which are pulse—like periodic variation in resistivity with amplitudes over three times the standard deviation. These abnormally large pulses appeared half a month before the 7.8 mainshock.

Figure 9 shows the number of resistivity pulses with amplitudes over three times the standard deviation for two array lines at the Changli station for each month from 1975 until the end of 1977. The number of pulses increased two months before and five months after the Tangshan mainshock, with the largest number occurring within two weeks before the 7.8 event. There were no unusual pulses found in other periods.

The predominant pulse period is 13 hours and these pulses have an average daily delay of 0.8 hours (Qian, et al., 1990 I). It iswell known that the tidal force M_2 has a period of 12 hours and 25 minutes as well as a daily delay of 0.8 hours. We therefore suggest that the resistivity pulses are related to the earth tide M_2.

We know that tidal forces are applied to the earth continuously. Why is it, then, that resistivity response to the tidal forces is seen only two weeks before the Tangshan mainshock?

To answer this question, the weakening model is illustrated in Figure 10. The top of this figure is a schematic where the solid curve represents the constitutive equation of a geological system. Brittle rock failure, such as earthquakes, occurs in the strain weakening stage and we consider the stage where the slope of the constitutive curve changes from positive to negative as an impending—earthquake stage. Enlarging the maximum part of the curve, we obtain the lower curve in Figure 10. If we load the system at point E with the normally small tidal force, the resulting output will be small. However, if we take a similar tidal force input and apply it to point D′, the resulting output will have a large amplitude. Note that this amplification will only occur at points close to peak stress or when the stiffness (k) is equal to zero (Qian et al., 1990 I). Hence, by monitoring for such large responses from a strained rock system, we can determine whether the system is under the state of $k=0$. Determining this state is crucial in predicting the system instability related to earthquakes.

Figure 11 is another type of geoelectric measurement, that of self—potential. This is a plot of daily data recorded in the entire year of 1976 at the Xiji station, about 120 km from the Tangshan epicenter. It can be seen that for the first half of the year, there was essentially no change in the record. But starting at the end of May, significant variation in the signal occurred. High frequency components were superimposed on this marked change. Analysis of these components showed a variation of a half—month period, similar to that of the tidal force MS_f.

If we now examine the power spectrum density of self—potential for the half month period, we obtain Figure 12, which shows data from two different stations, one at Baodi, 80 km, and the other at Xiji, 120 km, from the Tangshan epicenter. We see that two months before, and some time after the 7.8 mainshock, anomalies in power spectrum density four to six times above the usual background noise appeared. Note the very low power spectrum density in the earlier period. Upon comparison of these two very different sets of data, one resistivity and the other self—potential (see Figures 9 and 12), we note the following: these data were taken at three different stations, and are related to different tidal forces, M_2 and MS_f, respectively.

The fact that, under such differing circumstances, very similar phenomena occurred just prior to the $M=7.8$ Tangshan earthquake, indicates that a common mechanism in the earth is involved. We believe that our model simulates this mechanism.

Our in situ experiments indicate, resistivity and self—potential data indirectly and very sensitively reflect the strain or displacement of the crust (Zhao, et al., 1990; Qian, et al., 1990 II). Thus, by analyzing such data in conjunction with the effects of tidal forces, we may be able to identify short—term or impending earthquake precursors.

4. Concluding Remarks

In closing, we note that:

1). Geoelectric precursors for strong earthquakes clearly exist.

2). Although the underlying cause for these precursors is not known, the volumes, pressures and connections of pore—fluid are probably involved. Geoelectric measurements are the geophysical measurements most closely related to pore—fluid behaviors. they thus provide insights into the earthquake cycle that cannot be easily duplicated by other geophysical measurements.

3). China has accumulated a rich and unique library of geoelectric data from many earthquakes. Based upon the experience gained through the analysis of these data, methods for predicting the time, magnitude and location of strong earthquakes have been developed. These methods are currently being used for prediction with some success.

Note that we sometimes observe negative cases that lead to trouble with prediction.

4). We should research into the physical mechanisms of electrical precursors to earthquake and new technologies in detecting electrical phenomena.

