第7卷第3期　　西北地震学报　　Vol.7, No.3
1985年9月　　NORTHWESTERN SEISMOLOGICAL JOURNAL　Sept., 1985

ON THE VARIETY AND COMPLEXITY OF THE SHORT-TERM AND URGENT PRECURSORS OF THE TANGSHAN EARTHQUAKE

Mei Shirong
(Center for Analysis and Prediction, SSB)

The Tangshan earthquake (M=7.8) which occurred on July 28, 1976 is the greatest event among the modern catastrophes in China. It occurred in a region that was the most densely networked with seismic stations, a region that had the longest history in seismological work and had received much attention for a long time. Quite a few anomlies had been recorded before the quake took place. According to the anomalous phenomena, we pointed out that there was a possibility of an earthquake of magnitude 5—6 in the Beijing-Tianjin-Tangshan-Bohai area including the city of Tangshan. So many new complicated anomalous phenomena arose in the first half of 1976 that we could not simply understand by experience and have a correct judgement. Included in those phenomena was a great deal of information on short-term and urgent precursors, which we could not well understand. From this we can see that further analysis and study of the characteristics of short-term and urgent precursors are indispensable to the improvement of one's capability of judging the precursory situation and understanding the preparatory processes of an earthquake source. In this paper we will mainly discuss the features of short-term and urgent precursors of Tangshan earthquake.

Since the development of most of the short-term precursors grow from the mid-term ones, it is necessary to give a very brief description of the mid-term anomalies before coming to the subject.

The first striking features in the anomalies were the acceleration of the ground bulge in the Tangshan fault block area during 1968—1969 and the growth of earthquake frequency (small quakes) in the same period. After that came the turning point (1970—1972), in which the ground ceased uplifting and started sinking, and the frequency of small quakes decreased as well.

After 1973, anomalies in seismic velocity, b-value, underground water level, water radon, earth resistivity and gravity in succession, fault displacement and geomagnetic anomaly followed after the Haicheng earthquake in 1975. All the anomalies developed slowly with a certain trend(either increasing or decreasing). By the end of 1975 the anomaly items added up to a great number. Fig. 1 and Fig. 2 show their time and spatial distributions. From them, it is seen that all the anomaly trends are temporally synchronous and spatially concentrated in a relative way.

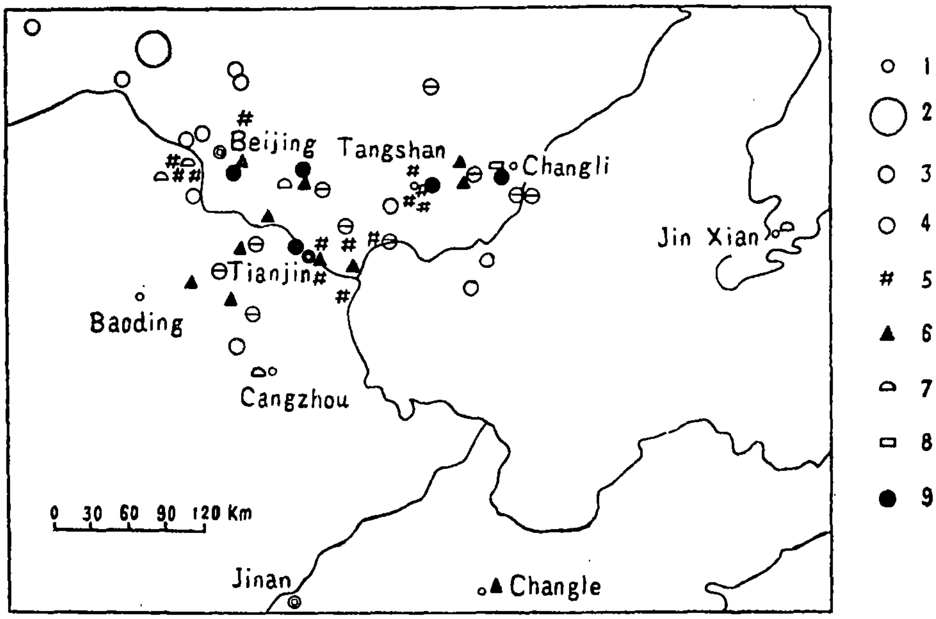
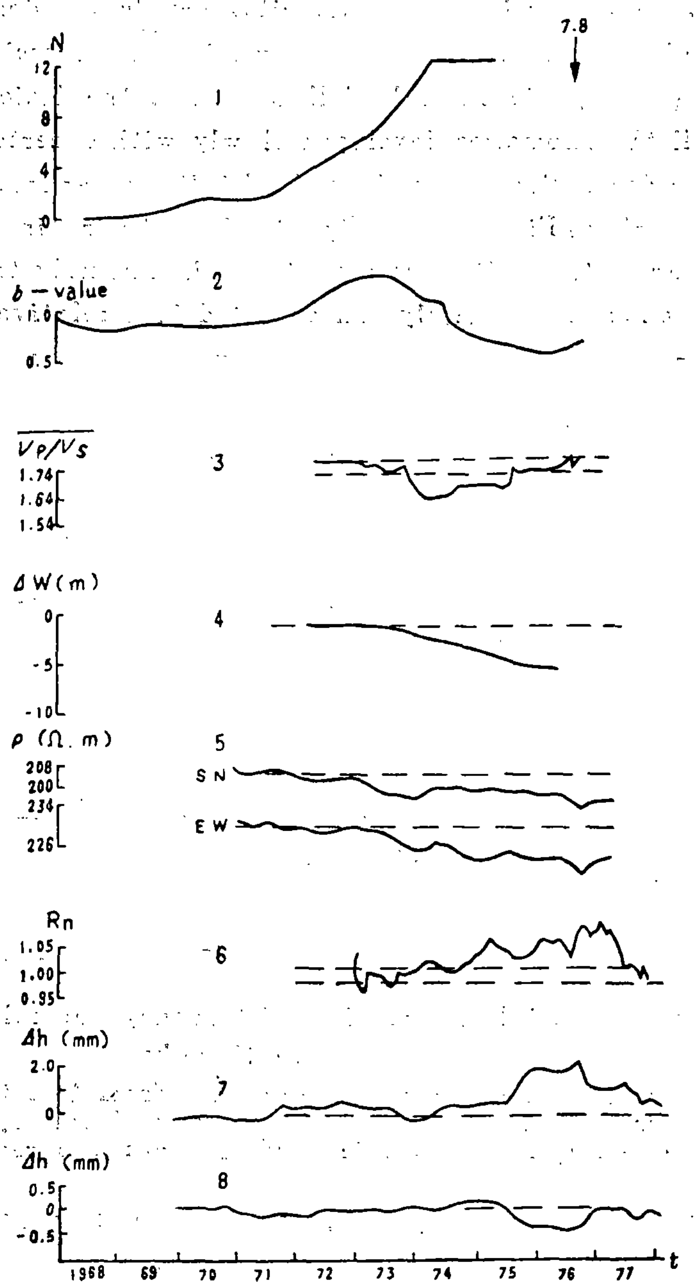


