The Tangshan earthquake is not an isolated and unexpected event. It has a breeding and formation process. In this paper some inherent observations of the Tangshan earthquake are summarized based on the historical and recent seismic activities in Tangshan and its surrounding areas as well as the characteristics of the Tangshan earthquake sequences itself. Fundamental data necessary for the analysis and study of the damage in the Tangshan earthquake are provided. Meanwhile, some seismic precursors prior to the Tangshan earthquake are also mentioned briefly.

I. Summary of Historical Earthquakes

China is a country of active seismicity and has also the longest historical earthquake record in the world. The statistics and analysis of historical earthquakes for more than 3000 years show that the distribution of strong earthquakes in China are characterized by the belt shape in space and the reoccurrence in time. Moreover, the stress accumulation and release are non-uniform in time and space within individual seismic zones, and the seismicity is also characterized by having different active periods (Shi Zhenliang et al., 1974). Therefore, it is necessary to investigate the distribution features of strong earthquakes on a larger time and space scale in order to study the processes of the Tangshan earthquake.

1. Strong earthquakes in North China

The seismic activity in North China can be considered for the whole area according to the epicentral distribution, focal mechanism, direction of long axis of isoseismals of historical strong earthquakes, as well as the mean crust thickness, geological structure and geomorphology. North China here is mainly referred to as the area with Helanshan as the west boundary, Yanshan-Yinshan as the north, Qinling to Dabieshan as the south and the Huanghai as the east. Many strong earthquakes occurred within this area, and four NNE seismic belts were formed, e.g. the Halan-Loupan belt, the Shanxi belt, the North China plain belt, and the Liaoning-Shandong belt, and furthermore, the EW Yinshan-Yanshan seismic belt was also formed. It is an active area for strong earthquakes in east mainland China. Earthquakes in this area are mostly of shallow focus, i.e. 10-30 km. The historical record shows that the distribution of seismic activity in North China is non-uniform in time, sometimes active and sometimes relatively quiet.
The statistics show that there occurred one earthquake of M=8.5, five of M=8, and twelve of M=7-7.9 in North China from 1000 AD to the present. The occurrence frequency is not high but the earthquakes were quite large. Figure 1 shows the magnitude distribution of historical earthquakes over time in North China. It can be seen in the figure that there were four active periods for large earthquakes in North China: in the first active period (1011-1076) earthquakes mainly occurred in the Shanxi and the North China plain belt; in the second period (1290-1368) earthquakes mainly concentrated in the Shanxi belt; in the third period (1484-1730) earthquakes were distributed in all of the four belts; in the fourth period (1815-present) earthquakes mostly concentrated in the North China plain, the northern part of the Liaoning-Shandong belt and the Yinshan-Yanshan belt (Fig. 2).

Another feature of strong earthquake activity in North China is the time interval between two adjacent active periods which is comparatively long, more than 100 years generally. Within an active period strong earthquakes often occurred in clusters and the time of occurrence was quite concentrated. For example, there occurred five earthquakes of M≥8 in North China during the third active period which lasted for 246 years, and three of them occurred within 27 years from 1668-1695; this feature became more clear in the fourth active period. From 1815 to 1980, there occurred seven earthquakes of M=7-7.8, and four of them occurred within 10 years from 1966-1976. The 1966 Xingtai earthquake marked the beginning of the highest seismic activity in North China during the fourth active period, and the Tangshan earthquake was the most conspicuous event within this period.

2. Destructive earthquakes in Tangshan and its surrounding areas

Tangshan is located at the intersection of the EW Yinshan-Yanshan seismic belt in the northern part of North China and the NE North China plain belt. Although no earthquakes of M>7 had ever occurred previously in the Tangshan area, seismicity in its surrounding areas was quite active. According to historical records, 22 destructive earthquakes of M≥4.75 had occurred in Tangshan and its surrounding areas since 1485, including one earthquake of M=8. Table 1 lists the historical earthquakes in Tangshan and its surrounding areas. Figure 3 shows the distribution of epicenters of historical earthquakes. It can be seen in Table 1 that seismic activity in the Tangshan area corresponded to the occurrence of strong earthquakes in North China. For example, the seismic activity in the Tangshan area correspondingly increased before the M8 Sanhe-Pinggu earthquake in 1679 in the third active period, and an earthquake of M=6.25 which occurred in Luanxian in 1624. Strong earthquakes in North China began to migrate to the north after the fourth active period, especially after the 1966 Xingtai earthquake, while seismic activity in Tangshan and its surrounding areas continued to increase. Successively, there occurred the 1970 Fengnan earthquake, the 1973 Dacheng earthquake, two earthquakes in Changli in 1974 (see Fig. 3), and after that, an earthquake of M=7.8 struck Tangshan in 1976.

II. Characteristics of Seismic Activity Before the Tangshan Earthquake

Earthquakes are a result of tectonic movement. Under the action of tectonic stress the earth crust deforms continuously, with increase of the elastic strain energy. This is the
earthquake process including its origin and occurrence. Therefore, it is very important to study the variation of the stress state of the crust in a spatial region for estimating the potential hazard and the destructive effects of earthquakes.

Seismicity patterns reflect comprehensively the rock properties and the stress state in the crust. During the development process of large earthquakes, there will be some anomalies in the distribution of small to moderate earthquakes in time and space. The crust stress increases and gradually concentrates towards a future focal region until the rupture of rock occurs. Because of the inhomogeneity of media, crust stress and variation of the environmental conditions for the development of earthquakes, the anomalous seismicity pattern becomes quite complicated. Correctly identifying the anomalous pattern prior to an earthquake is an important problem to be solved in the study of earthquake prediction. Anomalous phenomena observed before the Tangshan earthquake will be summarized in this chapter.

1. Increase of occurrence frequency and intensity of earthquakes

Quite a lot of earthquake cases show that there was an increase of seismic activity around the future epicenter both in frequency and intensity in a large time-and space-scale prior to a large earthquake. The situation before the Tangshan earthquake was similar to this. Figure 4 shows the annual variations of earthquake (M ≥ 2.0) occurrence frequency in Tangshan and its surrounding areas (38°30'-40°41'N, 117°06'-119°50'E). It can be seen in the figure that the occurrence frequency in Tangshan and its neighboring areas began to increase from 1966 and reached a peak value in 1969. Then, the frequency decreased gradually and in 1975, just one year prior to the shock, the frequency was reduced to the lowest level, 14/year. This shows that seismic activity was relatively low just before the large earthquake. Moreover, it can be seen from Fig. 5 that the release of strain energy increased abruptly. It means that occurrence of strong and moderate earthquakes would increase similarly.

2. The concentration of seismic activity, and formation of seismic "gap" and belt

From the 1966 establishment of the Beijing Seismic Network to 1972, the spatial distribution of moderate and small earthquakes in the Beijing, Tianjin, Tangshan and Zhangjiakou areas was scattered (Fig. 6). Earthquakes began to migrate towards the east in 1973 and gradually concentrated in Tangshan and its surrounding areas.

Recently, more and more earthquakes show that a seismic "gap" will happen in the future epicentral area before a large earthquake occurs. According to Huang Deyu, et al. (1981), the distribution of small earthquakes (Ml ≥ 2) formed a "gap" with Tangshan as its center from July 1973 to the occurrence of the Tangshan earthquake. Small earthquakes were quite active within a ring-shaped area (Fig. 7). The long-axis of the inner ring is about 90 km and the outer one is about 130 km, with a NEE orientation.

It should be noticed from the spatial distribution of small earthquakes in the northern part of North China that two distinct belts were formed during the gap formation which happened during the last six months of 1975. Figure 8 shows that one belt extends from
Hohhot to Changli, oriented WNW; and the other extends from Xingtai to Luanxian, oriented NE. The Tangshan earthquake occurred at the intersection of these two belts.

3. **Swarm activity in a large area**

Although no obvious fore shock occurred before the Tangshan earthquake, there was a series of noticeable earthquake swarms which occurred in a large area around Tianjin and Tangshan during the six months before the Tangshan earthquake (Zhu Chuanzhen et al., 1981). Table 2 lists the time of occurrence and location of these swarms.

It can be seen from Table 2 that the swarms occurred in an area that extended 1200 km along a NE-SW direction and 1100 km along a NW-SE direction within an interval of six months before the Tangshan earthquake. This kind of swarm activity was not observed in the past in such a large area and with the time of occurrence of these swarms so concentrated. This might be a manifestation of stress increasing once again in North China. On the other hand, this phenomena may be related to the belt-shaped distribution of moderate and small earthquakes that occurred gradually after October 1975. It is interesting that this kind of phenomena also appeared before the Sanhe-Pinggu earthquake in 1679. For comparison, the distributions of strong and moderate earthquakes (including swarms) one year before the Tangshan and Sanhe-Pinggu earthquakes are shown in Fig. 9. It can be seen from the figure that before these two earthquakes active seismicities occurred both in the Shandong peninsula, which was SE of the epicenter, and south of Henan, which was SW of the epicenter. These activities tended to approach the epicenter several months prior to the main shocks. The distance between the two epicenters was not far, the magnitudes were approximately the same, and their geological conditions were similar, e.g. both of them occurred at the intersection of the North China plain and the Yanshan seismic belt. Though these two earthquakes were separated by 300 years, the crust had experienced similar stress evolution processes in a large area one year before the earthquake. Therefore, attention should be paid to similar breeding processes of large earthquakes.

4. **Variations of b-value in time and space**

It is well-known that there exists a linear relation between the earthquake magnitude \( M \) and the corresponding frequency of occurrence \( N \), i.e. \( \log N = a - bM \), where \( a \) indicates the frequency in a certain region, and \( b \) reflects the ratio between large and small earthquakes occurring in the region. The experimental results of rock fracture (Scholz, 1968) show that the frequency of microfracture and the strength of rock also satisfy the above empirical formula. Scholz further pointed out that the \( b \)-value is related to the stress state of rock, and decreases with the increase of stress; when stress approaches the fracture strength of rock, it decreases rapidly. Hence, it can be considered that \( b \)-value reflects the stress of the crust to a certain degree. Huang Deyu et al. (1981) used the method of space scanning to calculate \( b \)-value for different blocks in North China before the Tangshan earthquake, and the results are drawn in Fig. 10.

Figure 10 shows that the regions with lower \( b \)-values (\( b<0.60 \)) were concentrated in Tangshan and its neighboring area of about 30,000 km\(^2\) before the Tangshan earthquake. The \( M=7.8 \) Tangshan earthquake occurred in the NE part of this area. In order to investigate further the time process of stress variation in the breeding area of the
Tangshan earthquake, Huang Deyu et al. calculated the b-values in the shadowed zone (assumed to be the breeding zone) in Fig. 10 with an equal number of earthquakes. Then the curve of b-value over time was drawn (Fig. 11) and smoothed by taking three earthquakes as one step. The curve shows that b-value began to decrease gradually from 1970 in the breeding zone and extreme low values were seen in 1974. The b-value increased slightly during early 1975, and decreased rapidly after July 1975. It decreased to the lowest value prior to the Tangshan earthquake and increased again significantly after the earthquake. It seems that scanning the b-value in time and space for a large area can provide useful information for medium-term predictions of strong earthquakes.

5. Variation of wave velocity ratio

Based on the data obtained from the Beijing Seismic Telemetric Networks, Jin Anshu et al. (1980) calculated the mean velocity ratio $V_p/V_s$ in the epicenter and its neighboring areas before the Tangshan earthquake by using the Wadati method. Variation of the velocity ratio over time is shown in Fig. 12. From this figure, an anomalous variation of velocity ratio can be seen in the epicenter and its surrounding areas before the Tangshan earthquake. At first $V_p/V_s$ decreased and then increased again. The amplitude of variation was 13% lasting 19 months. The earthquake occurred about 13 months after the ending of the anomaly.

6. Stress drop of small earthquakes

Source parameters, such as seismic moment, stress drop, and focal dimension, etc. are physical quantities characterizing the mechanical process of seismic sources. By determination of these parameters, important information about stress changes, media condition, etc., in the focus region can be obtained. Zhu Chuanzhen et al. (1977) determined the source parameters of small earthquakes (M=1.9-2.9) in the focal region (aftershock region) in the frequency-domain before and after the Tangshan earthquake, based on the data recorded in the Beijing Seismic Networks. Figure 13 shows the variation of stress drop $\Delta \sigma$ of small earthquakes over time. The mean stress drop of small earthquakes was quite high in Ninghe, Tangshan, Luanxian and Luannan from 1971 to the occurrence of the M=7.8 Tangshan earthquake. The mean stress drop value was more than 15 bar generally, and the highest was 55 bar. This would reflect high stress in the focal region before the earthquake. The stress drop of small earthquakes decreased after the shock, lower than 15 bar generally. It is also seen in Fig. 13 that the stress accumulation process started from July 1974 in the focal region of the Tangshan earthquake and may have been accelerated. Besides, Hua Xiangwen, Diao Guiling et al. (1980) also observed a decrease of inconsistent ratios of initial motion for small earthquakes in the Beijing, Tianjin and Tangshan areas after 1973.

In summary, the following conclusion can be obtained from the above results: an anomaly of seismicity pattern did exist in different degrees in the Tangshan focal region and its surrounding areas 3-4 years before the Tangshan earthquake. In terms of spatial distribution, seismic "gap" area, low b-value area, area of anomalous wave velocity ratio, and area with high $\Delta \sigma$-value, etc. might all reflect the characteristics of media properties in the focal region. In terms of the time of occurrence, these all seemed to be synchronous. From the beginning of 1973 approximately, an extensive stress concentration in the focal region developed which formed a stress field for the Tangshan
earthquake, and it is this stress field which controls the seismicity pattern in the surrounding areas.

III. Sequence of The Tangshan Earthquake

1. Focal parameters of the \(M=7.8\) Tangshan earthquake and its strong aftershocks (\(Ms \geq 6.0\))

According to the results recorded by the Chinese Seismic Network, the epicentral location, time of occurrence and magnitude of the Tangshan earthquake and its strong aftershocks are listed in Table 3.

Obtained by means of the initial motion of the P-wave the focal mechanism solutions of the above mentioned earthquakes are listed in Table 4.

Assuming the fault plane to be a rectangle in shape and applying Haskells moving source model, the focal mechanism parameters were determined respectively for the \(M=7.8\) Tangshan earthquake and its strong aftershocks by use of the body-wave records of the WSSN long-period seismograph (Zhang Zhili et al., 1979; Y. Ishikawa et al., 1983). The results are listed in Table 5.

Obtained by the P-wave initial motion method, the orientation of the normal stress axis of the Tangshan earthquake was about N75ºE. This corresponds to the direction of the tectonic stress in North China. It shows that there was a close relation between the breeding and occurrence process of the Tangshan earthquake and the stress field in North China within a large area (Yang Lihua et al., 1981). Moreover, the seismic moment obtained by P-wave and the results \((1.44 \times 10^{27} \text{ dyne}^2 \text{ cm})\) of the field observations are closely consistent. Compared with other large earthquakes of the same magnitude in the world, the order of seismic moment is similar while only the stress drop is low.

2. Aftershock characteristics of the Tangshan earthquake

Although no distinct foreshocks occurred prior to the \(M=7.8\) Tangshan earthquake, there were a lot of aftershocks of high intensity after the earthquake. These aftershocks were distributed in a wide area and continued for a long period.

According to the "Catalogue of the Tangshan Earthquake" (compiled by the Seismological Bureau of Hebei Province, 1981), 868 aftershocks of \(M_L \geq 4.0\) were recorded after the \(M=7.8\) earthquake from July 28, 1976 to the end of 1978. They are listed in Table 6 according to their magnitudes and distribution over time.