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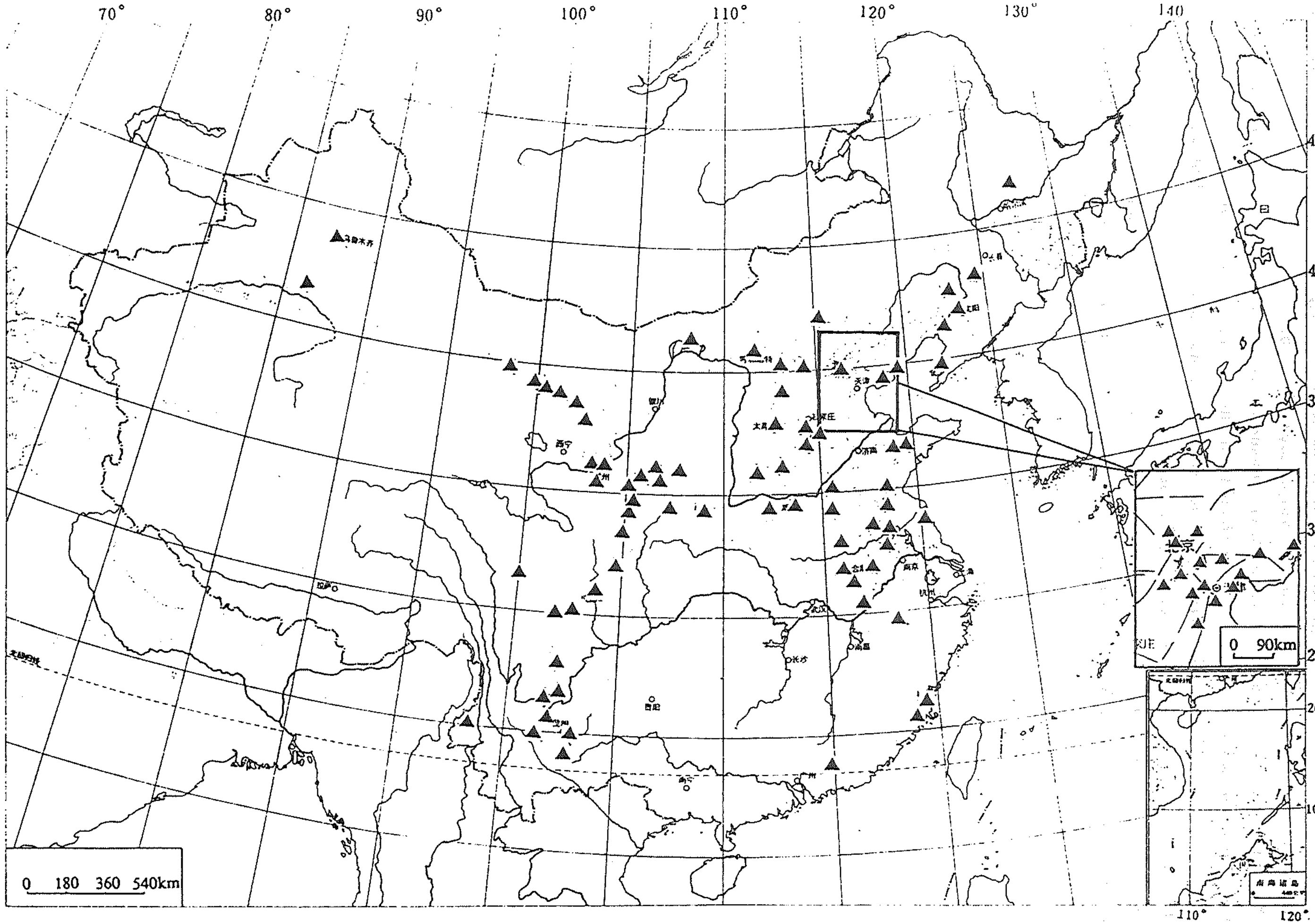


Fig. 1. The distribution of geoelectrical stations (▲) in China

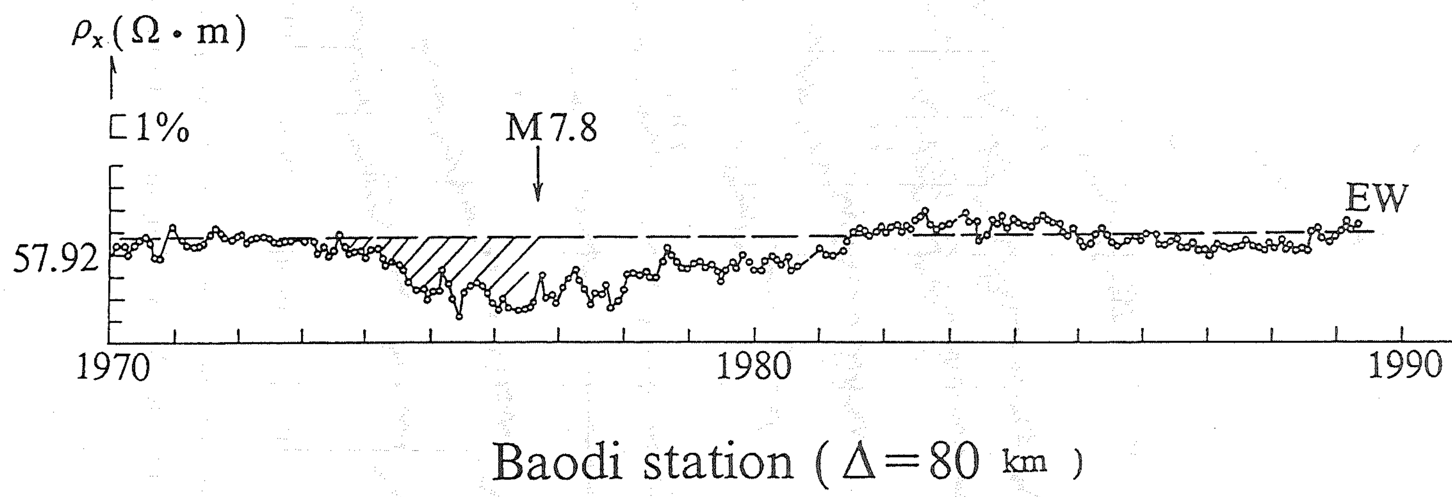


Fig. 2 Resistivity anomaly before the Tangshan earthquake observed at the Baodi station (Δ = 80 km).