Fig. 1 Spatial distribution of tendency anomalies before Tangshan earthquake.
1. M_L = 4—4.9 2. M_L = 5—5.9 3. epicenter from 1966 to 1972 4. epicenter from 1972. 9 to 1976. 6 5. water level 6. Radon 7. short levelling 8. geomagnetic field 9. earth apparent resistivity

I. Major anomalies within half a year prior to the occurrence of the earthquake.

After the beginning of 1976 more and more anomalous phenomena were observed inside and outside the area of the Tangshan fault block area. By and large they can be summarized as the following points(1, 2, 3):

1. The frequency of minor quakes in the Tangshan fault block area decreased continuously while the earthquake swarms in the surrounding increased. The earthquakes of magnitudes greater than 2 at Richter scale in the area of Tangshan and Tianjin within half a year prior to the Tangshan earthquake decreased unprecedentedly (Fig. 3). During the period from May 5 to July 26 even no microquakes($M<1$) were recorded. But the



7. short levelling 8. geomagnetic field 9. earth apparent resistivity

Fig. 2 Curves of some tendency anomalies before Tangshan earthquake.

1. accumulative frequency of shocks $M_S \geqslant 4$ 2. b—value
3. seismic velocity ratio 4. water level
5. apparent resistivity at Changli 6. average change of radon
7. short levelling at Dahuichang 8. short levelling at Niukouyu

activity of minor-quake swarms in the surrounding area increased markedly. From February through June, there occurred three earthquake swarms which had drawn our attention. During this period the area of minor quakes in the Beijin-Tianjin-Zhanjiakou region expanded first and then contracted rapidly in the last ten days of June to the neibourhood of Tangshan with a minimum area.

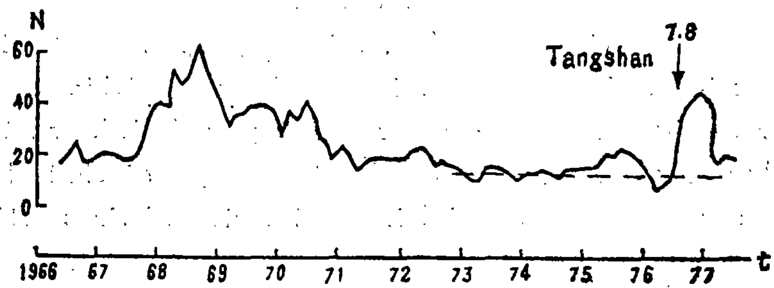


Fig. 3 Curve of earthquake frequency in area Tianjin-Tangshan region.

2. Deformation of the Tangshan fault zone and the increasing fault activify outside the zone.

In the Tangshan region walls of three wells were twisted and deformed in May 1976 and one of them collapsed on July 24. A negative anomaly with an amplitude of 7.2 mm appeared in the height-difference curve of short-range levelling at Ninhe station in the southwestern part of the Tang-

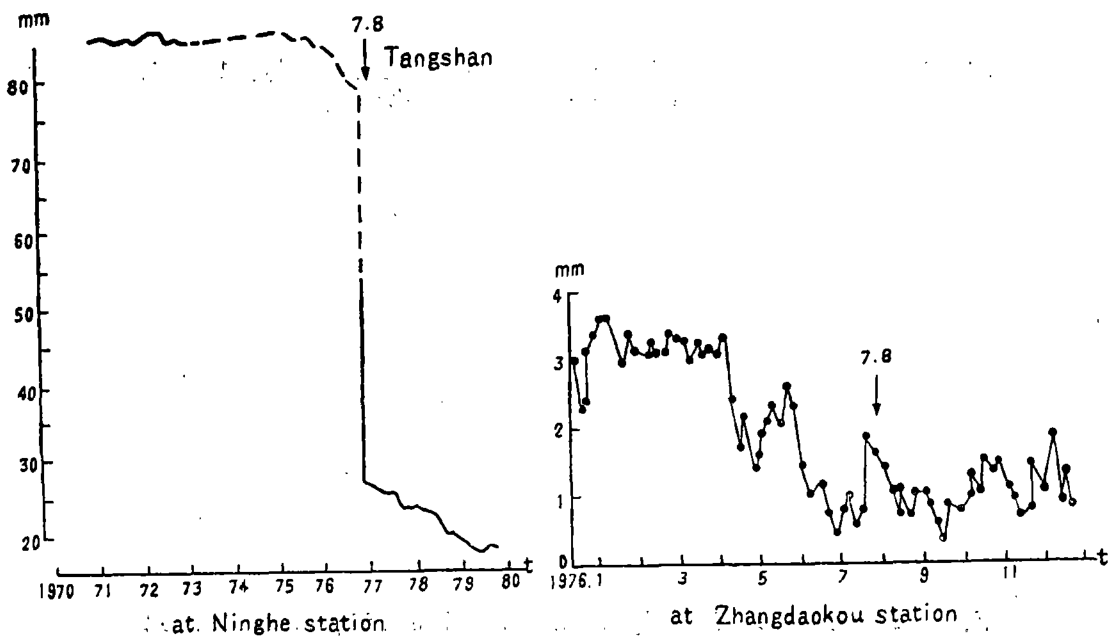


Fig. 4 Fault displacement curve.

shan fault block area from May, 1976. Fig. 4 show short-term change of the two deformation stations.