In seismology, the equation, \(n(t) = kt^{-p}\), is generally used to describe the attenuation of aftershock frequency over time \(t\). Here, \(n(t)\) is the number of shocks occurring in a unit time; \(k\) is a constant; \(p\) is called the index of aftershock attenuation.

For the Tangshan aftershocks, only earthquakes of \(M \geq 2.0\) were taken for statistical analysis. The frequency attenuation of aftershocks was quite low from July 31 to October 15, 1976, i.e. \(p = 0.98\), which is close to that of the Xingtai earthquake of 1966. The frequency attenuation \((p = 2.27)\) was accelerated after October 16. The attenuation curve is shown in Fig. 14.
The seismic energy released by the M=7.8 Tangshan earthquake was about 85% of the total energy released by the whole Tangshan earthquake sequence. This is also similar to the Xingtai earthquake sequence, but different from the earthquake sequence of the main shock-aftershock type, such as the Haicheng earthquake (1975, M=7.3) and the Bohai earthquake (1969, M=7.4). The energy attenuation of the Tangshan Earthquake was slow while the fluctuation was large. Figure 15 shows the variation of the daily largest magnitude over time for the Tangshan aftershock. Showing several peaks in the activity it is obvious that earthquake activity increased many times respectively in November 1976, March and May, 1977.

The b-value of the Tangshan aftershock sequence is 0.95 (Wu Kaitong, et al., 1981), obviously higher than the b-value (0.60) in this area before the Tangshan earthquake. This might be the result of a large amount of stress released after the Tangshan earthquake. Table 7 lists the b-values of some large earthquake sequences in mainland China in recent years. It can be seen in the table that the Tangshan earthquake sequence has higher b-values when compared with the other large earthquakes.

Figure 16 shows the epicentral distribution of the aftershocks (M≥4.5) from the occurrence of the Tangshan earthquake to the end of December 1976. The total length of the aftershock area was about 140 km, the width was about 50 km, and the long-axis direction was N47ºE, showing that the Tangshan fault might be the main fault of the M7.8 earthquake.

Due to the limited number of seismic stations and lack of crust structure and wave velocity data, the focal depth accuracy of the Tangshan aftershock was low. Only a portion of aftershocks were relocated by use of the trial and error method (Y. Ishikawa et al., 1983). Figure 17 gives the focal depth distribution of aftershocks which were located parallel to the long-axis direction (NE-SW) and perpendicular to the long axis direction in the Ninghe area (NW-SE). As a whole, most of the focal depths of the Tangshan aftershocks are between 5-20 km, and the focal depths seem to be deeper from the NE to the SW.

It can be seen also from Fig. 16 that the Tangshan aftershock distribution is closely related to the local geological structure. According to this, the active region of aftershocks can be divided into three regions: the Tangshan-Guye region as the central region with the M=7.8 Tangshan earthquake in its center; the Luanxian-Lulong region as the east region with the M=7.1 earthquake in its center; and the Ninghe-Tianzhuang region as the west region with the M6.9 and M6.2 earthquakes. Some characteristics of these three aftershock regions are described briefly as follows.

Central Region: It is the earliest aftershock region formed after the main shock. Before the occurrence of the M7.1 earthquake, aftershocks in this region occurred along a 50º NE direction. The spectral analysis of the long-period seismogram (Zhang Zhili et al., 1980) shows that in the Tangshan earthquake of M=7.8, the crust displaced on the two sides of the fault symmetrically. The mean rupture velocity was 2.7 km/s. The rupture propagated 70 km along a NE direction, and 45 km along a SW direction. According to the aftershock data of M_L ≥2.5 from July 28, 1976 to May 1978, the aftershock attenuation coefficients in this region, p= 1.21 and b = 0.96±0.11, were
obtained. The energy of the main shock was 99.2% of the energy released by all the earthquakes in this region (Lu Peiling et al., 1981). Based on these data, it seems that the seismic sequence in this region can be considered as a mainshock-aftershock sequence.

**West Region:** Three of the M≥6 earthquakes occurred successively in this region. The earliest earthquake occurred at 07h17m of the day in which the M=7.8 earthquake occurred. A sequence of secondary aftershocks occurred after these three earthquakes. They were distributed approximately along the Jing Canal fault in a NW direction. The joint plane I of the M6.9 earthquake listed in Table 4 was the actual fault plane of the earthquake, it reflects the activity of the Jing Canal fault. This is also obvious in Fig. 18. Of course, the seismic activity in this region was also influenced by the Tangshan fault as the aftershocks occurred after the M7.8 earthquake. According to the aftershock data of ML≥2.5 before May 1978, p = 1.08, b=0.73±0.04 were obtained. The energy of the largest earthquake was 81.5% of the released energy in the whole region (Lu Peiling, 1981). Thus, the seismic sequence in this region seems to be of a strong earthquake swarm type.

**East Region:** Aftershocks of the Tangshan earthquake concentrated mainly in the central and west region before the M=7.1 earthquake. Figure 19 shows that aftershocks occurred eight hours after the M7.1 earthquake, all distributed along a NW direction. Thus, it can be inferred that joint plane I of the M7.1 earthquake listed in Table 4 might be an actual fault plane. It reflects the activity of the Luanxian-Laoting fault. However, it should be noticed that some aftershocks continued to extend along a NE or near N-S direction. This might result from the activity of the sub-fault of a NE or SE orientation, affected by the M7.1 earthquake. Here we obtained p = 1.15, b = 0.85±0.06 (Lu Peiling, 1981) in this region. The energy of the M7.1 earthquake was 96.8% of the energy released by all aftershocks in this region. Therefore, the seismic sequence in the east region can also be considered as a sequence of the main shock-aftershock type.

In summary, it can be considered that the Tangshan earthquake consisted of three strong intraplate earthquakes which displayed a much more complicated movement. Butler et al. (1979) pointed out the complexity of dislocation of the Tangshan earthquake through a detailed analysis of surface and body wave records at distant stations, i.e. although the earthquake was mainly a strike-slip fault event, it also included thrust and normal fault events. The strike-slip earthquakes with high angle fault planes radiated most of the energy to the meizoseismal zone. Meanwhile, small co-seismic events with thrust features and the strong aftershock of M=7.1, which occurred a little bit later, again enhanced the intensity in the high intensity region. This provides a possible reason for the extreme disaster of the Tangshan earthquake. A second possible reason was the effect of local geological conditions on ground vibration. The three strongest earthquakes of the Tangshan sequence all occurred in the area covered by a thick sedimentary layer. This area is prone to the accumulation of seismic energy and increase in ground vibration effects. Thus, a large area of destruction occurred and the attenuation of intensity was slow.
References


(Translator: Zhu Chuanzhen)
Table 1. Catalogue of historical earthquakes in Tangshan and its surrounding areas (M≥4.75).

<table>
<thead>
<tr>
<th>No.</th>
<th>Date</th>
<th>Area</th>
<th>Epicentral Location</th>
<th>M</th>
<th>Intensity in Epicentral Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1485.5.27</td>
<td>Zunhua</td>
<td>40°12’ 118°00’</td>
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<td>VI</td>
</tr>
<tr>
<td>2</td>
<td>1527</td>
<td>Fengrun</td>
<td>39°48’ 118°06’</td>
<td>5.5</td>
<td>VII</td>
</tr>
<tr>
<td>3</td>
<td>1532.11.6</td>
<td>Sanhe, Xiadian</td>
<td>39°54’ 116°54’</td>
<td>5.5</td>
<td>VII</td>
</tr>
<tr>
<td>4</td>
<td>1536.10.22</td>
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<td>6</td>
<td>VII-VIII</td>
</tr>
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<td>5</td>
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</tr>
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<td>39°42’ 119°12’</td>
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<td>Bohai</td>
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<td>1624.4.17</td>
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<td>39°30’ 118°00’</td>
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<td>Dacheng</td>
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<td>5.25</td>
<td>VII</td>
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<td>22*</td>
<td>1974.5.7</td>
<td>SE of Changli</td>
<td>39°36’ 118°18’</td>
<td>4.75</td>
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</table>

*Two earthquakes with the same magnitude and epicentral location.

<table>
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<tr>
<th>Location</th>
<th>Epicenter of The Largest Earthquake in The Swarm $\phi$ $\lambda$</th>
<th>Beginning of The Occurrence of The Swarm</th>
<th>Maximum Magnitude ($M_L$)</th>
<th>Total Number of Earthquakes</th>
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</thead>
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<td>Beige</td>
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<td>1976.6.19</td>
<td>3.7</td>
<td>&gt;980</td>
</tr>
</tbody>
</table>

Table 3. Focal parameters of the Tangshan earthquake and its strong aftershocks.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time of Occurrence</th>
<th>Ms</th>
<th>Epicentral Location $\phi$ $\lambda$</th>
<th>Focal Depth (km)</th>
<th>Epicenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976.7.28</td>
<td>03-42-56</td>
<td>7.8</td>
<td>39°38' 118°11'</td>
<td>11</td>
<td>Tangshan city</td>
</tr>
<tr>
<td>7.28</td>
<td>07-17-32</td>
<td>6.2</td>
<td>39°27' 117°47'</td>
<td>19</td>
<td>Ninghe town</td>
</tr>
<tr>
<td>7.28</td>
<td>18-45-37</td>
<td>7.1</td>
<td>39°50' 118°39'</td>
<td>10</td>
<td>Shangjialin Luanxian</td>
</tr>
<tr>
<td>11.15</td>
<td>21-53-01</td>
<td>6.9</td>
<td>39°17' 117°50'</td>
<td>17</td>
<td>South of Lutai</td>
</tr>
<tr>
<td>1977.5.12</td>
<td>19-17-54</td>
<td>6.2</td>
<td>39°23' 117°48'</td>
<td>18</td>
<td>Jianzigu Ninghe</td>
</tr>
</tbody>
</table>
Table 4. Focal mechanism solution of the Tangshan earthquake and its strong aftershocks (Ms≥6.0).

<table>
<thead>
<tr>
<th>Date</th>
<th>Time of Occurrence</th>
<th>Mag.</th>
<th>Joint Plane I</th>
<th>Joint Plane II</th>
<th>P Axis</th>
<th>T Axis</th>
<th>B Axis</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976.7.28</td>
<td>03 42</td>
<td>7.8</td>
<td>30° SE 90°</td>
<td>120° SW 90°</td>
<td>75°</td>
<td>0°</td>
<td>345°</td>
<td>210° 90° From Zhang Zhili et al. (1980) from 129 stations in China and other countries</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>36° SE 80°</td>
<td>123° NE 73°</td>
<td>260°</td>
<td>19°</td>
<td>168°</td>
<td>5° 65° 70° From Zhang Zhili et al. (1980) from 53 stations in China</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>41° SE 85°</td>
<td>129° SW 70°</td>
<td>267°</td>
<td>18°</td>
<td>160°</td>
<td>10° 78° 7° From Qiouqun (1976)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20° NW 86°</td>
<td>113° SW 88°</td>
<td>21°</td>
<td>1°</td>
<td>241°</td>
<td>58° ditto</td>
</tr>
<tr>
<td>1976.7.28</td>
<td>07 17</td>
<td>6.2</td>
<td>52° 322° 84°</td>
<td>318° 228° 59°</td>
<td>100°</td>
<td>26°</td>
<td>1°</td>
<td>17° 241° 58° From Zhang Zhuli et al. (1980)</td>
</tr>
<tr>
<td>1976.7.28</td>
<td>18 45</td>
<td>7.1</td>
<td>26° 116° 61°</td>
<td>280° 10° 64°</td>
<td>242°</td>
<td>40°</td>
<td>334°</td>
<td>2° 66° 50° ditto</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>271° 181° 35°</td>
<td>355° 85° 86°</td>
<td>297°</td>
<td>39°</td>
<td>57°</td>
<td>32° 173° 35° ditto</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>300° 210° 45°</td>
<td>52° 322° 70°</td>
<td></td>
<td></td>
<td></td>
<td>R. Butler et al. (1979)</td>
</tr>
<tr>
<td>1976.11.15</td>
<td>21 53</td>
<td>6.9</td>
<td>330° 60° 60°</td>
<td>330° 90° 289°</td>
<td>21°</td>
<td>191°</td>
<td>21°</td>
<td>60° 60° Zhang Zhili et al. (1980)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>59° 149° 90°</td>
<td>149° 59° 63°</td>
<td>288°</td>
<td>19°</td>
<td>191°</td>
<td>19° 60° 63° ditto</td>
</tr>
<tr>
<td>1977.5.12</td>
<td>19 17</td>
<td>6.2</td>
<td>316° 46° 76°</td>
<td>45° 315° 86°</td>
<td>271°</td>
<td>7°</td>
<td>179°</td>
<td>13° 30° 75° ditto</td>
</tr>
</tbody>
</table>
Table 5. Focal mechanism parameters of the M7.8 Tangshan earthquake and its strong aftershocks.

<table>
<thead>
<tr>
<th>Earthquake Mechanism Parameter</th>
<th>1976.7.28 M=7.8</th>
<th>1976.7.28 M=7.1</th>
<th>1976.11.15 M=6.9</th>
<th>1977.5.12 M=6.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic moment (dyne. cm)</td>
<td>1.24 x 10^{27}</td>
<td>2.04 x 10^{26}</td>
<td>5.2 x 10^{25}</td>
<td>4.9 x 10^{24}</td>
</tr>
<tr>
<td>Fracture length (km)</td>
<td>96</td>
<td>55</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Mean dislocation (cm)</td>
<td>136</td>
<td>47</td>
<td>108</td>
<td>24</td>
</tr>
<tr>
<td>Stress drop (bar)</td>
<td>12</td>
<td>5.7</td>
<td>23</td>
<td>7.6</td>
</tr>
<tr>
<td>Strain drop</td>
<td>2 x 10^{-5}</td>
<td>8.6 x 10^{-6}</td>
<td>3.5 x 10^{-5}</td>
<td>1.3 x 10^{-5}</td>
</tr>
<tr>
<td>Energy of radiation wave (erg)</td>
<td>8.9 x 10^{22}</td>
<td>1.2 x 10^{21}</td>
<td>5.5 x 10^{20}</td>
<td>1.8 x 10^{19}</td>
</tr>
<tr>
<td>Mean velocity of fracture (km/s)</td>
<td>2.7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Distribution of M≥4.0 aftershocks of the Tangshan earthquake.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>7.0-7.9</td>
<td>2</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>6.0-6.9</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0-5.9</td>
<td>71</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>4.0-4.9</td>
<td>668</td>
<td>86</td>
<td>29</td>
</tr>
<tr>
<td>Total number of aftershocks</td>
<td>743</td>
<td>96</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 7. b-values of part of the large earthquake sequence.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M=7.2</td>
<td>M=7.4</td>
<td>M=7.7</td>
<td>M=7.9</td>
<td>M=7.1</td>
<td>M=7.3</td>
<td>M=7.8</td>
</tr>
<tr>
<td>b-value</td>
<td>0.72</td>
<td>0.88</td>
<td>0.60</td>
<td>0.52</td>
<td>0.57</td>
<td>0.93</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Figure 1. M-t diagram for North China (Qou Qun, 1976).

Figure 2. Strong earthquake distribution in North China seismic belt during the third and fourth active periods (Chen Feibi, 1979).
Figure 3. Epicentral distribution of historical earthquakes in Tangshan and its surrounding areas (1484-1976.7.28, M≥4.75).

Figure 4. Annual variations of earthquake frequency in Tangshan and its surrounding areas (Wu Kaitong, 1981).

Figure 5. Energy release (√E·t) of earthquakes in Tianjin, Tangshan and Bohai areas.
Figure 6. Epicentral distribution of $M_L \geq 4.0$ earthquakes before the Tangshan earthquake (1966.1-1966.6).