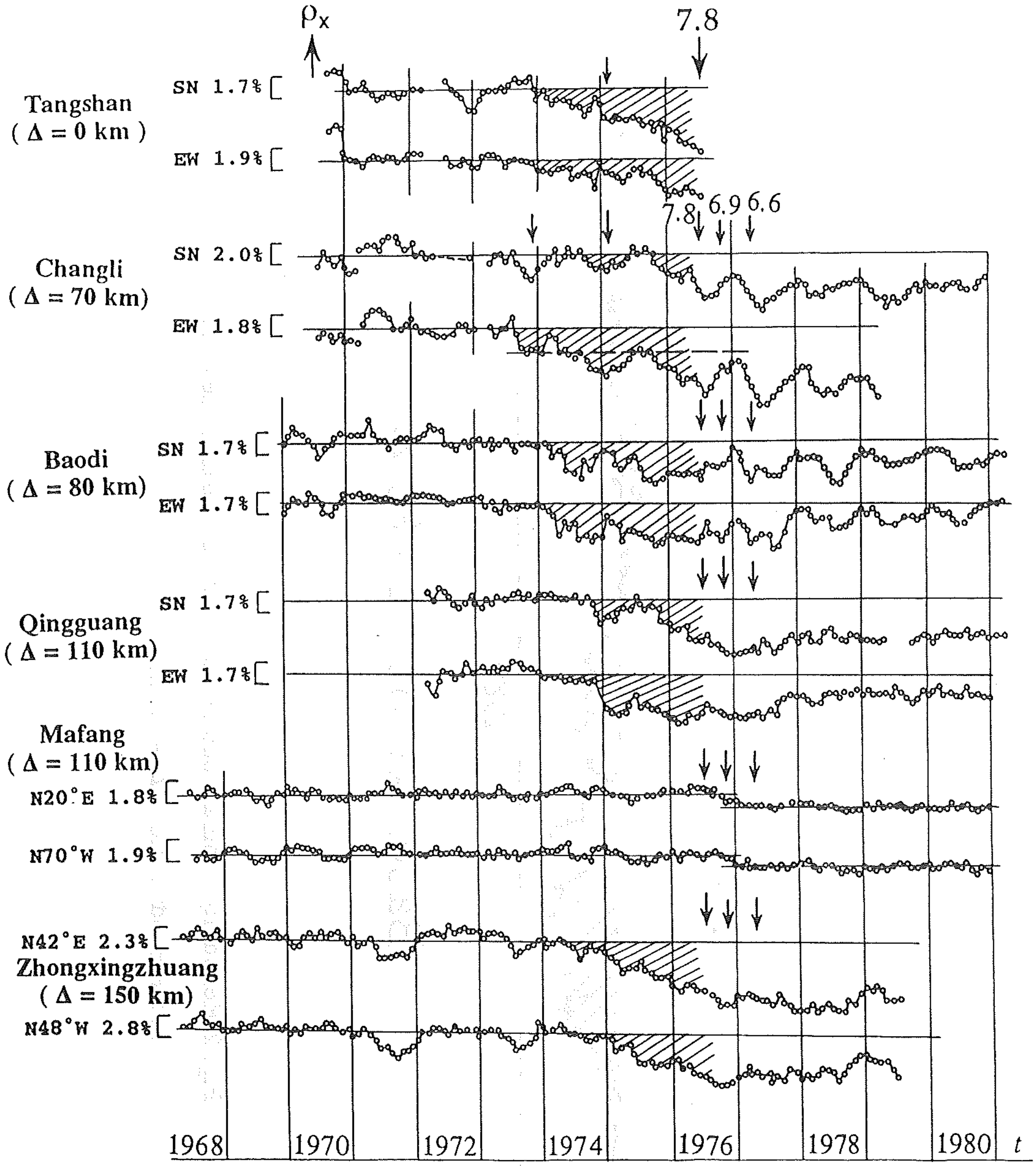


Fig. 3. The curves of monthly mean of resistivity recorded continuously at 6 stations around the M7.8 Tangshan earthquake epicenter.

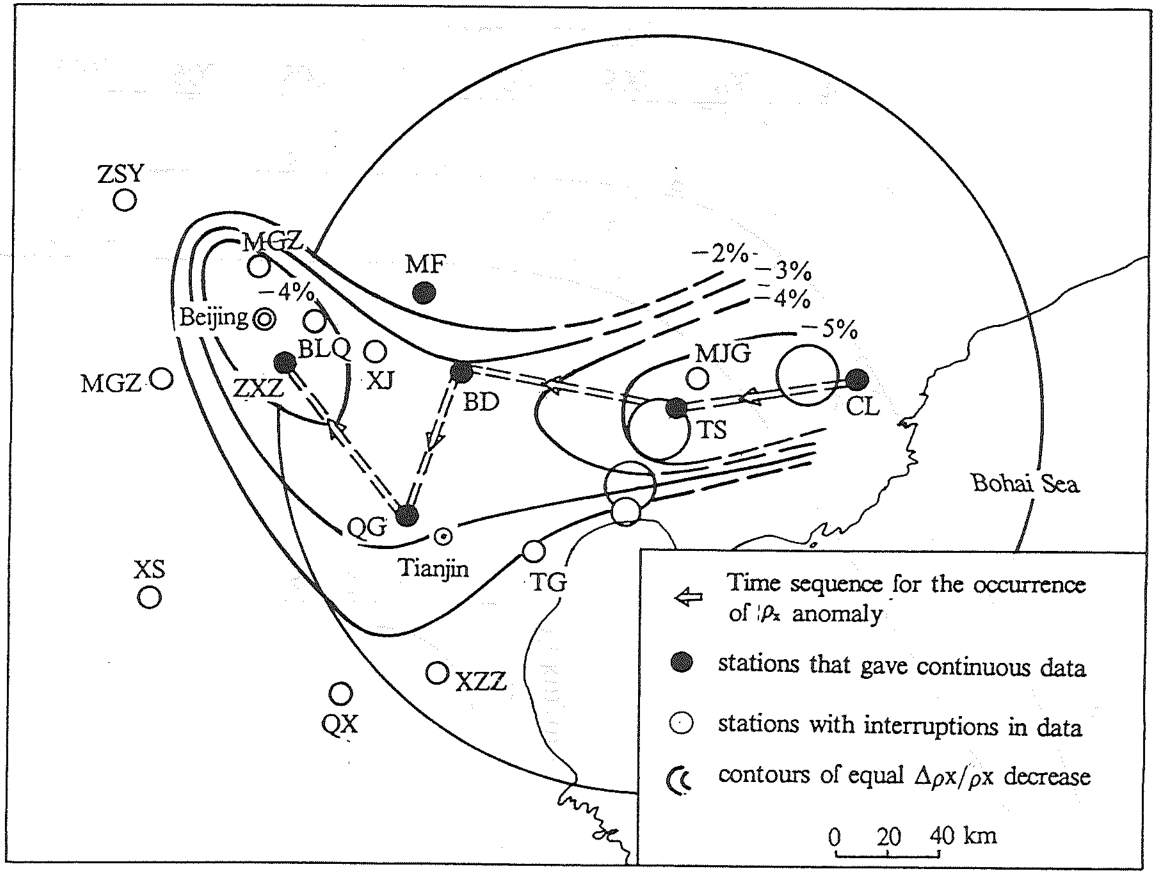


Fig. 4 The contour map of resistioity decrease, in percent, before the great Tangshan earthquake.