3. The gravity value in the Tangshan fault block area increased faster while that in the Beijing-Tianjin-Zhangjiakou area decreased (Fig. 5 a). It was found that the gravity had a change of 180—190 mg/l three months prior to the earthquake. One week immediately before the event at three stations in surrounding of Tangshan were simultaneously recorded anomalous decreases of gravity (Fig. 5 b). It is very difficult to interpret so rapid and prominent change in gravitational field within two to three months prior to the earthquake in terms of ground deformation and the effect of subsurface water. Chen et al, (4, 5) suggested that they resulted from the movement of the material in the interior of the Earth.

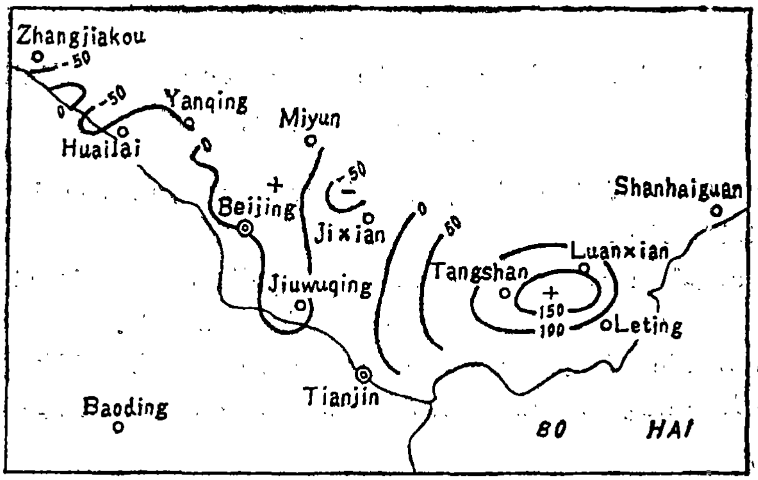


Fig. 5 a Gravitation change between March—July, 1976 in Area Beijing—Tianjin—Tangshan—Zhangjiakou.

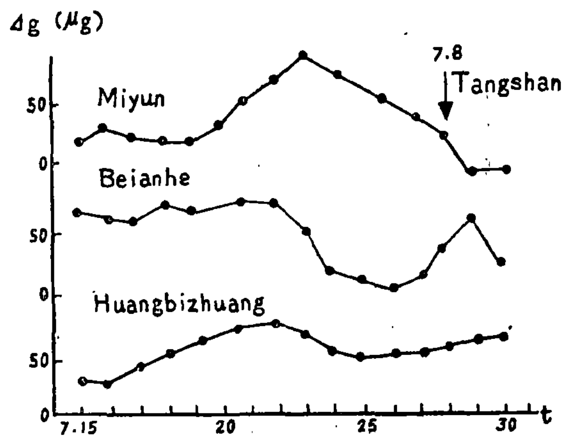


Fig. 5 b Change of daily average value of gravitation at stations Miyun, Beianhe, Huangbizuang.

4.Several months before the earthquake the level of ground water in the Tangshan fault block region showed an accelerating fall and experienced a drastic change a few days before the earthquake with a variety of forms. In the peripheral region falling or rising changes occurred.

From a couple of days until several hours just before the event the anomalies of the underground water level became more complicated and variform; sharp rise in water level and flush, even with spontaneous gushing; fall of the water level sharp decrease in flush, evenw ith interruption of the spring water flow; the sharp fluctuation of the level, the volume of flow and water pressure, the distortion responce of the level on the solid tide, and so on (Fig. 6a, b)[6].

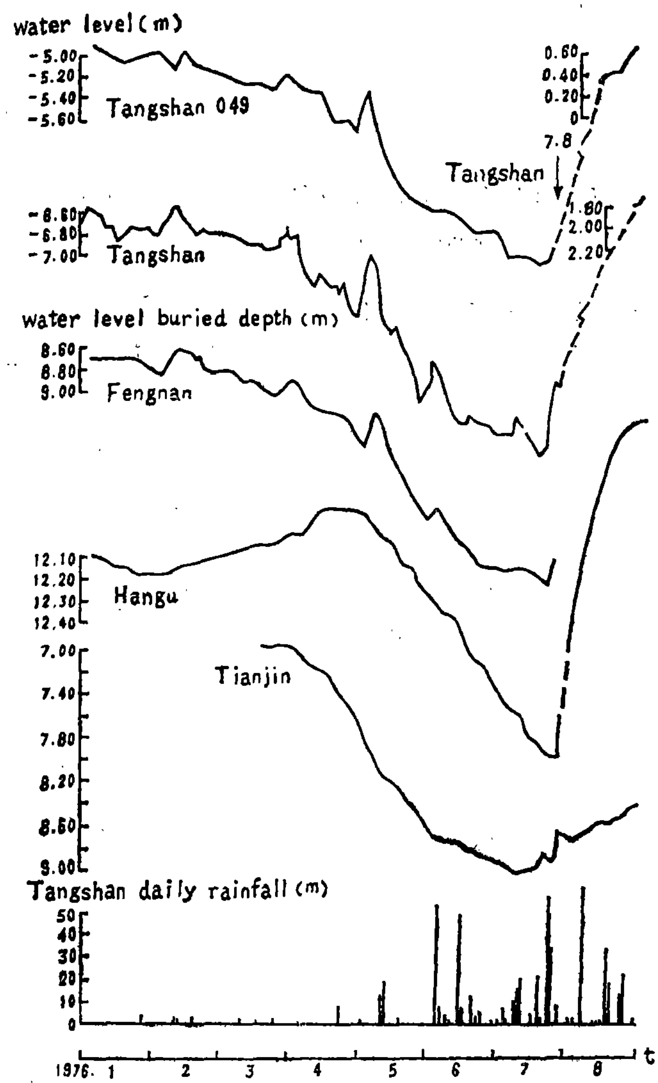


Fig. 6a Accelerating fall of underground water in Tangshan—Tianjin region.