Figure 7. Epicentral distribution of earthquakes ($M_L \geq 2.0$) in Beijing-Tianjin-Tangshan region from July 1973 to the occurrence of the Tangshan earthquake (Huang Deyu et al., 1981).
Figure 8. Epicentral distribution of $M_L \geq 1.0$ earthquakes in North China (October 1975-June, 1976) (Wu Kaitong et al., 1981).

Figure 9. Comparison of seismic activity before the Tangshan earthquake of 1976 and the Sanhe-Pinggu earthquake of 1679.
Figure 10. Space scanning of b-value of North China and its neighboring areas before the Tangshan earthquake (the scanning window: 4 degrees, number of earthquakes: N=50 (Huang Deyu et al., 1981).
Figure 11. b-value curve ($M_t \geq 2.0$) (Huang Deyu et al., 1981).

Figure 12. Variation of mean velocity ratio prior to the Tangshan earthquake (Jin Anshu et al., 1980).
Figure 13  Variations of stress drop of small earthquakes with time.
Figure 14. Attenuation of aftershocks in the Tangshan earthquake (Wu Kaitong et al., 1981).

Figure 15. Daily maximum magnitude of the Tangshan earthquake sequence (Chen Feibi et al., 1979).
Figure 16. Distribution of aftershocks (M>4.5) of the Tangshan earthquake and the main geological structure.

Figure 17. Distribution of depths of some Tangshan aftershocks (Ishikawa Y. Et al., 1983).

Figure 18. Aftershock distribution within one and a half days after the M6.9 earthquake occurrence (Ishikawa et al., 1983).

Figure 19. Aftershock distribution within 8 hours after the M7.1 earthquake occurrence (Y. Ishikawa et al., 1983).
The Tangshan earthquake had its own geological background. The regional geological background and seismogenic structure of the Tangshan earthquake are discussed in this section. This is based on the data obtained from the seismo-geological field investigation which provides basic data required in the study of the relationship between the seismic risk region, seismogenic structure and seismic damage in the future.

1. Regional Seismo-Geological Background

(1) Regional tectonic features

The Tangshan earthquake occurred in the northeast of the North China fault block region (Zhang Buchun et al., 1980) (Fig. 1). The structure of this region is heterogeneous, and the upper crust in this region can be divided into three structural layers in the vertical direction (Liu Hongyun et al., 1980). These are the pre-Sinian crystalline metamorphic basement layer, overlying layer formed by Sinian, Paleozoic and Mesozoic strata, and Cenozoic loose layer. There are five main fault blocks in the horizontal direction (Institute of Geology, Sino-Academy of Sciences, 1959, 1974), i.e. the Eldos subsidence fault block, the Shangshi upwarp fault block, the Jibo subsidence fault block, the Jiaoliao upwarp fault block and the Yinshan-Yanshan fault-fold belt.

The Tangshan seismic zone is located in the intersection of the NE Jibo subsidence fault block and the EW Yinshan-Yanshan fault-fold belt. The earthquake occurrence is related to the strong interactions of these two blocks.

Since the Cenozoic era the Jibo fault block has strongly subsided and is controlled by the NE fault. Subsequent upwarp and subsidence fault blocks striking NE were formed, such as the Jizong subsidence block, the Cangxian upwarp block, the Huanghua subsidence block, the Chengling upwarp block, and the Bozhong subsidence block. From the Cenozoic era the maximum subsidence amplitude of the Bozhong and the Jizhong fault blocks reached 10,000 meters. At the same time there were NW tectonic belts which appeared intermittently, such as the Hai-River and the Sunhe-Naukou fault belts, showing obvious neotectonic features. The EW structural belt was formed earlier, but in the Cenozoic period, activity also occurred.

In the Jibo fault block subsidence zone the NE Changdong fault belt extends from south to north then it is divided into two branches near Sidangkou: the west branch passes northeast of Tianjin and intersects with the Hai-River fault. The east branch reaches the vicinity of Tanggu and is cut by the Hai-River fault, then it extends continuously to Huangzhuangwa and intersects with the Ji-Channel fault. But, there are different opinions about the fault extension to the north of Tianjin and this problem must be solved by further study. The fault belt is composed of a
series of normal faults and has been strongly activated since the Himalayan movement. The east wall of the belt is greatly subsided and the Cenozoic thickness reaches 8,000 m (in Qikou); the west wall is uplifted leading to the loss of Eocene strata, and the Neogene thickness is only about 1000 m and the Quaternary is several hundred meters thick also. The crust thickness of the Jibo subsidence fault block is thinner than the other blocks in the North China fault block region. The thickness is generally from 34 to 36 km (Fig. 1).

The Yinshan-Yanshan fault-fold belt is composed of a series of EW great faults, folds and magmatite belts. The crystalline basement is composed of Archeozoic and Proterozoic metamorphic rocks, and is strongly folded and hardened. The overlying layer is composed of Sinian, Paleozoic and Mesozoic strata, and the Sinian thickness reaches about 10,000 meters. Because of the interaction of polygenetic tectonic movements, the tectonic framework is very complicated. Subjected to the N-S compression, most of the pre-Sinian deforms and changes to be E-W faults and folds. Later on, NE-NNE and NW fault belts are formed in the Mesozoic and Cenozoic tectonic movements. In the Cenozoic era, the differential fault block movements were very strong causing the fault blocks to be subsided step by step from north to south, and finally formed the present tectonical fault block mountain. The crust thickness of the Yinshan-Yanshan fault fold belt is greater than that of the other block regions, and the thickness increases from east to west and the maximum is 42 km.

(2) The deep tectonic environment

The isopleth orientation of the Bouguer gravity field in the region is generally the same as the tectonical orientation (Fig. 2). The Yinshan-Yanshan fault-fold belt lies to the north of Changping-Zunhua-Qinhuangdao, and its basement tectonic line and fault strike are basically E-W. The abnormal Bouguer gravity strike-lines and the abnormal deep strike-lines calculated from the Bouguer gravity data are basically consistent with the above tectonics (Wei Menghua et al., 1980). The abnormal value increases from -90 milligal in the north to -10 milligal in the south, and at the same time the crust thickness decreases from 40 km to 35 km, approximately. Taking the line from Baoding to Shi Jiazuang as a boundary, the topography shows higher in the west and lower in the east. The tectonic line orientation is NE. The abnormal deep gravity value increases quickly from -110 milligal in the west to -10 milligal in the east, and the maximum horizontal gradient is 1 milligal/km. Therefore, a NE gravity gradient belt is formed. The crust thickness increases quickly also from east to west, from 35 km to 42 km.

In the plain region, the abnormal Bouguer gravity belt is characterized by its NE extension, and the plus and minus abnormal belts alternatively appeared. The variation of abnormal deep gravity values is smooth, and the abnormal values are generally between ±20 milligal. But, the abnormal geomorphology is rather complicated. The upper mantle of the whole region shows a block-shape uplift so the crust becomes thinner and the thickness changes from 34 km to 37 km. There are several Jizhong upper-mantle uplift regions, Huanghua and Bo-zhong upper-mantle uplift regions, and the orientations of which are all NE-NEE.

In addition, there is a local upper-mantle uplift belt striking NW along the Beijing-Ninghe-Bohai gulf causing the abnormal deep gravity lines and the crustal isobath passing through this belt to be both distorted.
The Tangshan area lies in the intersection of the E-W Bouguer high gravity belt and the NE Bouguer high gravity belt.

(3) Regional seismic and geological background

The North China fault block region is a region of active seismicity, the characteristics of which are: belt-type distribution, periodicity and mobility. In the space distribution it can be divided into five seismic belts: the Yinshan seismic belt, the Fenwei seismic belt, the North China plain seismic belt, the Liao-Lu seismic belt and the seismic belt in the south edge of Yinshan-Yanshan. Since 1,000 A.D., there have been four seismic active periods (Institute of Geology, Sino-Academy of Sciences, 1974). The first active period is from 1011-1076 A.D., the second from 1290-1368 A.D., the third from 1484-1730 A.D., and the fourth from 1815 A.D. up to the present. At present, it is the peak of the fourth period. In space, seismic activity has the characteristic of mobility. In the first active period earthquakes were mainly distributed on the Jibo subsident fault-block; in the second active period earthquakes were mainly distributed on the Shanshi upward fault-block; in the third active period earthquakes occurred in each seismic belt in North China, and in the fourth active period earthquakes were distributed mainly on the Yibo subsident fault-block and on the tectonic belt south of Yinshan-Yanshan. The Tangshan earthquake occurred in the fourth active period.

In the North China fault block the seismic belts are consistent in location with the boundaries of the large or small fault-blocks. At present, the Jibo subsident fault-block and the tectonic belt on the south edge of Yinshan-Yanshan are most active. The 1966 Xingtai earthquake (M=7.2) and the 1967 Hejian earthquake (M=6.3) occurred in the former, and the 1976 Helin Geer earthquake (M=6.3) occurred in the latter. The Tangshan earthquake occurred at the intersection of these two belts.

To sum up, the Tangshan seismic region is located at the intersection of the obviously active tectonical belt on the south edge of Yinshan-Yanshan and the Jibo subsident fault-block. At the same time, it is also the intersection of the EW and NE Bouguer gravity high-value belt. It means that the deep structure is a new local crustal uplift region. Moreover, a deep upper-mantle uplift appears adjacent to the south and west of Tangshan. This is the regional tectonic background of the Tangshan earthquake.

2. Geological Structure in the Tangshan Area

At the intersection of the Yinshan-Yanshan fault-fold belt and the Jibo subsident fault-block, a Tangshan block of a rhombus-shape lies on the side of the Yinshan-Yanshan fault-fold belt surrounded by deep faults. There is a NE fault belt in the center of the block. The Tangshan earthquake did occur on this fault belt in the block.

(1) The tectonic sub-region of Tangshan and its surrounding areas

Tangshan and its surrounding areas are mainly cut by two groups of NE and NW faults into blocks, forming the basic tectonic framework of the region.

Based on the formation of the pre-Sinian crystal basement, the difference of Sinian and Paleozoic strata, especially the characteristics of Mesozoic and Cenozoic sediments, magmatic activity and fault limitation, the tectonic structure of Tangshan and its surrounding areas can be divided into the Jixian uplift block, the Tangshan subsident block, the Shanhaiguan uplift block,
the Jizhong subsident block, the Cangxian uplift block, and the Laoting subsident block (Fig. 3). Of these blocks, the movement of the Tangshan subsident block is most closely related to the Tangshan earthquake.

(2) Tectonic layers of different materials

The Tangshan subsident block and its adjacent blocks are composed of three tectonic layers of different materials: i.e. basement, overlying layer, and Cenozoic loose layer.

**Basement.** It is composed of the Dantazi group and Qianxi group in the Archeozoic era. The main rocks are different kinds of schist, gneiss, quartz, hornblend, granulite and so on. The exposed thickness is more than 10,000 m. When added to the covered thickness, the total thickness amounts to more than 20,000 m. But the exposed areas in Fig. 3 are comparatively small and distribute mainly in the northeast mountainous area.

**Overlying layer.** It consists of quartz, marble, limestone, sandstone, shale, andesite, limestone in Sinian, Paleozoic and Mesozoic group and strata with coal series. The total thickness of the layer is more than 10,000 m. Most of the overlying layers are buried under the loose layer, and only a small part are exposed in the north mountainous area.

**Cenozoic loose layer.** It consists of Tertiary and Quaternary clastic sediments. Besides the layers scattered in the small basins of the north mountainous area, most of the layers are exposed in the south plain, and the thickness varies from north to south and becomes large in the south, with a maximum of 5,000 m approximately (in Bogezhuang).

(3) Boundary faults of the Tangshan rhombus block and their activity

As mentioned above, the Tangshan subsident block is a NEE block rhombus in shape, bounded by four deep neo-active faults (Guo Shunmin et al, 1977). The south boundary of the fault-block is the Linghe-Changli deep fault, the north by the Fengtai-Yejituo deep fault, the east by the Luanxian-Leting deep fault, and the west by the Ji-Channel deep fault. Characteristics of their activity are as follows:

The Linghe-Changli Deep Fault

The fault extends to the Bohai sea in the north-east direction and also in the south-west direction. It interrupts and meets the NW Ji-Channel fault in the vicinity of Hangu (Fig. 3). Activity of the fault was strong in the Mesozoic era. The southeast wall subsided accumulating quite a thick layer of Mesozoic clastic rocks while the northwest wall uplifted, losing Mesozoic strata. According to the artificial seismic sounding data from the Geophysical Exploratory Team of the State Seismological Bureau in China, it is shown that the fault cuts down deeply to the Moho discontinuity surface. The new activity of the fault was very strong, the southeast wall subsided vigorously in Tertiary, forming accumulation of thickness about 4,000 m while the northwest wall was damaged. According to the boring data, the throw difference between both walls of the fault is about 500 m in Quaternary (Fig. 4). On the northwest wall of the fault there is a river longitudinal gradient belt parallel to the fault striking NEE, it is related to the uplift of the northwest wall and the subsidence of the southeast wall (Fig. 5). There are two sea erosion platforms of different levels on the granite outcrop of the Yanshan-Period north of Changli Town; their sea-levels are 40 m and 80 m respectively. There are many sea-erosion holes, caves, niches and mushroom-stones on the platforms (Photos 1, 2, and 3). The sea-erosion platforms
are all on the north wall of the fault. Granite in the south wall is deeply buried beneath the Quaternary loose layer and the buried depth is about 200-300 m. The marine clay layers of the mid-Holocene (based on spore-pollen formation analysis) are exposed on both sides of the fault, but the difference of layers in height is more than 15 m and this also proves subsidence of the south wall and uplift of the north wall. Since the Yuan Dynasty, the Luanhe River has breached and changed its channel several times for seven hundred years and the locations of the river breaches, e.g. Shapu, Shi-Jiakou and Dingliuhe, were in the vicinity of the fault.

The Fengtai-Yejituo Deep Fault

It is the boundary between the Jixian uplift block and the Tangshan subsident block, controlling the development of the Paleozoic strata. For instance, the very thick Sinian strata is limited north of the fault and the Paleozoic strata in the south. It is shown by artificial seismic sounding data that the fault cuts deeply to the Moho discontinuity, the west fault plane inclines in a NW direction, and the east fault plane inclines in a SE direction. The point of deflection of the fault plane is in the neighborhood of Zhenzizhen Town (Fig. 3). The neotectonic movement of the fault is evident: the east section is the boundary line between the mountainous and plain areas, and on the west section the difference in thickness of the Quaternary on two sides is about 500 m, the north wall is a subsident zone and the south wall is an uplift zone in Quaternary, and the Quaternary isopachs suddenly change along the fault (Fig. 5).

The Luanxian-Laoting Deep Fault

The fault controls the movements of the Shanhaiguan uplift block and the Tangshan subsident block. The former has been uplifted and the latter subsided for a long period. The fault plane inclines to the NE and is a high-angle over-thrust fault. Between Macheng and Yejituo it is composed of four parallel faults and was formed in the pre-Paleozoic era. The neotectonic movement is strong and there is a series of remnants of fault mountain striking NNW west of Luanxian. The uplifted seacoast, sea-dunes (20-40 m high), sea-erosion terraces, and islands connected to the continent are developed on the east side of the fault (Fig. 6) while the subsided coast, deltas and wetlands are developed on the west side. On the two sides of the fault there are the Luanhe alluvial fans of three historical periods, which are the results of the new differential fault movements. The west side of the fault subsided in the late Pleistocene causing the Luanhe River to shift to the west and form the early alluvial fans. From the Holocene to the past 3,000 years the east side of the fault subsided and the Luanhe River shifted to the east forming the middle-period alluvial fans. From 3,000 years ago up to the present the Luanhe River has shifted to the west again, and alluvial fans were formed by the shift on the last period.