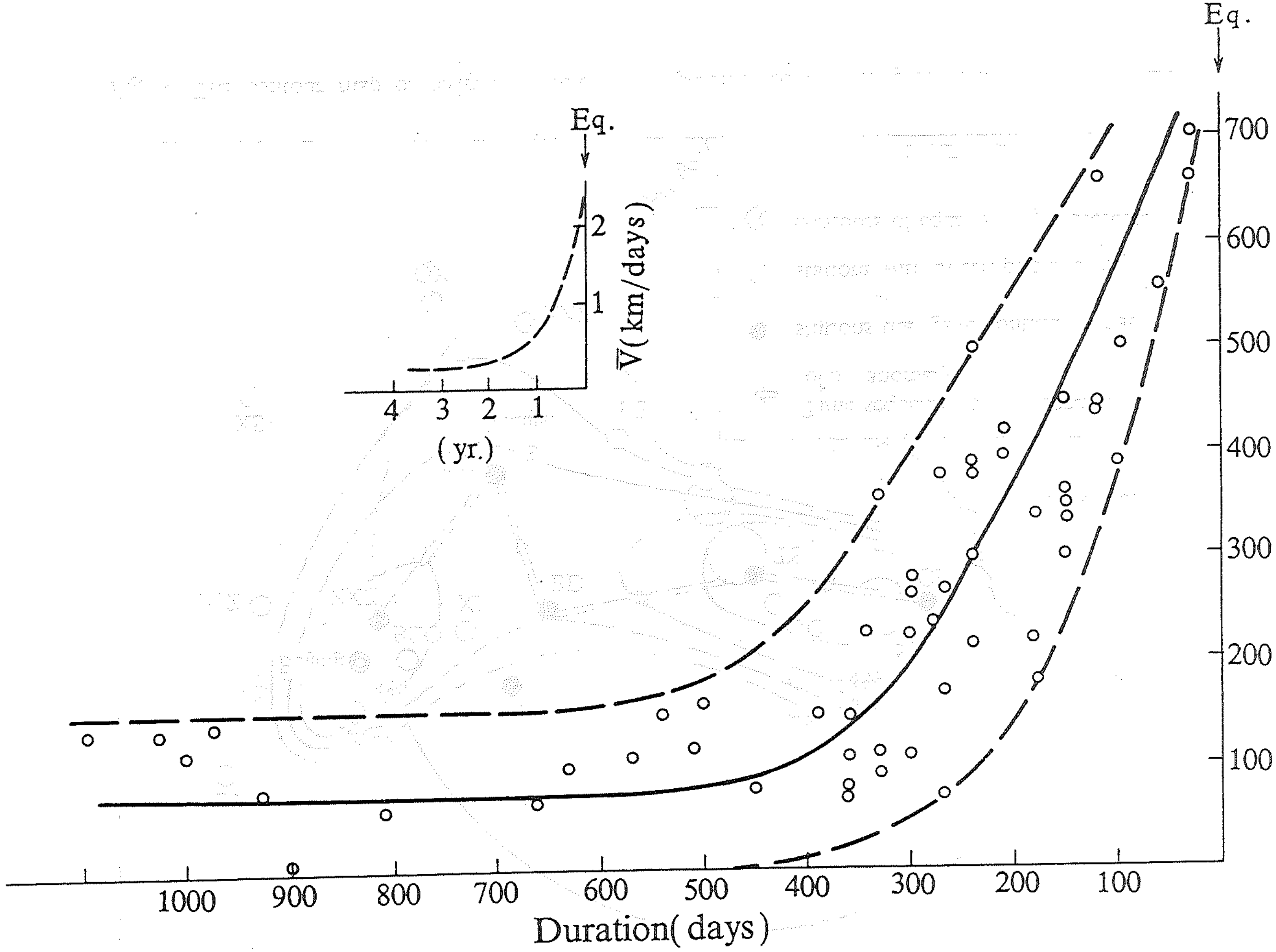


Fig. 5. The travel-time curve for the georesistivity precursor front

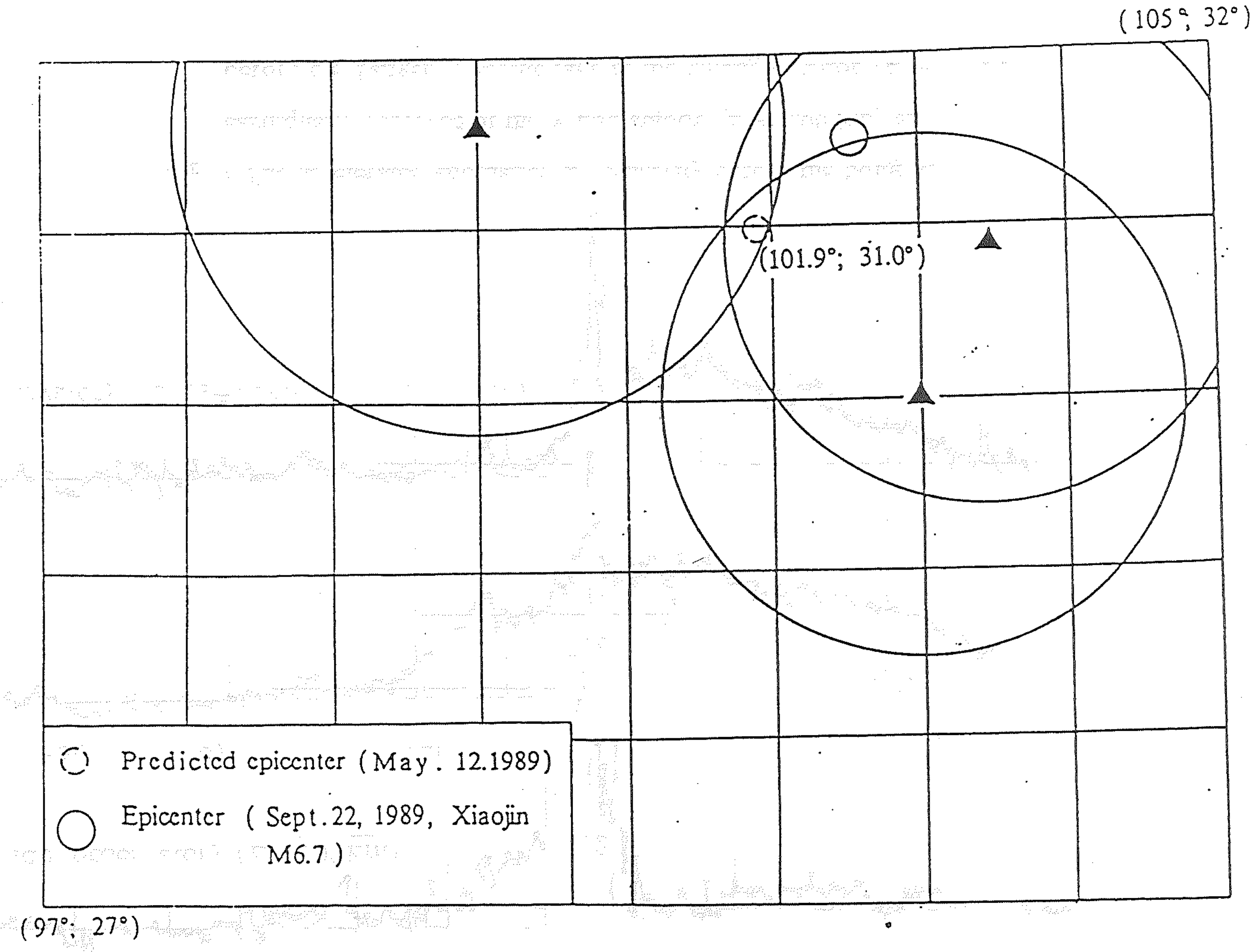


Fig. 6 The results of a test prediction.