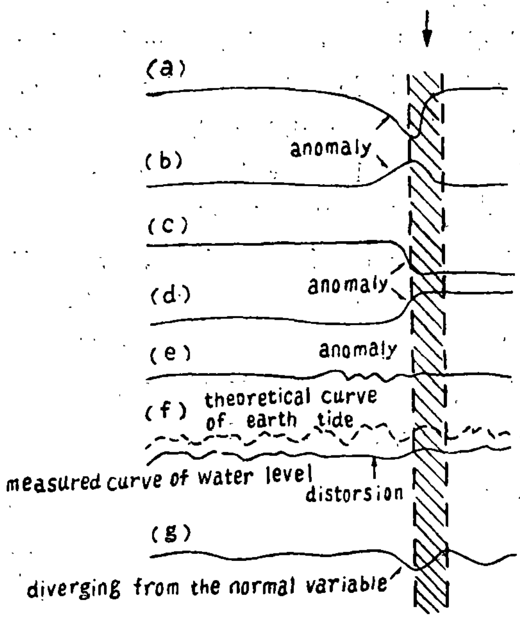


Fig. 6b Five kinds of anomalies of groundwater level before the earthquakes.

5. Several months before the earthquake a turning point of the tendency anomaly was recorded at the radon observational sites near the Tangshan

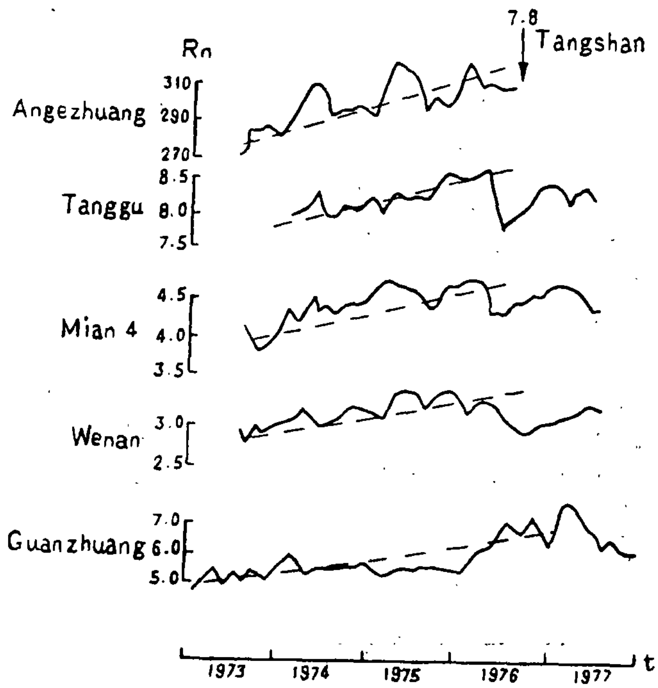


Fig. 7a Tendency anomlies of radon before Tangshan earthquake.

fault block region (Fig. 7 a)[7]. Half a month before the earthquake, sudden changes with large amplitude took place in the wells in Northern China, Mostly with an abrupt rise or fall in daily measurements. Ten days before the earthquake an obvious peak in frequency of abrupt change of water radon in this area showed, was recorded (Fig. 7 b)[8].

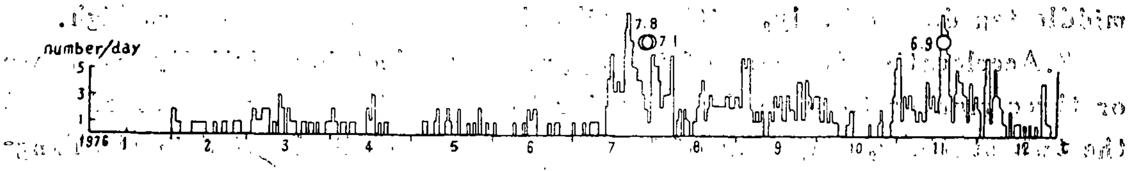


Fig. 7 b　The variations of daily number of wells with sudden changes of radon content in water before Tangshan earthquake

6.Other anomalies of the underground fluid. From January of 1976 the chlorine ions in the wells of the Tangshan networks started to increase on the basis of the stable value (3.2mg/l) to 3.6 mg/l, which was kept until the occurrence of the earthquake. In the same period, water radon and carbon dioxide contents of those wells also showed an anomaly (Fig. 8)[7].

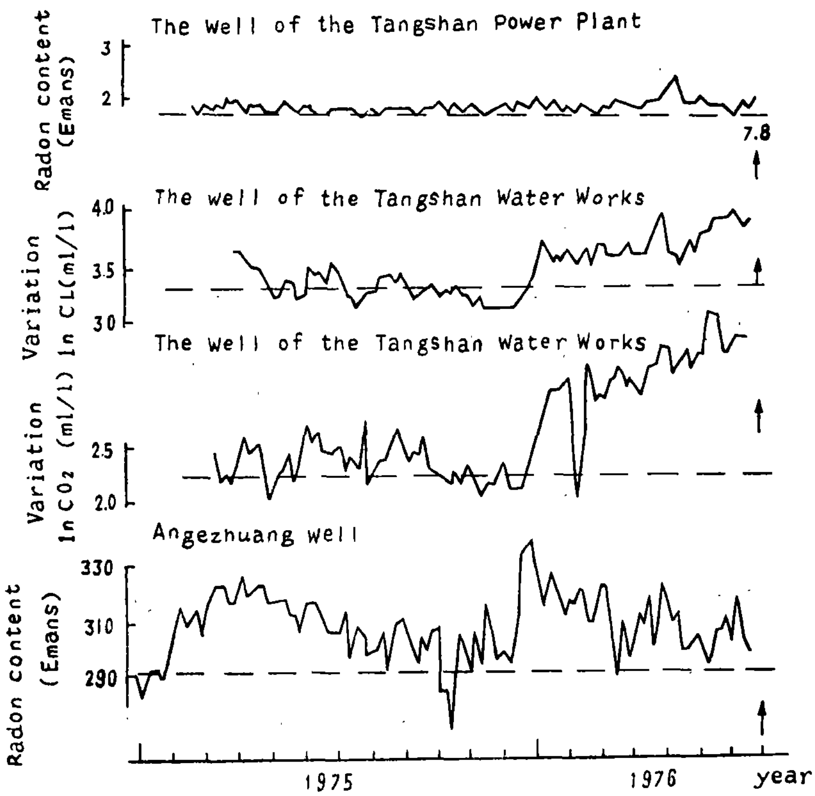


Fig. 8　Anomalous variation in hydrogeochemistry in the epicentral region of the Tangshsn earthquake.