The Ji-Channel Deep Fault

It is the boundary between the Tangshan subsident block and the Cangxian uplift block. It extends northeastwards and meets the EW Xianghe-Baodi fault. The fault controls the development of the Paleozoic strata and the distribution of the Mesozoic basins. The artificial seismic sounding testifies that the fault extends deeply to the Moho discontinuity. It was formed in pre-Paleozoic, but was still active in the Cenozoic. In the Quaternary the northeast wall of the fault was uplifted and the southwest wall subsided so that the difference of drop of the Quaternary base between both walls of the fault is more that 100 m. The fault not only controls the flowing direction of the Ji-Channel, but also controls the rivers on the two sides of the fault to flow in
different directions: rivers on the west side flow southeastwards such as the Haihe, the Qin- 
glongwan and the Chaobai rivers; rivers on the east side flow in a WWS direction such as the 
Douhe, the Shahe, the Qing Longhe and the Xinluanhe rivers.

As mentioned above, the Tangshan rhombus block is bounded by strong active deep faults so 
that it is a strong active fault block.

**(4) Interior tectonic structure of the Tangshan rhombus block and its new activity**

The rhombus block basement is composed of a pre-Sinian metamorphic rock series, the 
overlying layer is of a Paleozoic sedimentary rock series, lacking Mesozoic strata. In the Ceno-
zoic, a lot of Quaternary loose layers were accumulated and the sedimentary thickness increased 
southwards, more than 800 m (Fig. 5), showing the south-dipping feature of the fault block. In 
topography it appears as a piedmont plain. Residual hills distribute in the plain and disappear 
gradually from north to south.

There are a series of NE faults and folds in the fault block (Fig. 3). The main rupture was 
developed in the Paleozoic strata in the Tangshan fault belt, which is composed of three parallel 
faults:

1. **The Tangshan-Guye fault**

The strike of the southwest section is N30°E and that of the northeast section is N50°E. The 
south end of the fault is cut by a transversal fault nearly in an EW direction (Fengnan fault). The 
whole length of the fault is about 30 km. To the south of Tangshan it is composed of two parallel 
faults, which are the so-called No. 4 and 5 faults in the Kailuan Coal Mine. The distance 
between the two faults is about 500 m and the fault planes all incline to the NW and their dip 
angles are 70-80° and both of them are reverse faults.

2. **The Douhe fault**

The northeast section is a normal fault dipping to the NW, the southwest section is composed 
of parallel Quaternary small faults, the planes of which all dip to the NW, and the fault most west 
is a normal fault (Fig. 3), but the three in the east are reverse faults (Fig. 4). The total length of 
the fault is about 50 km.

3. **The Tangshan-Weishan-Changshan southern slope fault**

It is composed of several un-continuous NE faults, the fault planes of which dip to the NW 
and their dip angles are 80°, approximately. Most of them are reverse faults distributed along 
stratum planes. From the stratum sequence the fault offsets are very small. The total fault length 
is about 20 km.

The above three faults extend southwestwards and combine in a fault in the vicinity of Feng-
nan, which continues to extend to Mofangqiao and then disappears. There are a series of folds 
accompanying the Tangshan fault. Figures 3 and 6 show that the folds from the west to the east 
are the Fengtai anticline, the Che Zhoushan syncline, the Bi Ziyuan anticline, the Kaiping syn-
cline and the Tai Dongzhua anticline. Orientation of all fold axes is northeast. The folds are 
characterized by a narrow anticline, wide syncline, and separated tectonic structure. Among the 
folds the Kaiping syncline is the widest, its deformation is the greatest and both wings are
unsymmetric with the southeast wing extending smoothly and the northwest wing inclined abruptly, even to be inverted. The Tangshan fault belt is developed on this inverted wing, which cut vigorously by the faults, forms a long and narrow horst in the central Weishan-Changshan area bounded by the faults. In view of the topography, the horst displays itself as a smoothly upfolded ridge.

The Tangshan faults and their accompanying folds are similar to the tectonic evidence and the movement of the surrounding areas in the Yanshan period, so it is inferred that they were formed in the Yanshan period. In the Cenozoic, activity of the Tangshan faults was also found. The Tangshan-Weishan-Changshan south slope fault is the boundary between the upper and lower erosion surfaces. The upper erosion surface, about 200-250 m above sea-level, extends northeastwards along the Tachengshan-Weishan-Changshan zone and the lower erosion surface 40-80 m above sea-level extends southward and changes gradually to an alluvial fan (Fig. 7). Both surfaces are erosion surfaces of the same period broken by faulting. Controlled by the faults, a new horst tectonic structure was formed in the Tachengshan-Weishan-Changshan zone.

The Douhe fault extends close to the west side of the horst structure. The geomorphic views on both sides of the fault are quite different, the upper erosion-surface is on the east and the piedmont plain is on the west. Moreover, the fault controls the development of the Douhe River. There is a Quaternary isopach gradient belt along the fault, and the offset of the Quaternary basement on both sides is 350 meters approximately (Fig. 5).

The Tangshan-Guye fault not only controls the Shiliu River Valley, but also is the boundary between the lower erosion surface and the alluvial plain.

The perched depression lands surrounding Tangshan were laid down in a NE direction. The belt, with more depression lands and that with less depression lands, appear alternatively (Fig. 8) and the relative change of the subsidence and uplift in the micro-geomorphic view also reflects the activity of the NE fault structure.

Ma Jin (1980) studied the extension of the EW Baodi fault to the east. Based on the existence of a E-W anomalous belt of positive gravity values and a E-W belt of low magnetic values near Tangshan, a deep material variation belt is thus inferred. From much calculation by use of the finite element method it is shown that the existence of the E-W fault results in the highest stress accumulation in the Tangshan area. Moreover, from the analysis of the characteristics of the river system and Cenozoic sediment there is also evidence of the existence of an EW tectonic structure (Li Xianggeng 1980). This is the Fengtai-Fengnan fault in Fig. 3.

(5) Performance of the Tangshan faults in the deep structure

With the development of deep structure exploration in recent years many valuable data have been obtained. Based on the artificial seismic profiles made by the Geophysical Exploring Team, State Seismological Bureau a deep fault cutting through Conrad surface and Moho surface is discovered in the neighborhood of Tangshan, and the location of the deep fault is almost the same as that of the Tangshan fault so that it is believed to be a NE buried deep fault. The drop of the Moho surface on both sides of the fault is about 2-3 km, with the east wall subsided and the west wall uplifted. The natural seismic transfer wave profiles made by the Institute of Geology, State Seismological Bureau also show the similar results. The location of the buried deep fault corresponds to that of the shallow Tangshan fault but there are significant differences between
them. In the active period, the Tangshan fault belt was mainly formed in the Mesozoic (although differential activity occurred in the Cenozoic, yet the active amplitude is relatively small), and the buried fault was probably formed mainly in the Cenozoic (it is accompanied by the uplift of the upper mantle in the deep structure of the Jibo block and the thinning of the crust in the Cenozoic), therefore it is a fault extending from the deep structure to the shallow structure. From the view of activity the Tangshan faults are high-angle reverse faults which are related to the folding of the fault block in the Yanshan period, and the buried faults are normal faults which are related to the deep extension in the Cenozoic. From the scale of activity the throw amplitude of the Tangshan-Guye fault in the Tangshan fault belt is not more than 100 m, but that of the buried fault is 2-3 km. So, it is considered that the buried deep fault is not completely connected with the shallow fault and continues to develop from the deep to the shallow structure.

3. Tectonic Stress Field in Tangshan Area

The tectonic stress fields in North China and in the Beijing-Tianjin-Tangshan area have been studied by many scientists (Gao Mingxiu, 1979, Zhang Yuming et al., Ye Hong et al., 1980; Tapponier, P. and P. Molnar, 1979, Han Shoulin, 1979). The comprehensive research results show that the tectonic stress field in North China is subjected to two forces: one is the NEE-SWW regional horizontal compression and the other is the vertical force applied to the overlying crust from the lower crust by the upper mantle mass movement. Superposition of these two forces determines the development of earthquakes in the crust in North China, and the horizontal force component is generally greater than that of the vertical force. It is the Tangshan earthquake which resulted from the interaction of the compression and the vertical force in the crust.

(1) Regional horizontal compressive stress field

A lot of geological, seismic, and ground deformation data show that there is a nearly horizontal compressive stress field in the direction of NEE-SWW in the Tangshan area.

There are a series of NEE Cenozoic normal faults and graben-horst structures with extension and dextral torsion features in North China such as the Taihangshan front fault, the Changdong fault, etc. But the NW faults such as the Sunhe-Nankou fault, the Ersili Changshan fault, and the Jianchangyin-Beidaihe fault not only have compression but also have sinistral torsion features. From the analysis of the above two sets of faults the regional tectonic stress field should be of a NEE-SWW compression. The stress field in Tangshan is the same as in North China. The NE faults are high-angle normal faults and the NW faults are high-angle reverse faults. According to the satellite image interpretation the NE faults also have a dextral torsion feature. And in the Bohai Gulf, south of Tangshan, the isobaths of the late-Tertiary bottom plate show the existence of a series of NE echelon basins, the structure of which is similar to that of the Shanshi echelon graben basins and they also result from the NEE-SWW compression (Fig. 9).

Based on the triangulation data by the Seismic Measurement Team, State Seismological Bureau in the Tangshan area, any displacement of the triangular points relative to Miaoshan is almost surrounded by the Tangshan fault belt from 1970-1976, and the direction of displacements on both sides are clockwise, which is also the effect of the NEE-SWW compression (Fig. 10).
The seismic source mechanism of strong earthquakes in North China and the Tangshan earthquake (Shi Zhenliang, 1973, Qiuqun 1976) and the characteristics of earthquake cracks also confirm the above conclusion.

(2) Effect of the vertical force

Both of the deep crust sounding and the ground deformation results verify the effect of the vertical force in the Tangshan areas.

Based on the gravity data there is an upper-mantle uplift in the deep structure in the Jibo area, and the corresponding Cenozoic subsidence is associated with the crustal gravity-balance caused by the upper-mantle uplift. Uplift of the deep structure and subsidence of the lower are opposite in relation, and both are caused by the effect of the vertical force.

Based on the artificial seismic wave data (1979) by the Geophysical Exploring Team, State Seismological Bureau, a horst-uplift controlled by the faults is found between Tangshan and Fengrun (Fig. 11). On both sides of the horst-uplift the Moho surface and Conrad surface are separated by the faults, and the offsets of the surfaces are 2-3 km. According to the leveling data by the Geodetic Survey Team, Hebei Geological Bureau, the ground level in 1975 was 20 mm higher than that in 1974 (Fig. 12). The uplift may be the crustal arching caused by the vertical force (Guo Zengjian et al., 1977). The ground deformation is almost surrounded by the Tangshan fault, and it shows that the uplift of the NW wall and the subsidence of the SE wall are consistent with the results of the artificial seismic sounding. From the satellite earth-gravity data Tangshan is also a stress accumulation region beneath the crust (Hua Shoulin, 1979).

4. Seismogenic Structure of the Tangshan Earthquake

It is shown by the above-mentioned that there is a discontinuous fault in the Tangshan rhombus block bounded by four active deep faults. The fault has not been completely separated from the buried deep fault but is intersected by the EW Fengtai-Fengnan fault therefore, a closed region of complicated tectonic structures is formed. This closed region bounded by the rhombus block develops into a huge source body, subjected to the interaction of the NEE-SWW regional horizontal compression and the heterogeneous vertical force in the crust through the accumulation of stress in a long period. Finally, the total accumulated shear stress exceeds the shear strength of the rock causing sudden rupture of the tectonic closed region so that earthquake occurs (Fig. 13).

After the occurrence of the Tangshan earthquake ground cracks associated with the seismogenic structure occurred along the No. 5 fault in the Tangshan fault belt (Fig. 14), which directly shows the fracture feature and pattern of the seismogenic structure. The crack belt is 8 km long and is composed of the following five cracks belts in echelon type:

(1) Crack belt between Shengli Road and Yonghong Road. The total length of the belt is more than 700 m. It consists of secondary cracks in echelon, parallel to each other. On the road in front of the Tangshan Store of the Hebei Metallurgical Bureau the cracks show dextral torsion. A row of trees and underground R.C. plates were cut by shearing with an offset of 0.8 m (Fig. 14-I, Photo 4), width of the cracks is 0.5 m, and the SE wall subsided 0.4 m.
(2) Crack belt between Daxie Zhuangzi and the No. 10 Middle School. The total length of the belt is more than 800 m and the direction and arrangement of the cracks are similar to those of the first crack belt. In the court of the No. 10 Middle School the cracks show dextral dislocation and the fence walls, lanes, and door frames are dislocated in a dextral direction for 1 m and the subsidence of the SE wall is 0.2 m. The maximum horizontal offset of the belt is 1.3 m and the maximum vertical throw is 0.3 m (Fig. 14-II).

(3) Crack belt between Hanjia Houjie and Xing Wangjie. The size of the belt is small and its total length is 500 m. The location of the belt is about 100 m east of the last belt with similar features.

(4) Crack belt between Maja garden and Knitting warehouse. The total length of the belt is 1500 m and the dextral torsion is obvious. The maximum offset is 1.5 m and the SE wall subsided with a throw of 0.8 m (Photo 5).

(5) Crack belt between Lishang Village and Zhengjia Village. The belt passed through soybean fields, corn fields (Fig. 14-IV), and lanes, and the cracks are of dextral torsion and the maximum horizontal offset is 2.3 m. Some of the cracks are in echelon and subside in the northwest direction (Fig. 14-V).

Generally speaking, the NE ground cracks are the extension-dextral cracks, while the NW cracks are compression or compression-torsion cracks, and the latter are characterized by the rectangular drum shape and tile roof pattern (Photo 6).

The existence of the crack belt confirms once again the relationship between the occurrence of the Tangshan earthquake and the activity of the Tangshan fault belt.

Moreover, from the relationship between the source depth, source mechanism, isoseismals, aftershock distribution and the tectonic structure, results of the above analysis on seismogenic structure can also be proved. Origin of the Tangshan earthquake is 11 km deep and it is also located at the boundary between the granite layer and the metamorphic rock layer. The artificial seismic sounding data show that the fault at this depth is not obvious, but the Conrad and Moho surface below are separated obviously, showing that the earthquake origin lies in the deep tectonic closed region. Furthermore, the location of the meizoseismal area is consistent with that of the Tangshan fault basically, and the V and VI isoseismals of the Tangshan earthquake agree with the Tangshan fault belt in strike and location (Fig. 13), and the strike and direction of the IX and VIII isoseismals basically correspond to the orientation and shape of the Tangshan rhombus block. The ratio of the major axis to minor axis of the isoseismals is about 2:1, showing the significance of the NE structure.

Figure 15 shows the distribution of the aftershocks of magnitude greater than 4.5 which occurred after December 30, 1976. From the figure, the direction of the long axis of the aftershock distribution area, which is about 150 km long, is northeastward and this area is consistent with the seismogenic structure in location and orientation. The seismic source mechanism solution indicated that the fracture plane also agrees with that of the Tangshan fault belt.

After the occurrence of the main fracture of the Tangshan faults, by which the Tangshan earthquake was induced, the stress quickly migrated to the ends of the fracture and blocked by the transversal faults, e.g. the Luanxian-Leting fault and the Ji-Channel fault in the vicinity of the
ends, two new stress accumulation regions were formed. When the ends of the Tangshan faults run the blockade of the transversal faults the fracture continued to develop and caused the new fracture of the NW faults, consequently, strong aftershocks occurred on both sides of the fault (the M=7.1 earthquake occurred on the northeast side and the M=6.9 earthquake on the southwest side). These strong aftershocks are generally the result of the motion of a pair of conjugate faults. From the ground fractures the NE fracture plane shows dextral torsion and the NW fracture plane shows sinistral torsion (Li Zhiyi et al., 1979), so they are conjugate faults.