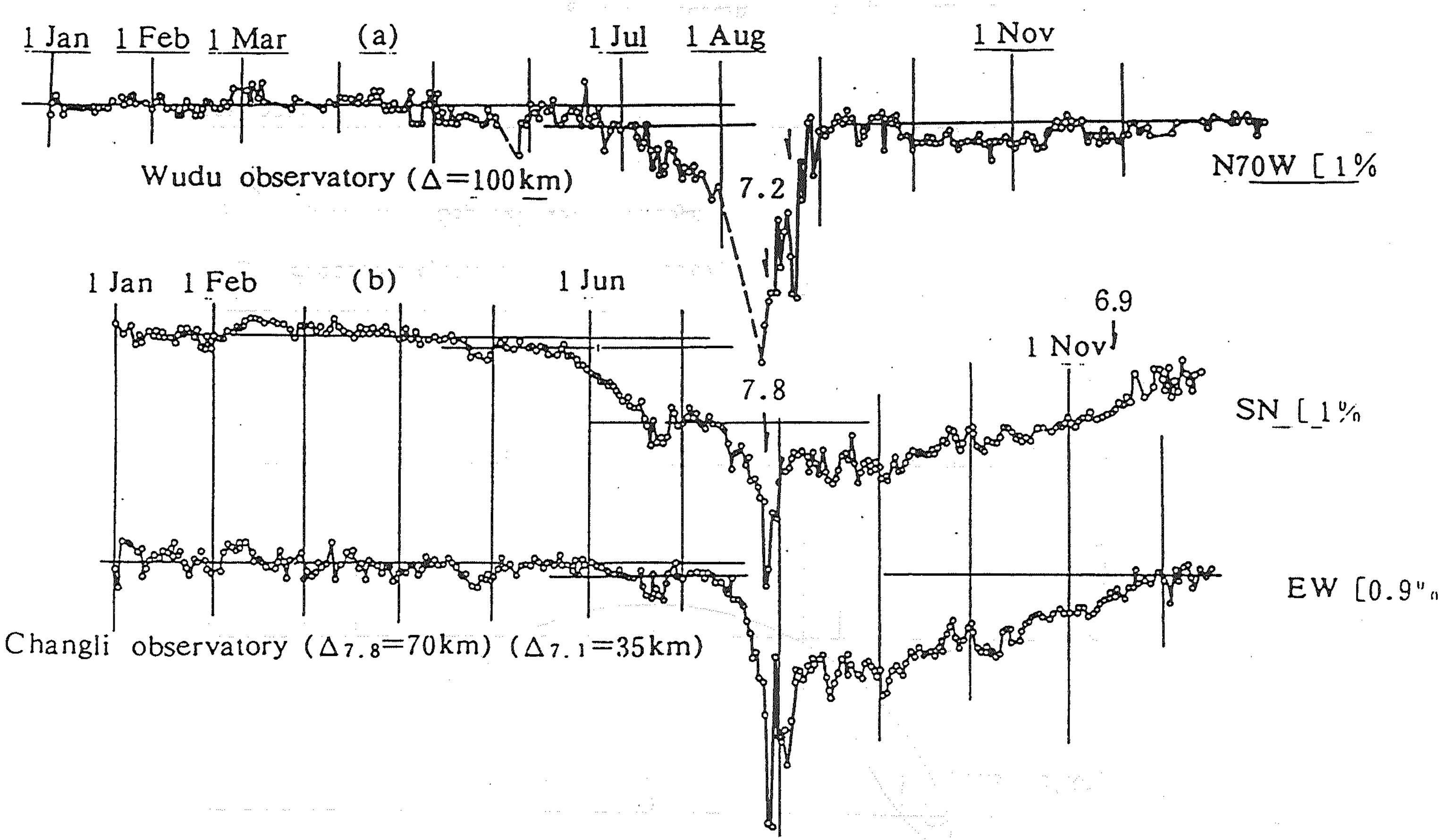


Fig. 7 The accelerated anomalies in resistivity before the Songpan earthquake observed at the Wudu station (Δ = 100 km) and before the Tangshan earthquake at the Changli station (Δ = 70 km).