Also recorded were the unusual behaviour of the oil wells around Bohai and intermittent gushing of the Qingsinwan No. 11 disused oil well which is 120 km away from Tangshan. Around July 10, the continuous gushes were seen, with a maximum horizontal projectile distance being 25 m. Mozhou No. 1 oil well 70 km from No.11, suddenly gushed in the middle ten days of July, with an oil column more than 10 meters high.

7. Accelerating decrease of the apparent geoelectric resistivity from two or three months to several days prior to the earthquake was recorded at the two stations, Majiagou of Tangshan and Changli, located in the Tangshan fault block region. (Fig. 9) [9].

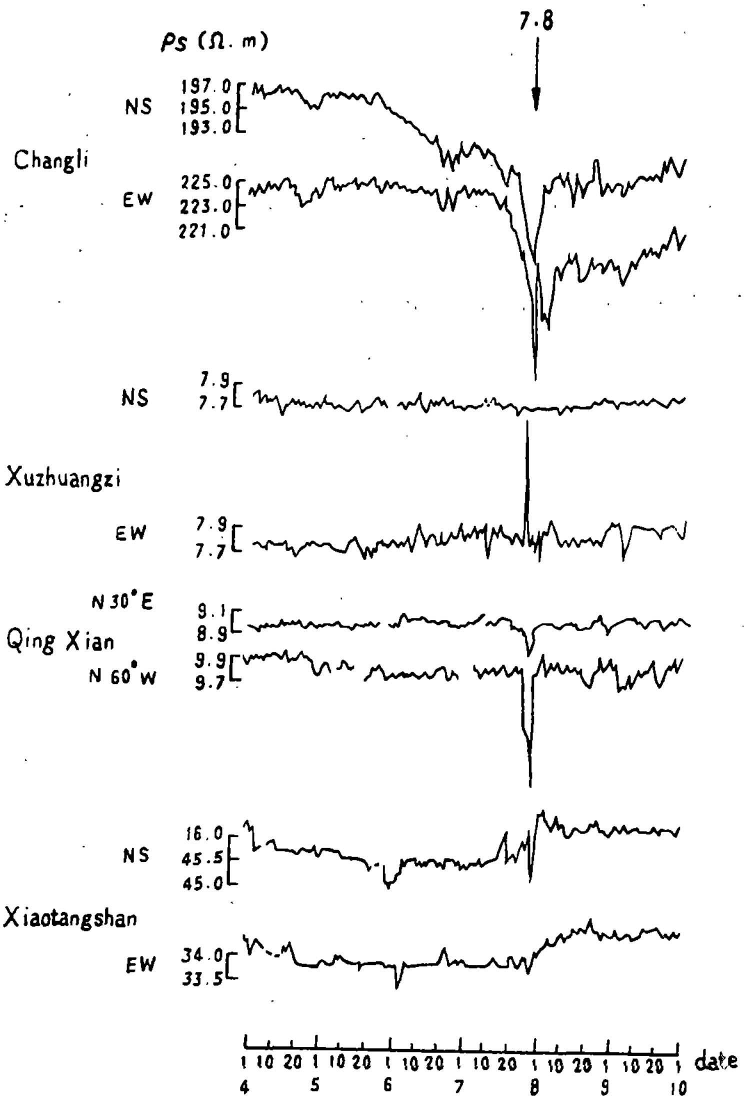


Fig. 9 Anomalies of earth-resistivity just before Tangshan earthquake at Changli, Xuzhuangzi, Qingxian, Xiaotangshan stations.

About ten days before the earthquake 9 among 24 earth electric stations in North China had recorded the sudden changet of resistivity, with an amplitude of abrupt changes being 3—6%, greatly exceeding three times the size of RMS errors[10].

8.One week before the earthquake arose the anomalies of microseisms and earth temperature. According to the observation of Changli station, one week prior to the earthquake, the microseismic amplitude at this station sharply decreased while at Madaoyu (170), Longquansi ($\triangle$=190 km) station only slight change were recorded[11].

In addition, the soil temperature at the depth of 80 cm around Tangshan,Changli abruptly increased from July 23 to July 25 (Fig.10).The increase of soil temperature was 1.6℃ in Tangshan, but with no anomaly at the depth of 40 cm there. This is few phenomena ever recorded in the preceding years.

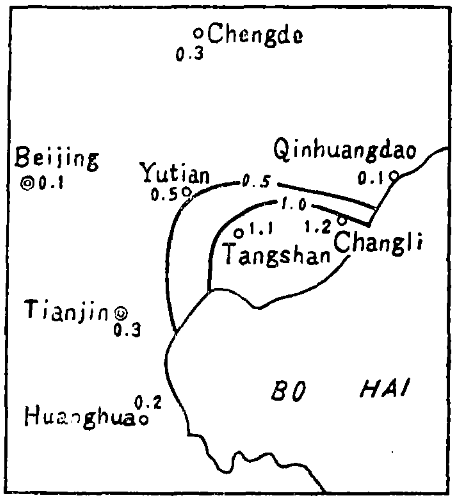


Fig.10 Isothermal lines of soil temperature in area of Tangshan and around it.

9.A great number of animal anomaly were found two days prior to the earthquake in the Tangshan fault block region.The total anomalies of animal behavior before the Tangshan earthquake amount to 2000 cases, including 70 kinds of animals. The spatial distribution of animal behavior anomaly is shown in Fig. 11. They are mainly concentrated on three zones which are the same orientation as the Tangshan fault; Qianan-Bencheng fault and Luanxian-leting; Changli-Ninghe fault.