5. Conclusions

The Tangshan earthquake occurred in the junction of the E-W Yinshan-Yanshan south front tectonic seismic belt and the NE Jibo tectonic seismic belt, the activity of which were obvious. Beneath the junction location there is a transform belt of mantle uplift. At the same time, the Tangshan earthquake was located at the local uplift area of the transform belt.

In the Tangshan rhombus fault block the tectonic closed region between the discontinuous Tangshan fault belt and the buried deep fault is subjected to the interaction of the NEE-SWW horizontal compression and the heterogeneous vertical force of the deep crust, so the strain energy gradually accumulates in the region and then a huge seismic source body is formed. The region suddenly ruptures when the total accumulated shear-stress exceeds the shear strength of the rock then an earthquake occurs.

This study is based on the seismo-geological field investigation made by the author and Mr. Li Zhiyi, Cheng Shaoping, Chen Xiancheng, Chen Xiaode, Yanzhuen and Li Rucheng. The author greatly appreciates the help of the above colleagues in this study.

(Translator: Guo Shunmin)

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Legend:
1. Large deep-fault cutting the fault blocks.
2. Inferred large deep fault.
3. General large fault.
5. Uplift belt of the NE fault-block.
7. E-W hill front fault-subsidence belt.
8. Cenozoic fault-subsidence basin.
9. Crustal isopath line.
10. The M>8.0 earthquakes.
11. The M=7-7.9 earthquakes.
12. The M=6-6.9 earthquakes.

Figure 1. The fault-block tectonics and the epicenter distribution of strong earthquakes in North China.
Figure 2. Distribution of anomalous gravity in Tangshan and its surrounding area (after Zheng Binghua et al).

Figure 3. Tectonic geology of the Tangshan fault block.

3. Quaternary loose layer and lower bed rock boundary. 10. Overturned syncline axis.
5. Deep fault or large fault 12. Fault number.
Legend:

Z — Sinian
E — Cambrian
O — Ordovician
C — Carboniferous
P1 — Lower Permian
P2 — Upper Permian
N — Neogene
Q — Quaternary

Figure 4. Tectonic profile of Long Wanzi-Tangshan-Huangtuo section (B-B’ in Figure 3)
Figure 5. The neotectonic movement in the Tangshan area.
Figure 6. Islands connected to the continent on the Bei Daihe coast.

Figure 7. Geomorphic profile after the breakage of erosion-leveling surface from the Douhe River to the Shilinehe River.
Figure 8. New activity of the Tangshan fault belt testified by the micro-geomorphology deformation.
Figure 9. Isobaths of the neogene bottom plate showing step-like basins in the Bohai Gulf.

Figure 10. Displacement vector of triangular points corresponding to Miaoshan from 1970 to 1976 (after the Seismic Measurement Team, State Seismological Bureau).
Figure 11. The crustal tectonics in Tangshan area. Thick line-inferred buried deep-fault.

Figure 12. Variation of the vertical ground-deformation (mm) from 1975 to 1976.

Figure 13. The seismogenic structure of the Tangshan earthquake.

- Large faults and deep faults with new activity
- Faults with new activity
- Fault directly related to the M=7.8 earthquake
- Tangshan earthquake faults and the fracture extension direction
- Seismic shear-fracture zone
- Isoseismals of the M=7.8 earthquake
- Isoseismal of the M=7.1 earthquake
- Isoseismals of the M=6.9 earthquake
- Epicenter
- Direction of the main compressive stress field
Figure 14. Distribution of earthquake cracks in the epicentral region of the Tangshan earthquake.
Figure 15. The Tangshan earthquake and aftershocks and the relationship between them and the tectonics (the seismic data come from the Institute of Geophysics, State Seismological Bureau. Deadline of the data: December 30, 1976) fault and inferred fault with new activity.
Photo 1. Sea erosion platform of the first level, north of Changli Town (elevation above sea level = 40 m).

Photo 2. Sea-erosion platform of the second level, north of Changli Town (elevation above sea level = 80 m).

Photo 3. The full geomorphic view of the palaeo-coast north of Changli Town.
Photo 4. Sinistral torsion of R.C. plates under the road in front of the Tangshan store, Hebei Metallurgical Bureau.

Photo 5. The displacement of a door frame on Jixiang Road, Tangshan City.

Photo 6. A bulge 5 m long and 0.3 m high on Fuxing Road, Tangshan City.
I. Geologic-Tectonic Background of the Tangshan Earthquake

The Tangshan earthquake occurred in the plate tectonic zone of North China. Its precursors and aftereffects had an influence far beyond the Tangshan earthquake area, covering a considerable area in the northern part of North China.

Earth science data accumulated in recent years show that the crust and lithosphere media in the North China area are non-homogeneous, with layers in the vertical direction and blocks in the horizontal direction. The boundaries between the ancient tectonic blocks in North China are usually classified as (1) geologic-tectonic zones, (2) geophysical anomalous zones, and (3) seismic active zones. These are also criteria for the classification of boundary zones between large or small blocks. The movement of the North China block, or its inner blocks, whether it is under thrust, over thrust, uplift or subsidence, torsion, compression, extension, rotation or other complicated movement between the blocks, will cause the accumulation of strain energy and development of earthquakes in the boundary zone. Seismicity will be further increased especially in the junction, overlap and contact locations of the boundaries of the blocks. Thus, it is more precise to define the crustal block movements as the plate movement.

From this observation the background of recent of strong earthquakes, especially the great Tangshan earthquake in the northern part of North China and the Hebei area will be discussed based on the plate tectonic theory and the seismicity associated with the plate tectonics.

1. The plate tectonic boundary zone in North China

The North China plate is bounded by the structural zones of the Helan mountain and the Liupan mountain in the west, the Qin mountains and Dabie mountain in the south, the EW structural zone of the Yin mountain in the north, while its east boundary is in the sea area (Yang Lihua and Li Qinzu, 1980).

There are four seismo-tectonic belts with obvious characteristics inside the North China plate. Meanwhile, they are also the boundary zones of its inner plates. These four seismo-tectonic belts are: (1) the fault subsidence seismic belt in the Shanxi uplift area, (2) the fault rupture seismic belt of the Taihang mountain front, (3) the Changdong fault rupture seismic belt and (4) the Tanlu fault rupture seismic belt. Therefore, five small plates also appear inside the North China plate: e.g., (1) the Eerduosi-Jinxi plate, (2) the Jinjiplate, (3) the Jizhong plate, (4) the Jilu plate and (5) the Liaolu plate. There is also a relatively large fault which is the Yellow River fault in the Eerduosi-Jinxi plate (Fig. 1).

* Seismological Bureau of Hebei Province. Wang Jingming, Chen Guoshun, Zheng Decheng and Pan Zushou also participated in the field work.
**2. The seismogenic structures which cause large earthquakes in North China**

From the analysis of the local structures of several large earthquakes in North China, it can be seen that most of the strong earthquakes occurred in particular structural regions. These structural regions and large structures, i.e. the plate boundary zone, include the junction areas of local and large structures, which are accompanied by fault basins of the Cenozoic era.

According to the preliminary studies of several large earthquakes in Beijing, Tianjin, Tangshan, Zhangjiakou and other areas in North China, the seismo-geological conditions of strong earthquakes in these areas are obtained as follows:

1. The junction, overlap and contact locations of the two plate boundaries, accompanied by a fault basin of the Cenozoic era, are the conditions of strong earthquakes of magnitude 7-8.

2. The area accompanied by relatively large fault basins of the Cenozoic era on the plate tectonic boundary zone also is a condition for the occurrence of strong earthquakes of magnitude 7-8.

3. The junction area of an active fault zone inside a plate and a plate boundary zone, accompanied by the fault basins of the Cenozoic era, is a seismogenic condition for the occurrence of earthquakes of magnitude about 6.

4. The junction, turning or branching location of ordinary faults (including deep structures), possesses a condition for the occurrence of earthquakes of magnitude 5.

5. The earthquake occurrence probability will be high for the fault basins controlled by the plate boundary zones, which have intense neotectonic movement in which there are large faults, structural junctions and geophysical anomalies in the deep structure.

**3. The seismogenic structural environment of the Tangshan area**

The Tangshan-Luanxian area is located at the northern boundary of the North China plate, i.e. the junction area of the south margin of the EW structural zone of Yinshan mountain (Yanshan fold belt) and the east boundary of the Jizhong plate (Changdong fault belt).

1. **Yanshan mountain fault-fold belt**

   The Yanshan mountain fault-fold belt is located in the northern part of Hebei Province, which is bounded by the great Zhangjiakou Beipiao fault in the north, adjacent to the Yinshan mountain structural zone. It meets the subsidence area in the North China plain in the south, passing through the great Baodi and Changli fault. Its crystalline basement is the ancient metamorphic Sangkan complex of the Archean era with strong fold and high-level hardening. Its covering strata have been relatively developed and possess marine and continental deposits of different eras, of which the Sinian strata are the most developed, having a maximum thickness of nearly 10,000 m. In this belt there are also activities of various kinds of igneous rock in different periods.

   The Yanshan mountain fault-fold belt has experienced many structural movements and its structural framework is relatively complicated during the early stages. A series of EW faults and folds were formed due to the NS compression. After the Yanshan mountain movement
of NNE and NE structures were also formed. In the east of Beijing the high-angle thrust fault is the main fault, and the anticlines take the second place. In the west of Beijing a series of plunging anticlines, normal faults and thrust faults are dominant. Because the NNE and NE structures formed after the Yanshan mountain movement cut off the EW faults the EW structure was activated recently. The structures in this area have become more fractured and more active. All the ancient structures have been activated since the Cenozoic era due to the influence of Himalayan movement. The activated faults include the nearly EW Ninghe-Changli fault, the NE Tangshan fault and the Luanxian fault, the NNE Taoyuan fault and Yuannan-Qianan fault, etc.

On the Yanshan mountain fault-fold, seismic activity occurs frequently. Over half of the destructive earthquakes in Hebei Province occurred here. Most of them were distributed in the junction, overlap and contact locations of the Yanshan mountain fault-fold belt and in the NNE and NE fault belts, and the EW trending fault-fold belt. This latter belt comes from Zhangjialou, Huailai and Zhuolu in the northern part of Hebei Province to the area of Tangshan-Luanxian-Lulong-Changli-Funing-Laoting, passing through Yanqing, Changping, Tongxian and Pinggu of Beijing city, and Sanhe, Dachang, Xianghe and Baodi of Hebei Province.

(2) Changdong fault belt

The Changdong fault belt has been active since the Yanshan mountain movement. It develops in the east side of the Changxian uplift in the subsident plain in North China as the tectonic boundary between the Changxian uplift and Huanghua depression. It is 245 km long, striking NNE, then turning to NE. Geographically it starts from the west of Dexhou in Shandong Province, then passes through Wuqiao, Dongguang, Bozhen, Changzhou, Changxian in Hebei Province, and turns northeastward through the east part of Tianjin to the vicinity of Lutai farm where it begins to join the Ninghe-Changli fault at the southern margin of the Yanshan mountain fault-fold belt. Then three active faults, i.e. the NE fault to the north of Tangshan, the Tangshan fault and the Luanxian fault, insert in the Tangshan-Luanxian area, forming a structural junction zone.

On the gravity anomaly map, the Changdong fault belt shows there is a gravity gradient zone with dense isopleths; but on the airborne magnetic survey map it is actually a positive anomalous zone of magnetic axis.

The seismic measurement and boring data shows that the Changdong fault belt consists of a series of normal faults, only part of it is cut by the transversal faults or inclined faults. Since the Himalayan movement the Changdong fault belt has been intensively active and the Huanghua depression on the east side of the fault has subsided vigorously (the subsidence center is close to Qikou in Huanghua County), where the maximum thickness of the Cenozoic deposits is up to 8,000 m. In this fault belt there were also activities of igneous rock and volcanoes during and after the Yanshan mountain movement.

Earthquakes that occurred on the Changdong fault belt are: the Dongguang-Nanpi earthquake of M=5.5 on September 18, 1704; the Changxian earthquake of M=4.75 on January 18, 1069; the Changxian earthquake of M=5 in April 1625; the Changxian earthquake of M=5 on February 23, 1893; the M=5 earthquake to the east of Tianjin on August 6, 1815; and Ninghe earthquake of M=4.1 on December 15, 1974, etc. Earthquakes that occurred in the junction area are the Fengnan earthquake of M=4.75 on May 25, 1970; the Tangshan earthquake of M=4.75 in
January, 1935; the Luanxian earthquake of M=5 in June, 1562; the Luanxian earthquake of M=6.25 on April 17, 1624; the Luanxian earthquake of M=5.25 in 1795; and the Luanxian earthquake of M=6.25 in 1945, etc.

In summary, as the north boundary of the North China plate, (the Yanshan fault-fold belt and the east boundary of the small-size Jizhong plate inside the North China plate) and the Changdong fault meet in the Tangshan-Luanxian area, the seismicity in this area is greatly increased, which constitutes the seismo-geological background for the occurrence of strong earthquakes.

II. Seismogenic Tectonic Stress Field and Seismogenic Structure

1. The seismogenic tectonic stress field of the Tangshan earthquake of M=7.8

The seismogenic tectonic fissure-zone of the Tangshan earthquake of M=7.8 begins from Anjizhai in the Daodi Commune in the south, then extends northwards passing through Lis-hangzhuang, the Party School of the Tangshan Prefecture Party Committee, Jixiang Road, No. 10 Middle School, Yonghong Road, Xiaoshandong Street in Tangshan city, and ends at the No. 29 Middle School to the north of Douhe. It is 8 km or more in length and 30 m in width, overall striking N30°E. This fissure-zone extends approximately along the NNE Ninghe-Tangshan basement fault, developed in the loess-like silt layer of the secondary expression of the Quaternary system, and shows an en echelon arrangement. The strike of each fissure is greater than N45°E. The en echelon fissures are nearly parallel to each other, and each segment of the en echelon fissures in the whole zone shows dextral torsional movement, with the maximum offset up to 1.53 m (Jixiang Road). Although the amount of offset of each segment is different, the evidence of the dextral torsional movement is quite obvious. This is consistent with the pattern of the tectonic stress field in the Hebei area (Fig. 2), i.e., based on the dextral torsion movement of the regional stress field. The dextral torsional movement of the seismic area also occurred, consistent with the stress condition of "acceleration of the same direction". The horizontal torsional offset of the seismogenic structure of the M=7.8 earthquake is 1,530 mm. Figure 3 is the model of the NNE fault subjected to the dextral torsional movement.

According to the results of the analysis of focal mechanism (Fig. 4), the strike of the joint plane A (maybe the fault plane) is 30° with a dip angle of 90°. The orientation of the principal compressive stress is 86.5° with an inclined angle of 18°, which is approximately consistent with the orientation of the principal compressive stress in the North China area and also with the above-mentioned model.

2. The seismogenic structure of the M=7.8 earthquake

The Tangshan seismic area is located at the junction of the NNE Ninghe-Tangshan fault and the NE Kaiping syncline (Fig. 5). The Ninghe-Tangshan fault is a main branch after the Changdong fault belt meets with the EW Yanshan mountain structural zone in the Tangshan area. The Kaiping syncline is a constituent part of the EW Yanshan mountain structural zone. The seismogenic structural fissures with obvious fault phenomena occurred at Jixiang Road in Tangshan city.