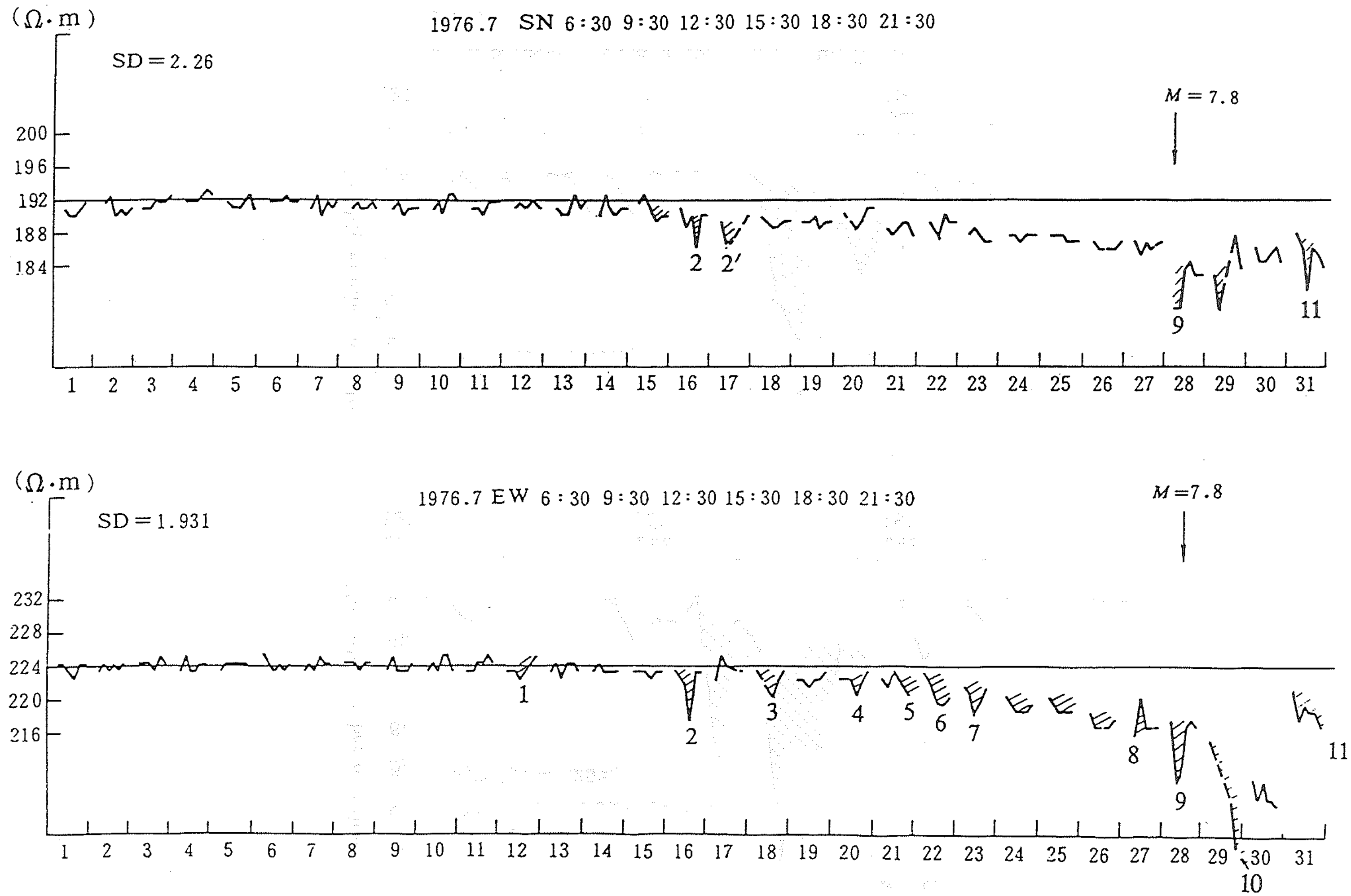


Fig. 8. Data of georesistivity observed at the Changli station in July 1976.