10.A couple of hours prior to the earthquake, anomalous sound, light and electromagnetic phenomena near the Tangshan fault block arose. The

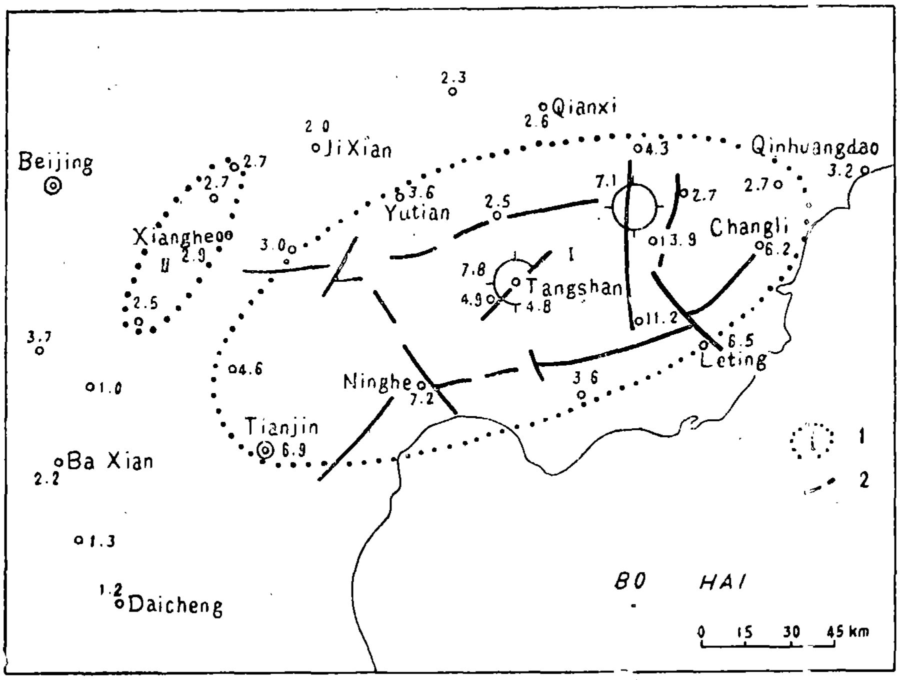


Fig.11 Spatial distribution of animal anomal behaviories before Tangshan earthquake (number of anomalies per community).
1.area of animal behavior anomalies 2.fault

earliest occurrence of earthquake sound before Quake was noted at 23 h in 27. The earth sound was low and had no directional characteristics. From half an hour to several minutes before the earthquake, different types of earth sound were heard in the area of earthquake. The earthqake light prior to the earthquake had the characteristios of various colours and different shapes.

Electro-magnetic anomalies prior to the quake included the anomalies in microwave propagation radio wave received and those in teletyping machines, VLF receiver and monitoring radars.

Ⅱ.The complexity of the short-term and urgent precursors

Comparing the anomal phenamena with the mid-term trend anomalies mentioned above, it is easy to see certain connection and rather great difference between them in kind and morphology, in varying amplitudes and speeds, and in temporal and spatial distribution of anomalies. Such connection indicates that the short-term and urgent anomalies are the continuous development of the mid-term anomalies and the difference indicates that the development into the short-term and urgent stage is not only a change in quantity, but also partially the beginning of a change in quality. The anomalies in this stage show six characteristics which are as follows:

1.Muitiformities in kind and morphology

The first six of the ten kinds of anomalies mentioned above, are all the developments on the basis of the mid-term trend anomalies and the rest four kinds are new. Their morphology is rather complex and variform and vary different from the simplicity shown by the mid-term anomalies. For short-term anomalies there are both accelerating or decelerating changes on the background of the mid-term trend anomalies and those that keep peaceable. For the anomalies of an impending earthquake, there are peak, valley, wave, step and pulse shapes. The curves of same observative item recorded at different observative station are not same.

Some abrupt anomalies are added on the trend-anomalies, and some abrupt anomalies appear on the background of no trend anomalies. These facts indicate that short-term and urgent anomalies are very much affected by local conditions.

2.The accelerative and drastic variability of the short-term and urgent precursors.

Generally speaking, the amplitudes and speeds of short-term anomalous changes are greater than those of mid-term trend anomalies, and therefore they are called accelerating changes.The amplitudes and speeds of the urgent anomalies are greater than those of short-term anomalies, but with shorter duration, so they are called abrupt changes.

3.The occurrence in batches of short-term and urgent anomalies

The anomalous phenomena arising within half a year before the earthquake are mainly divided into five groups: anomalies of carbon dioxide (CO_2) content in wells Jin 2, Miansi, Zhangdaokou of Tianjin, and waterworks of Tangshan at the beginning of 1976; accelerative changes of short level in Ninhe and Zhangdaokou region, the wall deformation of three wells in Tangshan city and the gushing of the disused well in Qingsian, a synchronous turning of the anomly in water radon concentration of a number of wells etc. during April and June; the abrupt rising of Radon content in underground water, the sudden changes of earth resistivity, and the airjet from the wells during the second ten days of July, the turning jump' of the level of underground water for the impending quake, animal behavior anomalies, earth temperature anomalies, collapse of well walls and the macro-anomalies of the level of underground water three or four days before the quake; a large quantity of anomalous phenomena of earthquake sound and light, and electromagnetic phenomena within one day to a few minutes before the earthquake.

4. Variability of the spatial distribution of short-term and urgent precursors

The medium-term trend anomalies are relatively concentrated in the Tangshan fault block area, but the distributing area of the short-term and urgent anomalies is a function of time and space. Fig.12 is the distribution map of the mid-term and shortterm anomaly points. It can be seen from this that the area of short-term anomalies is larger than that of mid-term anomalies. But the distribution area of the suddenly arising anomalies extends to 600 km or more (sudden rising of Radon content in underground water in Qingjiang of Jiangsu province) in the second ten days of July, but the suddenly arising anomalies within two or three days before the event are rapidly concentrated into the Tangshan fault block, resulting in the sudden quiescence of a large quantity of suddenly-arising anomalies in the Tangshan fault block area.