According to the satellite photographic studies, the Ninghe-Tangshan fault is a large fault with a total length of more than 250 km which extends continuously to the northeast from
Tangshan (the reliability of the satellite photographic studies is limited, for reference only). Based on the geological and geophysical prospecting data, it has been confirmed that the Tangshan Coal Mine No. 5 fault (Fig. 6), the Houtun fault and the Wanglantun fault north of the Ninghe-Tangshan fault, mainly developed in limestone of the Cambrian and Ordovician periods and in a coal series of the Permo-Carboniferous period. They are rupture faults intermittently distributed and dipping northeast. The dip angle is greater in the upper and smaller in the lower regions having a vertical dislocation of 40-300 m. The Houtun fault is a normal fault with its northwest wall subsided 300 m, breaking the Quaternary alluvium and controlling the development of the Douhe terrace. The northwest wall of the No. 5 fault is upthrust, the southeast wall subsided and the Quaternary stratum deformed. The Wang-Lantun fault has broken the stratum of the Tertiary period for 200-500 m. These three faults are all active, and since the mid-Pleistocene era they all have experienced obvious activities.

The Kaiping syncline, with its long axis greater than 70 km and short axis 12-20 km, is characterized by its openness. The rock formations on both sides are unsymmetric, and that on the northwest side is vertical or even overturning. Compressional faults distribute densely along its orientation, its southeast side is smooth, with a dip angle less than 25°. There are faults striking EW and NNE approximately, cutting the Kaiping syncline. The rock formations on the south and north side of the Kaiping syncline are consistent with the EW Yanshan mountain structural zone, but the strike becomes northeast due to the insertion and transformation of the NE structure.

From the observations the characteristics of the seismogenic tectonic structure of the Tangshan earthquake of $M=7.8$ are as follows:

1. The earthquake occurred in and was controlled by the junction area of large-size tectonic zones. The northern part of the Ninghe-Tangshan fault passed by the vicinity of the NNE No. 5 fault at the Tangshan Coal Mine, and was obviously activated during the $M=7.8$ earthquake.

2. The strike of the long axis of the isoseismal of intensity $X$, 36 km long, is N 45-50°E. The maximum width in the intensity $X$ area is 15 km. The area is a ladle in shape with a wider southwest end, which is approximately consistent with that of the Kaiping syncline basin, and the long axis of which is close to the syncline axis.

3. The occurrence of the relatively large aftershocks in the Tangshan seismic area is strictly limited inside the Kaiping syncline, which indicates that earthquakes are controlled by the tectonic zone.

4. The central part of the seismogenic structural fissures shows that the ground has been dextrally dislocated, and that the south and north parts gradually became fractionally bent and branched, and then disappeared.

### 3. Seismogenic tectonic stress field of the Luanxian earthquake of $M=7.1$

The seismogenic tectonic fissure-zone of the Luanxian earthquake of $M=7.1$ begins from Wangzhuang and Shezhuang in the south, and after passing through Ligezhuang and San-shanyuan ends in the Tiejuzhai-Zhaogezhhuang area in the north and gradually disappears. The total length of the zone is more than 6 km and the strike is NS approximately. This fissure-zone
is distributed along the basement fault in the west of Luanxian. It started from Shezhuang in the vicinity of the meizoseismic region, striking N15°W, extending northward through Ligezhuang to the vicinity of Sanshanyuan, then the strike turns to be N20-25°E. It is cut by the NEE fault after passing through Zhaogezhuang, then passing by Shangjialin and continuously extends northwards. The distribution of the seismogenic tectonic fissures is consistent basically with that of the basement structure, developing in the Quaternary alluvium ground surface near the Luanhe River system. On the highway in the neighborhood of Shezhuang in the south, a compression uplift striking N 10°E appears, which indicates that the tectonic fissures were subjected to EW compression. On the segment from the north of Shezhuang to Ligezhuang-Sanshanyuan, the en echelon fissures appear to be subjected to left-handed torsional movement, which reflects the left-handed stress state due to EW compression subjected by the NNW fault. From the north of Sanshanyuan, the fissure-zone turns to be NNE en echelon arrangement, subjected to dextral torsional movement. As a whole, the seismogenic tectonic fissure-zone of the M=7.1 earthquake is an arc in shape, protruding westward, which was caused by the EW compression (Fig. 7).

4. The seismogenic structure of the Luanxian earthquake of M=7.1

The Luanxian seismic area is located in the fault subsident basin between the fault west of Luanxian (from NNW to NNE) and the Luanxian-Lulong fault (striking NNE). The seismogenic tectonic fissure-zone develops at the arc-shape turning point of the fault west of Luanxian, i.e. in the vicinity of Sanshanyuan.

The structural characteristics of this earthquake are as follows:

(1) The intensity of the meizoseismic region is IX. The region is 32 km long and 20 km wide, the strike of its long axis is SN, consistent with that of the fault west of Launxian and the Luanxian-Lulong fault.

(2) The nearly NS arc-shaped seismogenic tectonic fissure-zone is similar to the northern segment of the fault west of Luanxian generally. It was subjected to compressional torsion, showing that the fault west of Luanxian is a new active fault.

(3) The relatively large aftershocks in the Luanxian area are limited to the vicinity of the fault west of Luanxian and the Luanxian-Lulong fault, and in the fault subsident basin area between these two faults. Close to the fault west of Luanxian occurred one aftershock of M>6 and more than ten aftershocks of M≥5; near the Luanxian-Lulong fault occurred four aftershocks of M≥6 and more than ten aftershocks of M≥5. Aftershocks of M=3-4 occurred quite frequently here. This has further proved that the earthquake of M=7.1 was controlled by these two faults.

In summary, the Tangshan earthquake of M=7.8, the Luanxian earthquake of M=7.1 and their strong aftershocks are the result of reactivation of nearly all of the faults in the Tangshan area under the action of the EW regional compressive stress field (Fig. 8).

(Translator: Yang Lihua)
Figure 1. Distribution of Cenozoic tectonic stress fields in the North China plate.

Figure 2. Analysis of the seismogenic tectonic stress of the Tangshan earthquake of M=7.8.
Figure 3. Model of the NNE fault in the North China plate subjected to dextral torsional movement.

Figure 4. Focal mechanism solution of the Tangshan earthquake of M=7.8.
Figure 5. Local seismogenic tectonic structure of the Tangshan earthquake of $M=7.8$.

Figure 6. Profile of the No. 5 fault at Tangshan Coal Mine.
Figure 7. Stress analysis of seismogenic tectonic fissure-zone of the Luanxian earthquake of M=7.1.

Figure 8. Stress concentration zones in Tangshan seismic area.
The development and occurrence of earthquakes are controlled by the activity of tectonic systems in an extensive area. As an example, the occurrence of the 1976 Tangshan earthquake was basically consistent with the activity of the tectonic systems in North China.

1. Relationship Between Regional Tectonic Systems and Earthquake

The regional tectonic structure in North China is quite complicated. The basic tectonic framework in this region consists of three major tectonic systems, namely, the Yinshan latitudinal tectonic system, the reflecting arc of the east wing of the Qilu-Helan ε-shaped tectonic system, and the NNE Neocathaysian system (Fig. 1). These tectonic systems were formed in the Yanshan movement or earlier. Tectonic activities in the latest geological era and the recent era are based on past activities of the above-mentioned systems and are the neogenic activities of the existing tectonic structure reformed under the new regional tectonic stress field.

The Neocathaysian tectonic system is the most important active system in the east part of China, formed mainly by a series of NNE upheavals and downwarps and their accompanying large-size fault belts. In the north part of North China the chief components of the Neocathaysian system are (from west to east): the Shanxi ζ-shaped basin, the Taihan mountain uplift, the Jizhong subsidence, the Chanxian uplift, the Huanghua subsidence and the Taihan piedmont fault belt, the Chandong fault belt, and the Tanlu fault belt, etc. This tectonic system was formed at the end of the Mesozoic approximately, and it controlled the Cenozoic and the Mesozoic sedimentary facies and paleogeography in North China, and had been very active since the Cenozoic era. The maximum height of depression in the subsidence zone (Huanghua subsidence, Qikou area) is 8000 m, while at the top of the uplift zone, or at the direct outcrop of base rock on the ground surface, the Cenozoic strata can be as thin as 0-300 m, showing the evidence of strong differential movement. Geodetic measurements in the last twenty years show that the latest tectonic movements also reflect the activity characteristics of the Neocathaysian structure, i.e. the uplift zone raises and the subsidence zone depresses continuously. The dominant orientation of the major axis of the secondary structure in its uplift and subsidence is NNE. Figure 2 gives the vertical displacements of some major fault belts in North China obtained from the long-term measurement. This shows that some NNE faults were extremely active in the last 20 years. For instance, in the period 1969-1975, the total amount of vertical displacements in the Changzhou segment of the Changdong fault was 79 mm, and the average annual rate was greater than 10 mm.

The seismicity in North China is consistent with the Neocathaysian strong activity. It can be seen in Fig. 1 that the epicenters of the earthquakes which occurred after 1815, the beginning of

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the fourth seismic active period especially those in 1966-1976, such as the Xingtai, the Hejian, the Bohai, the Haicheng, the Helinger and the Tangshan earthquakes, were all located along the NNE active tectonic zone. The seismogenic tectonics of these earthquakes are either NNE major faults or their associated components, indicating that the recent seismicities in North China resulted from the strong movements of the NNE structures. Moreover, the focal mechanism solution, orientation of the major axis of the meizoseimal area, strike of the seismic crack belt and distribution of aftershocks in space, etc., all were governed by the NNE tectonic structure (Zhu Q.Z., see this chapter).

Based on the geological and seismic data, it should be pointed out that the movement of the Neocathaysian system which was formed in the Mesozoic has changed from left-lateral in the Geochronic era to right-lateral shear at present. Thus, it can be inferred that the orientation of the normal compressive stress in the tectonic stress field of North China would be east-west approximately. This can be proved by the pattern of seismic faulting and in-situ earth stress measurements (Fig. 3).

The Yinshan latitudinal tectonic system mainly consists of close folds and thrust faults formed by ancient metamorphic rocks, the Sinian and part of the Paleozoic and Mesozoic strata. In the north part of North China this tectonic system suffered from multiple strong movements and had been disturbed by other tectonic systems. Geological data show that neotectonic activities along this latitudinal structural system were also obvious. The Yinshan and the Yanshan areas had uplifted over a long time, forming the present Yinshan and Yanshan mountains, while the south border of the system adjacent to these mountains had suffered a strong subsidence in the Cenozoic. In the Laoting subsidence for example, the Cenozoic sediment is as thick as 2200-3800 m. Connecting and intercepting features of the latitudinal tectonic zone with the NNE active tectonic zones can be seen generally in this area. The Yinshan tectonic system either prevented the development of the NNE active zones or was cut by them. It seems that the effect of the existence and activity of the system on the seismicity of North China may be twofold. Firstly, when the NNE active tectonic zones were intercepted by the latitudinal tectonic system, the system would "prevent" or "lock" the development of the NNE tectonic zones, thus leading to stress accumulation in the connecting area. Secondly, the activity of the latitudinal tectonic system would also cause an increase of activity in the NNE tectonic zones, and accelerate the rupture in the seismogenic process. Complexity of the seismicity in North China is due to the characteristics of this tectonic system. For example, in the 1976 Tangshan earthquake strike-slip the reverse faulting and normal faulting were all included.

In general, recent earthquakes in North China were controlled by the Neocathaysian structures, and the existence of the latitudinal structures would be an important condition for the development and occurrence of earthquakes. This is the local tectonic background for the 1976 Tangshan earthquake, and, in a certain period in the future, seismicity in North China will follow this pattern.

2. Special tectonic conditions for the Tangshan earthquake

Based on the above studies, the recent earthquakes in North China mainly occurred in the compound area of the NNE active tectonic belts and the latitudinal tectonic system. The 1976 Tangshan earthquake did occur in such an area.
(1) Major faults in the tectonic compound area and their activity

The Tangshan seismic region was located in the compound area of the south flank of the Malangyu composite anticline in the Yinshan fold belt of the latitudinal tectonic system and the Tangshan fold belt of the NNE structure adjacent the Yinshan range in the north and the Jidong plain in the south (Fig. 4). The Tangshan earthquake resulted from the inter-restraint and interaction of these two active belts.

In the seismic region the EW faults and folds of different sizes were developed in the Paleozoic strata and those before Paleozoic. They were extremely active since the Cenozoic and Mesozoic eras. Of the large-size fault belts, the greatest are the Baodi-Changli fault belt and the Shaheyi fault belt.

(i) The Baodi-Changli fault belt

It is located at the south border of the Baodi-Tangshan uplift fully covered by Quaternary sediments. It can be seen from the Bouguer gravity anomaly map (Fig. 5) that there exists an EW gravity gradient zone from Baodi to the south of Changli with a length of about 260 km. It can be proved by the artificially induced ground motion measurement and boring data that the above zone is an EW fault belt, dipping to the south. The fault belt deepens to the Moho surface, with the upper portion as a normal fault and the lower-portion as a reverse fault (relative uplift between the south wall and the north wall of Moho is 3 km). The fault belt is of a large-size, controlling the development of its two sides. The differential movement of the fault is apparent, and the maximum difference of the Cenozoic sedimentary thickness on the two sides is more than 5,000 m. Due to the activity of the fault, the north coastline of the Bohai Sea shifted gradually to the south since the Neolithic Age, and the average annual shifting rate increased from 12.5 m to 20-60 m/year in the recent 5000 years, based on an approximate calculation. Repeated geodetic measurements in 1952-1972 show that the differential movement on the two sides of the fault was obvious, with the north side uplifting, and the south depressing continuously.

(ii) The Shaheyi fault belt

The belt starts from south of Fengrun extending eastward through Zengzizhen and Shaheyi to the east of Yejituo with a general strike of NEE-EW, its length is about 40 km and most parts are covered by Quaternary sediments. It controls the development of the Paleozoic strata. North of the belt is the deepest Sinian system, while in the south, Paleozoic strata mainly exist. On the Taipingzhuang-Shaheyi segment a compressed rupture zone of 1 km wide is exposed. On the north border of the zone there is a fault striking N 80W, while on the south border another compression fault dipping south-west occurs with the Jingeryi group covered inadvertently on the Wumishan group. The Archaean group of the fault on the south border is of a reverse thrust feature upon the Dahongyi group of the Sinian system, and it is of a compressional feature. However, it should be noted that these tectonic evidences were formed during the Yanshan movement. Because the present-day tectonic stress field has changed, the nature of this rupture zone should have changed as well. According to the geomorphic features of the zone, it can be inferred that the present activity of this rupture zone is probably extensional.
Besides the above two EW fault belts in the seismic region, there are also other latitudinal faults in the vicinity in the south, such as in Hangu, Zhangzhuangzi, and Paigezhuang, etc., but they are rather small in size and much less active. However, in the area between Tangshan and Fengnan, no latitudinal faults of large-size are found, based on different information.

The NNE tectonic zone was formed and developed on the background of the south wing of the Malanyu composite anticline at the end of the Mesozoic. Under the NS normal stress, this zone crossed and transected the latitudinal tectonic line as shown in Fig. 4. But, as the recent tectonic stress field changed, the neo-activity of the NNE tectonic zone showed dextral translation. The main components of this zone are: the Tangshan fold-fault belt, the Balizhuang fault belt and the Luanxian fault belt as well as some associated NNW twisted faults. Since the Cenozoic these components were extremely active, controlling the sedimentary thickness and forming the NNE narrow subsident zone or concentrated gravity gradient zone (Fig. 6).