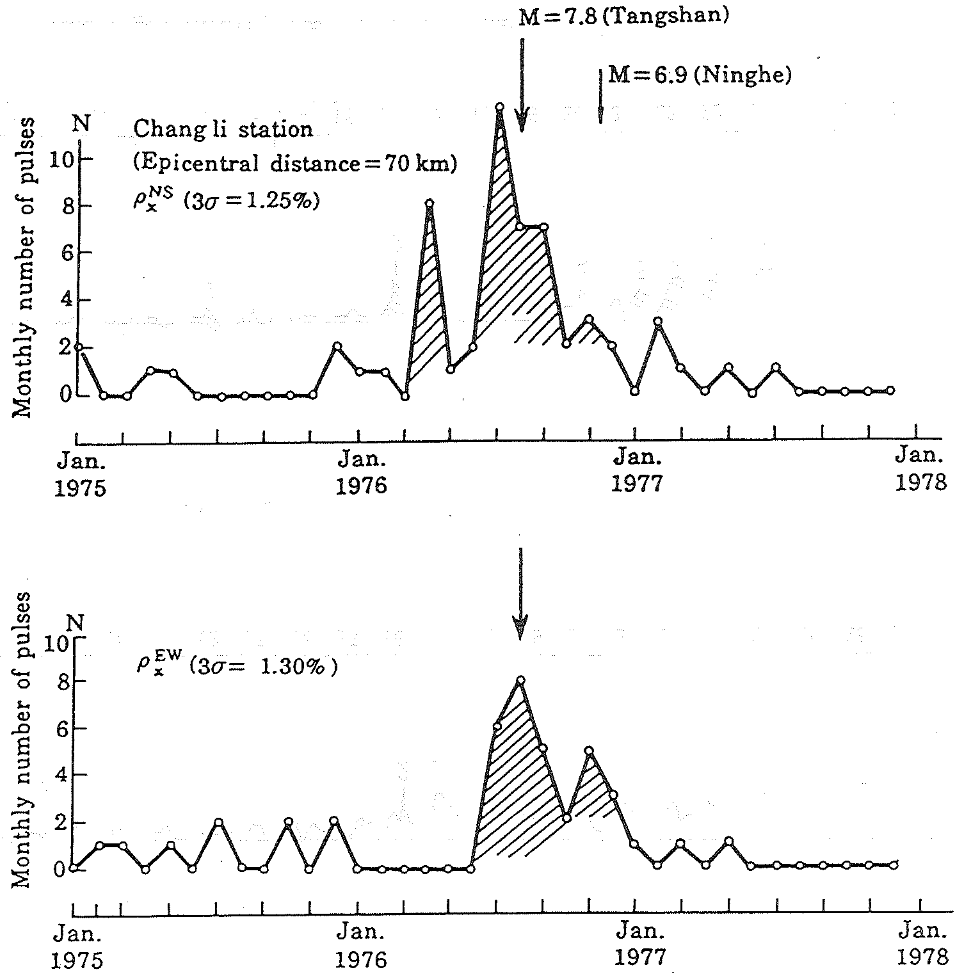
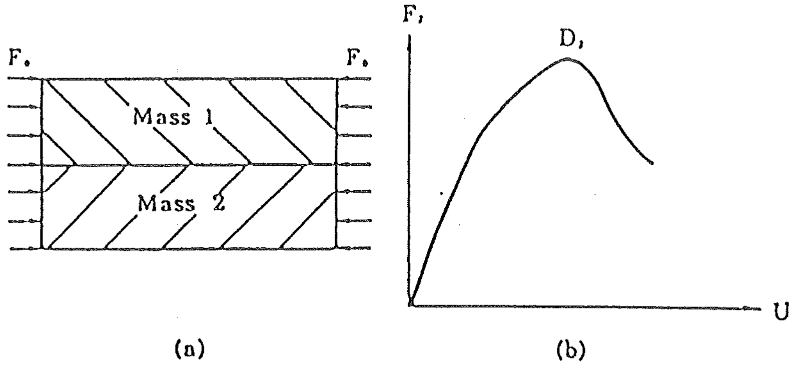


Fig. 9. Number of resistivity pulses in each month at the Changli station from January 1975 till December 1977.



(a) A system where two geological masses are mutually interacting.

(b) the load - displacement curve for the mass 2.

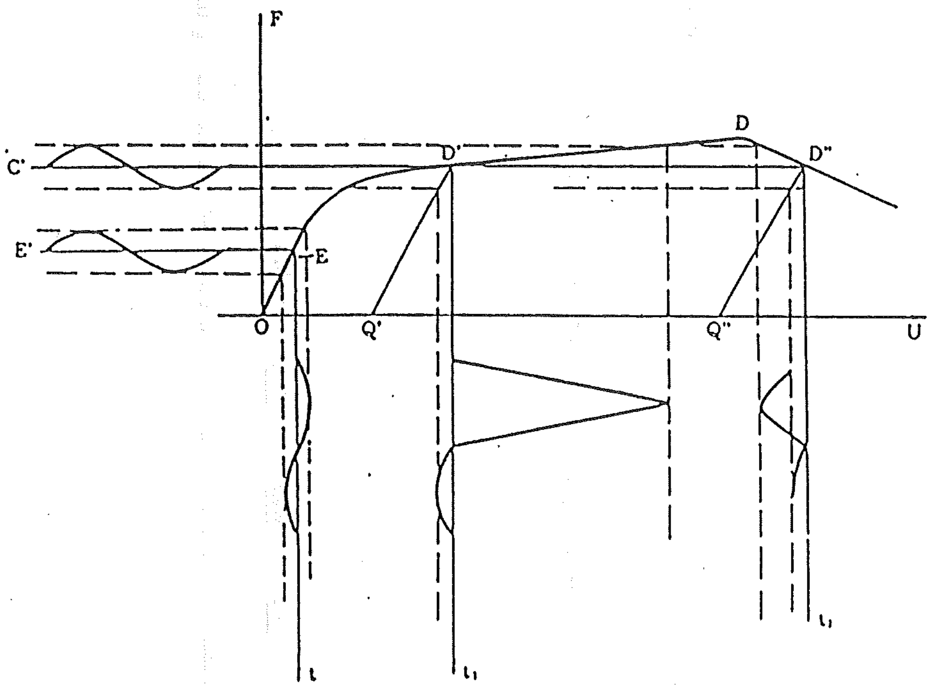


Fig. 10 Schematic diagram showing the model for impending-earthquake precursors triggered by tidal force.