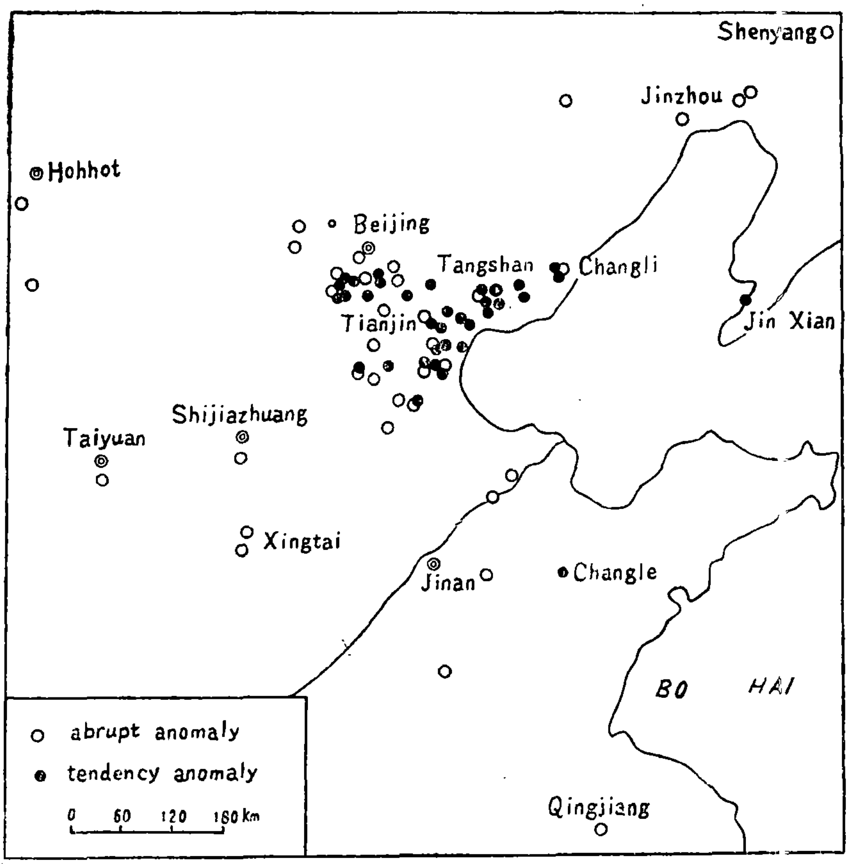


Fig.12 Distribution of tendency anomaly and abrupt anomaly before Tangshan earthquake.

5.Inhomogeneity of the space distribution of short-term and urgent anomalies.

All the anomalies are not found everywhere within the above-metioned anomalous distributing area. The anomalous areas and non anomalous areas cross each other, forming several anomalous areas and zones.

On the other hand, in the areas where anomalies are relatively concentrated, such as the Tangshan fault block area, the anomalous areas and non-anomalous aresa cross each other, and all midterm, short-term and urgent precursors do not appear at the same observational site. Of the nine geoelectric resistivity stations, there are five at which mid-term anomalies are recorded, two at which short-term anomalous are noticed, and four which gives the records of urgent anomalies. There are only few stations which have the simultaneous records of mid-term, short-term and urgent precursors.

6.The uncertainly of the relationship between the amplitude and arising time of the short-term and urgent anomalies and the epicentral distance.

Data of all short-term and urgent anomalies, such as underground water level,the radon content in underground water,geoelectric resistivity, show that the relationship between the amplitude of the anomalies and the epicentral distance is very uncertain. There may be large variations far away and small ones nearby, even no variations at some stations.This is different from the dependence of stress-strain accumulation effect upon the epicentral distance.

Ⅱ.Our understanding of the mechanism on the forming of the charateristics of short-term and urgent precusors

Among the above-mentioned six characteristics, the core is variability.(Variability of variety of anomalies and their morppology, strength, rate of change and spatial distribution with time.)The variation of the regional stress field with time arising from tectonic motion is very slow. But the varying short-term and urgent precursory field demand a varying regional stress field, which requires a source other than tectonic motion to make itself variable in a regular way. This source is not a factor outside the Earth. Many deep-going researches have shown that the stress variation in the Earth's interior caused by outside factors is insignificant As all the anomalies during the stage from short-term precursors to an impending earthquake have large amplitude and quick variation, they demand correspondingly a great stress or strain variation. The reasonable source is the source region of a large earthquake itself.

Crustal quakes result from the rock rupture caused by developing micro-cracks. In general, they have the processes from stable expansion to unstable expansion. The stage from short-term precursors to an impending earthquake corresponds to the unstable expansion of cracks during the development.processes of an earthquake source. At this stage the stress and strain mainly result from the work done by the elastic-strain energy stored in the body. The fracture expansion is not controlled by the load. Many shortterm and urgent anomalies are directly or indirectly related to various changes in the source body. In order to understand the variations in the precursory field, we must first try to understand the variations in the source volume. This is the key to the problem of the complicated field changes.

In the Tangshan fault block area arose a series of prominent phenomena, which were as follows: well-wall deformations and collapses, the accelerative falling of underground water level, the production of chlorine ions in the water, the drastic rising of gravity value, the accelerative decreasing of earth resistivity, the rising of earth temperature, the unprecedented decreasing of minor-quake activity, the drastic changes of underground water level just two days before the earthquake, the large amount of animal anomaies, the earthquake sound, the earthquake light and electromagnetic anomalies and so on. From all the anomalies it is seen that the epicenral area underwent drastic changes within 2—3 monthes to a tew days just before the earthquake. At least. there are three factors that cause these changes, mainly: the accelerative expansion of cracks, the accelerative upward surging of deep substances, and the accelerative creep of faults. All the three factors require high stress to account for Morever, they lead to the changes of physical properties of the rock in Tangshan earthquake source volume. Such changes in local media canbe simulated with a softinclusion, which affects the regional stress field by exerting on it varying stress which is superposed on the regional stress field caused by the tectonic movement.