The Tangshan fold-fault belt consists of the NNE Fengnan anticline, the Kaiping syncline and the Tangshan fault belt lying between them. The Balizhuang fault belt extending west of the Tangshan fold-fault belt is located between the Fengtai anticline and the Wuologu syncline. Seismo-exploration data show that it is a deep-seated fault ruptured down to the Moho discontinuity. The Luanxian fault belt extending east of the Tangshan fold-fault belt consists mainly of three compression-torsion faults striking N15-20°E with a width of 20 km, namely, the Bijiadian-Fangezhuang fault, the Shangang-Leizhuang fault and the Lulong-Luanxian fault. The NNW torsional faults distribute mainly in the mountain area north of the Tangshan fold-fault and the south segment of the Luanxian fault. The faults are usually 15 km in length approximately, striking N10-20W with a smaller dislocation and the fractured surface is generally smooth and vertical. This group of faults twist the NE and NNE tectonic lines anticlockwise.

The macroscopic epicenter of the M=7.8 Tangshan earthquake was located in the Tangshan fault belt, which consisted of a series of NNE reverse faults in the south-east wing of the Fengnan anticline and north-west wing of the Kaiping syncline. In the upper crust, this fault belt can be divided into two branches, the west and the east branch. The west branch includes compressional faults with a high dip angle, such as the N25-30°E Douhe fault and the east and west Fenghuangshan faults. Compressional lens and mylonite can be seen in the bedrock outcrop area in the north segment of the Douhe fault. The strata on the two sides of the west branch are vertical and reversed. The Cenozoic isopach where the fault passes through is a concentrated gradient belt with a Cenozoic sedimentary "trough" 370 m in depth. The geomorphology on the two banks of the Douhe River differs extremely. On the east bank is a planation surface 200-300 m high above the sea level; on the west bank is a piedmont plain with a drop of 150-200 m. The east branch begins from Weishan mountain in the north and ends at Anjizai in the south, passing through Majiagou and the urban area of Tangshan. It consists of a series of NNE faults, an en echelon with a strike of N25-20°E. According to exploration data, the fault belt consists of five or more faults, among which the Lixianzhuang Steel Plant fault and the Anjizai-Xinlizhuang fault are of large-size. Based on the boring data the vertical dislocation of the bedrock in the latter is more than 300 m and that in the Quaternary may reach 100-150 m. Geodetic data also demonstrate that the west side of the fault dropped continuously for 70 mm relative to the east side during 1968-1975, but from 1975, after the Tangshan earthquake the west side uplifted 925.7 mm again (Fig. 7). This kind of differential movement of large amplitude shows that the new activity of the fault is very strong.
According to the available data it is inferred by the authors that the Tangshan fault belt is not an isolated fault in the interior of a block, but is an extension of the Chandong fault belt, a large-size boundary fault in the north. Of course, we do not have sufficient data to prove our inference at present, but much attention should be paid to this problem as it relates to the seismogenic tectonics of the M=7.8 Tangshan earthquake.

The Changdong fault belt is a large-size and extremely active intra-crustal fault belt, developing in the interior of the subsident zone in the North China Plain. The segment of the fault belt south of Ninghe has been well-known but to the north of Ninghe it had no relation with the Tangshan fault belt on previous tectonic maps. It is proved by the recent explosion seismic data that there exists a horst-type Moho convex surface along Ninghe-Tangshan-Fengran, on the two sides of which faults pass through. Elevation of faults on the two sides differs more than 1-2 km (Fig. 8). The fault belt on the west side corresponds to the Balizuang fault belt on the ground surface, while that on the east side to the Tangshan fault belt on the ground surface shows there exists a fault in the deep crust from Ninghe to Fengran passing through Tangshan. This kind of deep fault is rather large in size in the latitudinal direction generally, and it cannot be believed that the fault is only limited to an area of several tens of km in length. Along this deep fault towards the south, the fault on the east side connects with the Changdong fault belt, showing that the Tangshan fault belt may have some relation to the Changdong fault belt in the deep crust. This inference is also proved by the gravity anomaly data and aero-magnetic survey data. Furthermore, on the satellite image there exists an obvious contrast in color from the north of Changxian to Tangshan, reflecting a very clear trace of linear structure. This also shows that the Tangshan fault belt is connected with the Changdong fault belt.

Of course, the size of the Tangshan fault belt exposed on the ground surface is hardly to be compared with the Changdong fault belt. It is inferred that this is because the north segment of the Changdong fault belt is not exposed on the surface, and the Tangshan fault belt is a preliminary pattern of a fault exposed on the ground surface, and it cannot control the formation and development of the fault block yet. Further study will be needed to prove the above inference.

**2) Effect of the main components of the composite tectonic region on the development and occurrence of the Tangshan earthquake**

The above mentioned data shows that the NNE Tangshan fault belt and the latitudinal tectonic zone are the main tectonic components which played the main role in the Tangshan earthquake. Although the patterns of activity of the two components are different, their effects on the development and occurrence of the Tangshan earthquake are unique.

It can be seen from Fig. 4 that the north segment of the NNE Changdong fault belt intersects the latitudinal tectonic zone north of Ninghe and stops in the Tangshan block south of the NW Shaheyi fault belt after passing through Tangshan. Obviously, the activity of the NNE fault belts has to be limited by the latitudinal tectonic zone thus forming a so-called "locked segment". However, it should be noted that for the specified Tangshan region this "locked segment" is not only located at the end of the fault belt but also in the whole compound region of more than 50 km long. It is because the Tangshan earthquake focal region is located in this special composite tectonic region that the Tangshan earthquake did not occur at the intersection point of the faults or at the end of the faults but occurred in the middle of the "blocked segment" (just
25 km from the two ends of the segment approximately), i.e. between Tangshan and Fengran. As to whether rupture occurs first in the middle of the "locked segment" and then an earthquake will be induced, or whether there are other seismogenic factors, further investigation and study needed.

The recent activity of the latitudinal tectonic zone reveals that the zone not only suppressed the activity of the NNE structural zone, but also accelerated and enhanced stress accumulation in the "locked segment" owing to its activity. Crustal deformation data show that before the Tangshan earthquake, from the beginning of 1975, the EW zero baseline has been moving southward, reflecting the latitudinal Yinshan tectonic zone extending outward under the action of the nearly EW normal stress, and showing the characteristics of recent activity in the south slope of Yanshan mountain. The recent activity of the EW faults also shows the tendency of this movement. Most of the rupture surfaces of the EW main faults incline southward, and, in the recent activity, the south wall of the fault depresses, thus a relative subsidence zone or strongly warped subsidence occurs. Therefore, a gradually decreasing terrace structure from the north mountainous land to the south plain in the Tangshan area appears. Such movement will certainly produce a thrusting force from north to south. The overall thrust to the south acts on the NNE tectonic fracture and has a tendency of developing northward, thus, it is possible to accelerate and enhance stress accumulation in the "locked segment".

The existence of the Tangshan fault belt and its activity is the direct effecting factors for the development and occurrence of the Tangshan earthquake. But, as we mentioned before, the activity of the Tangshan fault belt was not isolated. It was constrained by the activity of the Changdong fault belt so the fact that the intensity of the Tangshan earthquake was underestimated previously is probably due to the fact that activity of the Tangshan fault belt was considered to be isolated.

It is shown by the historic data that the Changdong fault belt is one of the main active fault belts in North China, in which a series of earthquakes of M=3.5-6 occurred in the past (Table 1). Some of the earthquakes occurred in the south and middle of the belt, others occurred in the composite tectonic region in the north. For more than ten years after the 1966 Xingtai earthquake the seismicity in North China had a tendency of migrating from south to north. In the discussion on the seismic risk in Hebei Province it was believed by the geologists in the Provincial Seismology Bureau that the location for the end of the migration is situated in the compound area of the Taihanshan piedmont fault belt and north end of the Changdong fault belt as well as the Yanshan tectonic zone. Before the Tangshan earthquake the creep of the Changdong fault belt accelerated, as discussed in many papers in detail before. The seismic precursors which occurred frequently in large areas, also prove the above fact. For example, oil was blown intermittently several times from the Wan No. III waste oil well in the vicinity of the main branch of the Changdong fault belt before the Tangshan earthquake, showing the fault had crept intermittently. The segment of the Changdong fault belt most favorable for stress concentration and release before the Tangshan earthquake was the Tangshan fault belt in the north, where the end of the great shell-shape fault and the special compound area of the EW tectonic zones were situated. Therefore, the occurrence of the Tangshan earthquake resulted from activity on the Changdong fault belt, based on a macroscopic point of view. However, the causative fault was its north extension part, i.e. the Tangshan fault belt.
(3) Verification of the causative fault

A lot of information on the relationship between earthquake and geological structure was obtained in the Tangshan earthquake. Such information can be used to verify further the estimated causative fault.

The epicentral intensity of the Tangshan earthquake is XI. The major axis orientation of both intensity X and XI regions is NNE, and the ratio of the major axis to minor axis is 3:1. The orientation of the major axis of the isoseismals is inconsistent with that of the estimated causative fault. The major axis orientation of lower intensity IX, VIII regions, etc. gradually changes from NE to EW approximately, showing the effect of main tectonic movement components in the composite tectonic region.

After the Tangshan earthquake thousands of aftershocks, whether large or small, occurred continuously before the largest Luanxian aftershock of M=7.1. The direction of the aftershock distribution agreed with that of the Tangshan fault belt very well. This also proves the Tangshan fault belt was the causative fault. After the main shock the variation of the crustal stress also occurred along this fault. The related parameters of focal mechanism solution also reveal that the activity of the causative fault is mainly a horizontal dextral torsion (right lateral) movement.

The well-known seismic ground crack zone from Sheng-li Road to Wangmatai in Tangshan city also verifies the existence and activity of the causative fault. The whole length of the ground crack zone is 11 km with a strike N30°E consisting of a series of N40-80°E cracks en echelon (see Chapter 3). The direction of the zone is very apparent and it extends continuously passing through the epicentral region of the main shock, and its location is consistent basically with each branch of the Tangshan fault belt geographically.

In summary, the Tangshan earthquake of M=7.8 occurred in a compound area between the active NNE tectonic zone and the EW tectonic zone in the recent geological era. The activity of the NNE tectonic zone was suppressed by the EW tectonic zone forming the so-called "locked segment" in which strain energy was accumulated gradually under the action of the NW normal stress, and then forming the source of the event. As the crustal stress exceeded the resistance of rock, the "locked segment" broke so the existing Tangshan fault belt ruptured suddenly, leading to the occurrence of the quake.

(Translator :Meng Xianliang, Lu Rongjian)
Table 1. Earthquakes occurred in the Changdong fault belt and its north composite area

<table>
<thead>
<tr>
<th>No.</th>
<th>Date</th>
<th>Location</th>
<th>Lat.</th>
<th>Long.</th>
<th>Epicentral Intensity</th>
<th>Magnitude</th>
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<tbody>
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<td>1</td>
<td>1068.8.14</td>
<td>Changxian</td>
<td>38.5°</td>
<td>116.1°</td>
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1. Latitudinal tectonic zone
2. Neocathaysian tectonic zone
3. Qilianshan-Luliangshan tectonic system
4. $\varepsilon$-type tectonic structure
5. Bohai rotational shear structure
6. Faults
7. Main active faults
8. Folds
9. Geosyncline
10. Subsidence
11. Uplifting
12. $M \geq 6.0$ Earthquake epicenters
13. $M \geq 7.0$ Earthquake epicenters
14. $M \geq 8.0$ Earthquake epicenters

(shaded circles-epicenters of earthquakes occurred after 1815 A.D.; blank circles-epicenters of earthquakes occurred before 1815 A.D.)

Figure 1. Tectonic systems and distribution of epicenters in North China.
Figure 2. Recent vertical crustal deformation in North China.
Legend:
1. Causative faults solved by the primary P-Wave and their movement characteristics
2. Measured maximum (horizontal) normal stress value and its direction stress field
3. Inferred maximum normal stress direction in the regional tectonic stress field

Figure 3. Main seismic faulting and measurement of absolute crustal stress values in North China.
Figure 4. Geological structure of Tangshan region.
Figure 5. Bouguer anomaly of gravity in Tianjin-Tangshan region (m/gal).

Figure 6. Cenozoic sedimentary thickness contour of Tangshan region (in m) (after No. 1 Coal Mine Exploration Brigade, Hebei Province).
Figure 7. Re-leveling across the Anjizhai-Xinglizhuang fault.

Figure 8. Geophysical exploration profiles across Tangshan.
THE CRUSTAL DEFORMATION ASSOCIATED WITH THE TANGSHAN EARTHQUAKE

Xie Juemin*

Crustal deformation is one of the geophysical phenomena accompanying every earthquake. The crustal deformation before and after a great earthquake can be represented by its vertical and horizontal components. Large amounts of geodetic data were collected in the Tangshan area before and after the earthquake of 1976. Based on these data, the crustal deformation in an extensive area around the epicenter and its characteristics are discussed in this paper.

I. Horizontal Crustal Deformation

(1) Horizontal deformation measurements and data processing

Before and after the Tangshan earthquake of 1976 three re-surveyings were performed in this area: (1) a triangulation measurement made before 1960; (2) a trilateration measurement by use of a microwave distance meter in 1971; and (3) a post-seismic horizontal deformation measurement by use of a microwave distance meter, carried out from September 1976 to November 1976 just after the Tangshan earthquake. Most of the stations in these three re-measurements were the same, thus providing valuable data for the study of the horizontal deformation before and after the earthquake.

The accuracy of the triangulation measurement before 1960 was quite low (the relative accuracy of these measurements was about 9x10^-6). Based on the results of the measurement it is impossible to judge from these data if there were horizontal deformations before the earthquake.

The two measurements in 1971 and 1976 were carried out with the same microwave distance meter of Type DI50. In 1971, 70 sites at 32 stations were measured. After the earthquake, because some stations were damaged and could not be used, the re-measuring trilateration network in 1976 was slightly different from that in 1971, i.e. only 53 sites at 28 stations were measured. The range of surveying can be seen in Figure 1. Among the 28 common stations at which measurements were made both in 1971 and 1976, we have selected 25 stations that can be used to calculate coordinates for the study of the horizontal deformation before and after the earthquake. Since the "Gaoshan" Station (No 21) had slipped southward due to the influence of quarrying, the data obtained in this station were used for reference only. Therefore, there are only 24 stations with available data. These stations are approximately uniformly distributed along the two sides of the Tangshan fault.

In the analysis of horizontal deformation, a "fixed station" where no variation of deformation occurred during these re-measuring intervals, should be chosen so as to compare the coordinates of different measurements and to calculate the horizontal crustal deformation. In practice, it is difficult to determine an actual "fixed station" in the region where great deformation has occurred after an earthquake. As a general rule the post-seismic deformation is larger near the

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epicenter and attenuates along the two sides of the fault symmetrically. Considering that the
trilateration network before and after the Tangshan earthquake was approximately uniformly
distributed on the two sides of the seismic fault, the "gravity center" of this network could be
considered unchanged and the displacements at all stations of the network measured in 1976
were the deformations caused by the quake (by the generalized inverse matrix difference
correction method with no fixed station in the network). This processing method is more
consistent with the actual case of post-seismic deformation than the method in which a "fixed
station" is chosen.

In the course of calculating the data of each measurement, the two correction methods —
generalized inverse matrix correction method and classic correction method — have no dif-
fERENCE in the distribution of errors. In both cases the measuring errors in the network can be
distributed most reasonably, and the sum of the squares of the corrections can be minimized.
With the correction of the generalized inverse matrix, the measurement network in 1976 is most
suitably fitted to that in 1971, and the sum of the squares of the vectors of the latter corre-
spending to the former is minimized, i.e. the gravity centers of the two networks were
unchanged. In the corrected displacements no effect of the primary data errors and their inferred
errors induced by the unproper selection of the "fixed station" will occur. Thus, post-seismic
horizontal deformation data consistent with the calculations will be obtained.