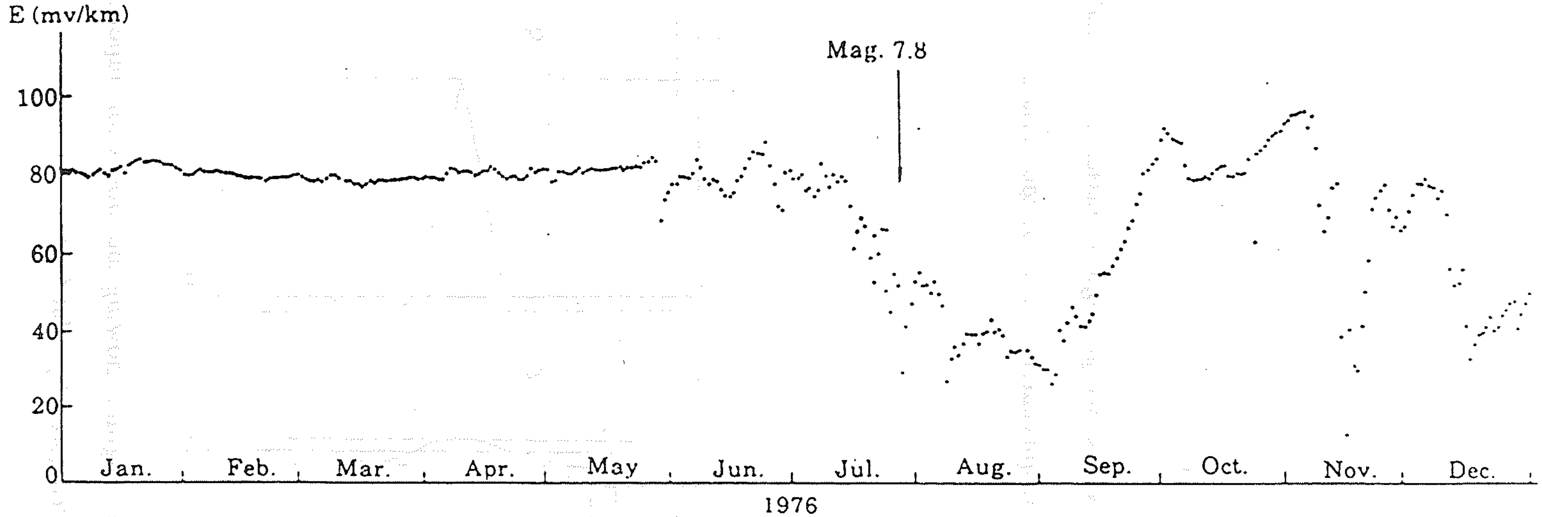


Fig.11. Daily means of natural electric field in the E–W channel during the whole year of 1976 at Xiji station.

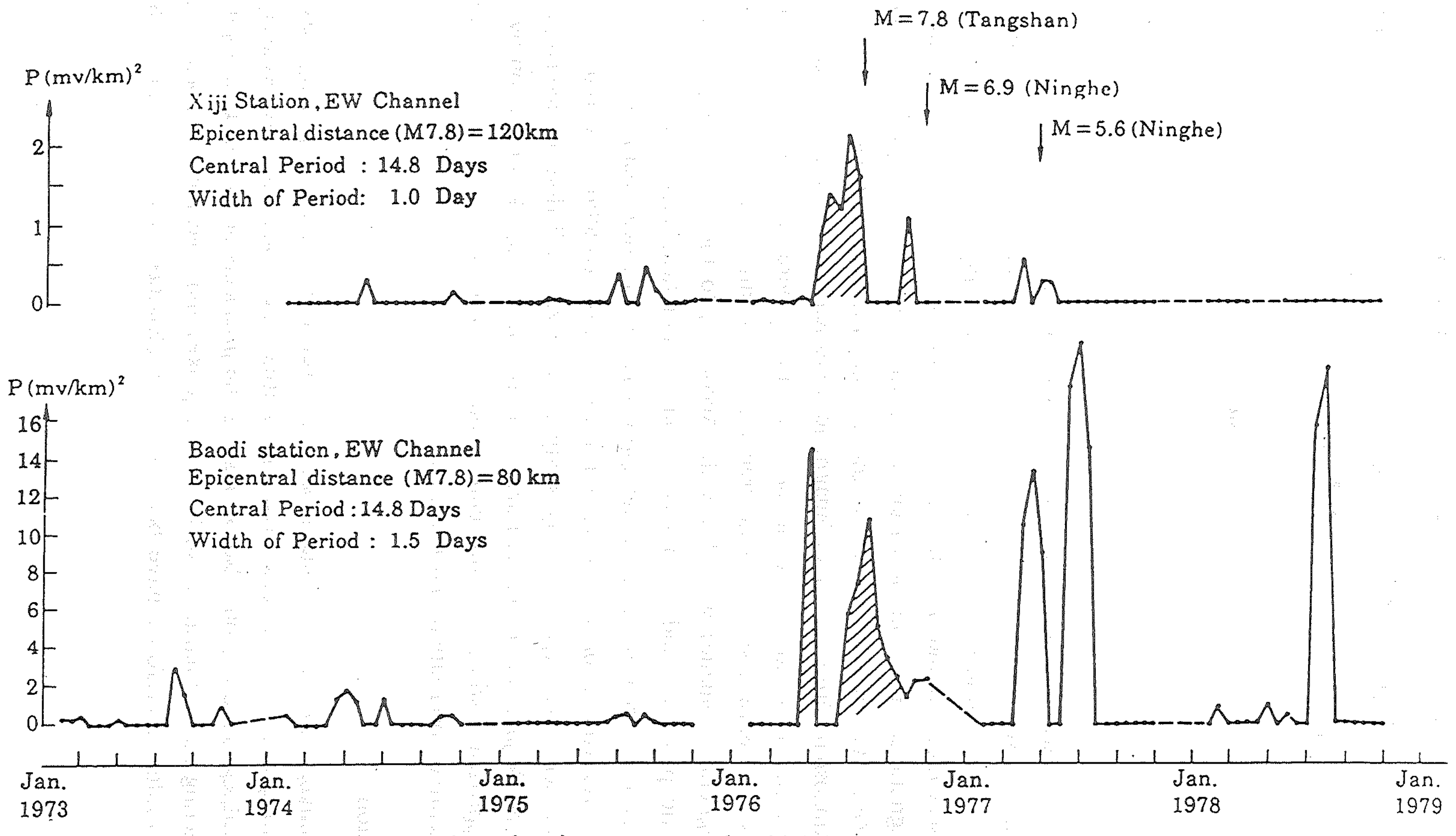


Fig.12. The anomaly in power spectrum of geoelectric response to the tidal force MS_f at the impending-earthquake stage of the *M* 7.8 Tangshan earthquake.