The infuence of the soft inclusion (near the source body) upon the regional stress field is strongly affected by tectonic framework and related to the structure, size and medium variation of the source body (12). Calculations of the preliminary finite elements show that the strongly affected field will be 1—2 times the size of the source volume, at most 4—5 times, if the elasticity modulus of the source region is reduced to 2/3 of the surrounding media. In the case of Tangshan earthquake the Beijing-Tianjin area where various anomalies were comparatively concentrated is just 2 times the size of the source. If we take the field tor 5 times the size of the source, i. e., 500—600 kilometers, then all the urgent precursors far away can be accounted for.Calculations also show that in different directions the stress variations in the source area periphery can be positive or negative. This is a good evidence for the difference of the influence of the source volume on the different part of the periphery. Furthermore, it should be pointed out that the responsiveness to stress variation of different types of precursors at differeent observational points is related to the physical properties of the observed things.The underground water and gas are the most responsive media to stress and strain; therefore among short-term and urgent precursors, there are many anomalous variations of the underground water level and the chemical element content in water and gas. Also there exists close relationship between the responsiveness of the underground water to stress variation and the specific condition of the water-containing layers. Of so many complex factors, the infuence of local condition is an important factor.

Meanwhile, the action of the soft inclusion on the regional stress field is related to the properties of the fault zone.Some faults are apt to creep. but others are difficult.

In the case of the same stress increments, the faults which are apt to creep begin to squirm, thus resulting in a variety of anomalies. At last, some anomaly areas are formed. The creeping and sliding may be stable or intermittent. The anomalies resulting from the stable show a certain tendency, while those resulting from the intermittent show the characteristict of arising in batches and suddenly to a certain extent. In the areas where creeping fauts cross each other the time-space distributions of anomalies become much more complicated An additional local stress field is then producced on the faults that are creeping accelerately. The numerical calculations of the dislocation theory[13] show that if a strike sliding occurs in the faults, the shear stress in most of the surrounding areas is obviously decreased, while at the two ends of the faults and at a certain distance perpendicular to the fault trends stress-concentrated areas appear. Meanwhile, surrounding the faults there appear alternately compressive and expansive areas. If a slow creep occurs along the faults at a finite speed, (or the faults squirm segment by segment), then the shear stress areas and stress-concentrated areas around the faults will inevitatly vary with time. And the sphere of the compression-expansion areas of the hydrostatic stress will vary with time as well. Thus, the stress and strain state at the different points around the faults may show different forms of variation with the transferring of the fault creeping-sliding. The stress variations at some points may first increase slowly, then decrease gradually, while those at other points may be contrary to that. In this way, in and around the creeping-sliding faults there is a great variety of precursor curves. In addition, the friction strength and the shear stress distributions along the creeping faults are generally non-uniform. As a result the creeping-sliding transfer is sometimes fast and sometimes slow, and sometimes even stops. Maybe this is due to the fact that the curves cometimes turn, sometimes steepen and sometimes reverse.

The response to the additional stress increment is affected by the material structure in the surface layer of the Earth's crust. There is usually some water on the bottom of the deposition layers. The deep hot materials which are rising make the water here overheated as a result of the poor heat conductivity of the depositional layers[14]. The overheated fluid is extremely unstable. Once there are some variations in the source, say, some movements caused by creep or pre-displacement, the overheated fluid may be triggered to boil. This process is generally extremely violent. It is an amplifier of the predisplacement. Maybe some sudden anomalies just before the earthquake are related to it. As has been stated above, the complexity of the short-term and urgent precursors, in the final analysis, is determined by the complexity of the source processes and the structure, physical properties, stress state in the source. The reason why different earthquake have different short-term and urgent precursors mainly lies in the fact that they have different sources. The Tangshan earthquake shows one of the most complicated sources among them. Its complicated precursors reflect the complex structure in deep and shallow layers the stress state, the physical properties of media and the complicated movement of the deep materials. The present discussion only provides a preliminary and qualitative analysis: To definitely reveal the relationship between the precursors and the source processes so as to offer an effective way of prediction, many problems remain to be tackled. From the above qualitative analysis, however, it is seen that the short-term and urgent precursors are not in disorder although they are very complicated. They are controlled by the source and in close connection with the preparatory area. It is helpful to judge the properties of a phenomenon if one can get hold of such a link.

References

〔 1 〕Mei Shirong (Editor-in-chief), The 1976 Tangshan Earthquake, Seismological Press, 1982.

[2] Zhang Guomin and Qiu Jingnan, An analysis of the process of preparation and the Medium-term precursors of the 1976 Tangshan earthquake(M=7.8), Paper for International Symposium on Earthquake Prediction UNESCO Headquarters, Paris, 2—6 April 1979.

[3] Zhang Zhaocheng, Characteristics of short-term and imminent precursors before the Tangshan earthquake, Earthquake, No.4, 1983.

[4] Chen Yuntai et al, Variations of Gravity before and after the Haicheng Earthquake, 1975 and the Tangshan earthquake, 1976, Acta Seismologica Sinica, Vol.2, No.1, 1980.

[5] Zhu Yueqing, Gravity anomaly, M-discontinuity deformation and seismogenetic process of the Tangshan earthquake, Earthquake, No.3, 1984.

[6] Wang Chengmin, Zheng Hongpo, The short-term variation of the ground water level before earthquake, Acta Seismologica Sinica, Vol.4, No.4, 1982.

[7] Zhang Wei and Lin Yiyao, Preliminary study on the application of hydrogeochemistry to earthquake prediction, Acta Seismologica Sinica, Vol.3, No.1, 1981.

[8] Yang Yurong et al., On the phenomena of abrupt rising of the Radon content in the underground water, Journal of Earthquake Studies, No.1, 1982.

[9] Qian Fuye et al., The origin of earth resistivity changes in the shallow layers surrounding the epicentre before the Tangshan earthquake, Journal of Earthquake Studies, No.2, 1981.

[10] Jin Anzhong, On the sudden change of earth resistivity near the epicentral area just prior to the 1976 Tangshan earthquake, Acta Seismologica Sninica, Vol.4, No.2, 1982.

[11] Zhu Chuanzhen et al., Preliminary study of the microseisms in relation to earthquake, Acta Geophysica Sinica Vol.20, No.1, 1977.

[12] Zhang Yingzhen et al., The nine large earthquakes in China during 1966—1976, 1982.

[13] Huang Fumin et al., The stress field of a dislocating inclined fault, Acta Seismologica Sinica, Vol.2, No.1, 1980.

[14] Guo Zengjian et al., A possible mechanism of imminent precursors abrupt boiling of overheated fluid, Northwestern Seismological Journal, Vol.1, No.1, 1979.