(2) Horizontal crustal deformation induced by the Tangshan earthquake

Large-scale horizontal crustal deformation was induced by the Tangshan Earthquake. The
landform and ground surface damage in the meizoseismal area showed the result of severe
horizontal movement. From the geodetic data it can be found that after the earthquake the
stations had obviously shifted when compared to those in 1971. In the epicentral region the
change of the sides, such as in Zhangzhuangzhi-Dafenggezhuang and Zhangzhuangzhi-Jianzigu
was most prominent. The former was shortened 1.955 m and the latter was elongated 2.673 m,
which showed severe right-lateral movement of the two faces of the fault. This is the main
characteristic of the post-seismic horizontal deformation.

After adjusting the two measurements in 1971 and 1976 by use of the generalized inverse
matrix correction method the calculated variances of observations with unit weight are
\( \sigma^2_{\text{71}} = 66.87 \text{ cm}^2 \) and \( \sigma^2_{\text{76}} = 12.58 \text{ cm}^2 \), respectively. Table 1 shows the change of coordinates
of each station before and after the Tangshan earthquake after the correction. In Table 1 \( X \) is the
NS axis, \( \Delta x > 0 \) means the station moves towards the north; \( y \) is the EW axis, \( \Delta y > 0 \) means the
station moves towards the east; and \( (\Delta x^2 + \Delta y^2)^{1/2} \) is the resultant displacement of the station.
From Table 1 it can be seen that there are some stations except the "Gaoshan" Station with
horizontal displacement over 2 m.

Based on Table 1 the displacement vector of each station can be drawn as shown in Figure 2.
The error ellipses of displacements are also shown in Figure 2. The length of the semi-major
axis and semi-minor axis of ellipses equals twice the original length. Based on the displacements
in Table 1 and Figure 2 and the vertical distance of each station to the fault, we can get the
component of displacement along the fault strike at each station; from the result of spectral
analysis of seismic waves, the fault strike is N30°E, (see Figure 3). Figure 3 shows the elastic
rebound and the right-lateral dislocation of the fault during the earthquake. At the same time it
also implies that on the north-west side of the fault the attenuation of the horizontal deformation is quicker than that on the opposite side.

From Figures 2 and 3 some distinct characteristics of the horizontal deformation after the Tangshan earthquake can be seen.

1) The horizontal deformation induced by the Tangshan earthquake is quite prominent. The horizontal displacements at most stations were two times greater than the calculated errors. Their distribution shows a close relationship between the deformation and the occurrence of the earthquake.

2) The amplitude of the horizontal displacement of each station decreases with the increase of the distance from the station to the fault. The range of deformation is possibly beyond the Tangshan subsidence block, a third order tectonic unit.

3) The orientation of the horizontal deformation shows an obvious right-lateral movement along the two sides of the seismic fault. The extension movement is not notable.

4) The post-seismic horizontal deformation is mainly induced by both the main shock of M7.8 and the aftershock of M7.1. Judging by the distribution of the deformation amplitude, the horizontal deformation is mainly controlled by the main shock of M7.8. The influence of the aftershock of M7.1 on the deformation pattern is not significant. The reason for this is probably that the M7.1 shock occurred at the east side of the measuring region, and its seismic energy was much less than that of the main shock.

II. Vertical Crustal Deformation

(1) Precise leveling measurement and data processing

From 1954 to 1975, one year before the Tangshan earthquake, 11 leveling measurements were made in the Tangshan area. All leveling was performed according to the specifications for first-order leveling. The surveying lines were not exactly the same for all these measurements but they all included the Tianjin-Tangshan-Shanhaiguan line which runs across the epicentral region of the great earthquake. After the earthquake, from September 1976 to January 1977, an overall post-seismic re-leveling was made in this region. Thus, the vertical deformation data before and after the earthquake were both obtained. The Tangshan leveling network is part of the North China leveling network. For the sake of analyzing conveniently the vertical deformation before and after the earthquake, locations within the region of intensity VII were used for obtaining data. The selected regions include Baodi, Zunhua and Changli north of the Bohai Gulf, the area of which is about 200 km in length and 150 km in width. The leveling lines run across the main faults and structures in the Tangshan area. Figure 4 shows the details of the re-leveling network.

Similar to the horizontal deformation analysis, we must choose a "fixed station" as correctly as possible so as to determine the vertical crustal deformation before and after the earthquake. From past experience it is well-known that a change of benchmark is influenced by underground water and other factors. The influence is especially significant in the plain area with a thick overburden layer. Thus, it is difficult to find a "fixed station". Considering that all re-leveling networks in the Tangshan region were distributed symmetrically around the epicenter, and from
preliminary analysis, the relative change between all the re-measurements before the earthquake were relatively small (less than 50 mm). It can be assumed that during the period from 1954 to 1975 the variation of the elevation reflected the crustal elastic deformation caused by the seismogenic stress field and the gravity center of the whole leveling network would not have moved up or down at all. Then the gravity center used as the "fixed station" for comparing the changes between the re-levelings measured before and after the quake can be considered more reasonable. For this reason, we have the corrections of conditional observations for all measurements made during the period from 1954 to 1975, then we reduced all corrected results to the mean elevation plane in 1969. Thus, the same results can be obtained as those in the generalized inverse matrix correction.

The deformation of several uplift and subsidence regions occurred after the Tangshan earthquake. It shows that the gravity center of the network had already subsided during the earthquake so that the overall vertical deformation cannot represent the elastic deformation caused by the earthquake. Preliminary analysis also shows that the deformation was quite small in the Jixian-Qianan and Fengrun-Zunhua areas north of the Tangshan region. The local blocks were relatively stable. This may be associated with the thin overburden of this hilly area and the comparatively stable geological structure. Thus, in the processing of the data collected from 1975 and 1976 an adjustment of conditional observations was carried out for the two measurements separately. Based on the assumption that the average elevation of all the nodes in the two leveling loops, A and B (Fig. 4), did not change during the interval of the two measurements, the elevation change of other loops before and after the earthquake is calculated. This assumption is more reliable than that for a "fixed station", thus reducing the inelastic deformation included in the post-seismic deformation.

(2) Vertical crustal deformation before and after the Tangshan earthquake

From 1954 to 1975 there were two regions (Region C and Region D in Fig. 4) where vertical deformations were relatively large. They were located in the south-west part of the whole monitoring area.

Region C includes the areas of Ninghe (Lutai), Panzhuang, Hangu and Tianjin. The change of vertical deformation in this region before 1970 was not significant. The relative annual change of deformation was within 20 mm. After 1970 subsidence generally occurred in this region and after 1972 there was a tendency to increase the subsidence annually. The subsidence possibly reflects the local tectonic movement due to the gradual increase of the ground stress before the earthquake. In this region a great amount of underground water was pumped up for industrial use at that time. After 1970 the underground water level decreased annually, forming an underground water funnel. Related studies in this respect shows that in areas with relatively large deformation the duration and amplitude of the deformation are in accord with the change of the underground water level. The subsidence regions are consistent basically with the distribution of the underground water funnels. For this reason the subsidence in this region before 1974 cannot be considered as the crustal deformation induced by the earthquake. In 1975 the underground water level in this region was relatively steady but medium-term abnormal deformation was measured at some stations around this region. The vertical deformation change near the epicenter of the Tangshan earthquake was relatively low during this period. The relative
annual deformation gradients were quite small. Therefore, it is impossible to obtain quantitative precursor information from these data.

Region D includes the vicinity of Tangshan city and its southwest area. The change of uplift was not significant in this region during the period from 1954 to 1959, and after 1959 the uplift increased annually forming an upwarped area. Around 1969 the total amount of uplift had exceeded 30 mm (Fig. 5). After 1970 the region began subsiding but until the occurrence of the earthquake the change of subsidence was not remarkable. So, the above-mentioned upwarping process was probably the precursor caused by the seismic stress field.

The local conditions in the epicentral region were rather complicated. Coal mining and the use of underground water might influence the deformation. The change of two benchmarks, "Shanjin 25" and "Shanjin 26", showed that in 1970 the epicentral region was still uplifting, which might be the further development of the uplift shown in Figure 5 (see Fig. 7). But from benchmark "2052" we can see that this benchmark subsided significantly from 1969 to the occurrence of the earthquake. The above-mentioned three benchmarks were located on both sides of the seismic fault. Their change possibly implies that a fault creep might have occurred to some extent before the earthquake. But it should be noted that in the period from 1970 to 1975, when benchmark "2052" changed greatly, there was a group of wells pumping underground water, thus forming a local underground water funnel. This might be the primary cause for the subsiding of benchmark "2052". Based on investigation, there were also some other influencing factors near benchmark "Shanjin 26". Therefore, the data are not sufficient to prove the above change was the result of the fault creep.

In the analysis of the vertical deformation data before the earthquake the following should be noted:

1) Before the Tangshan earthquake there was an abnormal process of vertical deformation but the abnormal deformation region did not coincide with the epicenter. The epicenter is northeast of the upwarped region.

2) The abnormal upwarping before the earthquake was the further development of the historic uplift in this area. There is evidence which shows that the present coastline of the Bohai Bay in the north has shifted about 20 km southward as compared with that measured in 1820 (Qing Dynasty), see Fig. 9. Based on preliminary studies this phenomenon is not relevant to the deposit from Luanhe, or to the sea regression, but may be the result of crustal uplift movement in the Tangshan area in the recent hundred years or more. Thus, as to the crustal upwarping before the Tangshan earthquake, its long-term background can be traced back to about 150 years ago.

3) During the period from 1971 to 1975 before the Tangshan earthquake the vertical crustal deformation was in a relatively quiescent period. This would probably indicate that this region was locked for several years just before the Tangshan earthquake. It was also an important characteristic of the vertical deformation before the earthquake.

The vertical crustal deformation in an extensive area and of large amplitude was induced by the Tangshan earthquake. Generally speaking, the local or macroscopic damage of the ground surface is also a kind of crustal deformation but the geodetic measurement is mainly used to
study the characteristics of the deep crustal deformation in an extensive area. Based on the calculated data from the geodetic measurements the variation of vertical crustal movement induced by the earthquake was over 1 m.

The vertical crustal deformation induced by an earthquake includes crustal block deformation and fault fracture due to the release of strain energy. In some segments the latter is dominant. The post-seismic changes of elevation of some leveling lines across or near the fault are relatively large, which indicates that apparent fault fracture occurred during the quake (see Fig. 8).

In the epicentral region the southeast side of the seismic fault subsided as compared with the northwest side. The benchmarks located in the urban and suburban areas of Tangshan reflected the characteristic of this fault movement. Benchmarks "Shanjin 26", "III71" and "2051", etc. subsided greatly, while benchmarks "Shanjin 25-1" and "2052", however, uplifted remarkably. From the change of these benchmarks the fault strike can be approximately estimated (Fig. 7).

Figure 9 is the vertical crustal deformation contour map from 1975 to 1976 (before and after the earthquake), which shows that in a large area the vertical deformation induced by the earthquake was much larger than the error which would occur in surveying and calculation. The overall tendency of the deformation in Fig. 9 is basically in accord with the change of the benchmarks in the epicentral region, that is, the uplift region is in the northwest side of the fault and the subsidence region is in the southeast side. The deformation in the subsidence region is much larger than in the uplift region both in extent or in amplitude. The deformation decreased slowly along the extending direction of the main tectonic zone (in the strike of the fault), but rapidly in the direction perpendicular to the tectonic zone (the fault) in this area. Thus, the deformed area distributes in a long narrow belt in northeast direction.

The uplift region northwest of Tangshan is an upwarping of an ellipse-shape, with a NE strike and the direction of the major axis is N40°E. The maximum uplift of 208 mm in amplitude is in the southern part of the uplift region (Fig. 9).

There are three main subsidence regions located respectively in the northeast of Ninghe, southeast of Tangshan and Leizhuang (west of Luanxian). The centers of these regions coincide approximately with the epicenters of the earthquakes of M7.8, M7.1 and M6.9, respectively. The maximum subsidence amplitudes were 1521 mm, 718 mm and 1024 mm. The whole subsidence zone extends in a NE direction. The major axes of all subsidence regions are also approximately in a NE direction. The pattern of deformation contours is similar to that of isoseismals, which indicates that both are controlled by the local tectonics.

The uplift region northwest of Tangshan is not symmetric with a smooth uplift in the northwest wing and a steep uplift in the southeast wing; the subsidence region southeast of Tangshan is not symmetric either with a steep subsidence in the northwest wing and a smooth subsidence in the southeast wing. Thus, a severe crustal deformation slope was formed at the junction of the uplift region and the subsidence region showing obvious fault fracture. The total strike of the slope is N50°E, which is consistent with that of the ground fissures in the epicentral region and the distribution of aftershocks. In view of the geologic tectonics the epicentral area is located in the NW wing of the NE Kaiping syncline, which had suffered severe deformation and reversion due to strong tectonic movement, causing a group of fractures cutting the NW wing. It
is also the location with maximum post-seismic deformation. The Zunhua-Fengran-Zhengjiawan leveling baseline passes through the Kaiping syncline perpendicularly. The profile of difference of elevations along the line in 1975-1976 (Fig. 10) shows the vertical dislocation between the two sides of the seismic fault.

The crustal deformation and the damage to ground surface are related but they differ in extent. Both of them have some influence on the distribution of the earthquake damage. What Fig. 9 shows is only the overall pattern of pre-seismic and post-seismic vertical deformation. Actually, in both of the uplift and subsidence regions there are some benchmarks, the deformations of which were different from those in the corresponding region generally. They may reflect only the local and shallow surface layer deformation in the vicinity of these benchmarks. For example, the post-seismic subsidence near Loting was about 50 mm, that of benchmark "Huangcheng 3-4" (east of Loting) was 184 mm, and that of "Changluan 14" (north of Loting) 134 mm, but that of "Changluan 13" was 50 mm uplifting, contrary to the above three benchmarks. Their changes were quite different from each other. From the investigation of seismic intensity it is found that in the neighborhood of Loting there is a small area of intensity VIII within the area of intensity VII. Judged by geologic tectonics the vicinity of Loting was cut by several nearly vertical faults. The tectonic structure was quite particular and sand spouts occurred everywhere. Therefore, the abnormality of deformation and seismic intensity were probably induced by these particular geologic and geomorphic conditions, which reflected the influence of the site conditions in different respects. Besides Loting there are other places where similar conditions exist. The damage to some typical benchmarks is listed in Table 2. Most of the benchmarks subsided and a large amount of them are located in the coastal plain where the overburden layer is thick and the underground water level is high. The change of some individual benchmarks which was quite different from those in the corresponding region can not be considered generally as the deformation in the deep crust.

Reference


(Translator: Xie Juemin)
Table 1. The Horizontal Displacements of Trilateration Stations Before and After the Tangshan Earthquake

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Figure 1. The trilateration networks measured in 1971 and 1976 in the Tangshan area.

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GEOMORPHOLOGIC CHARACTERISTICS IN THE
BEIJING-TIANJIN-TANGSHAN AREA AND THEIR
RELATION WITH TECTONIC ACTIVITY

Xing Jiaming and Zou Baoshan*

The Beijing-Tianjin-Tangshan area is located in the north part of the North China plain with Yanshan Mountain to the north and Bohai Sea to the southeast. The whole area inclines from the northwest to the southeast. The block-faulting effect of Yanshan Mountain is remarkable, its elevation is generally 1000 to 1500 m, only a few peaks are above 2000 m. The height of the mountain gradually decreases from northwest to southeast. In front of the mountain there are hills which are generally lower than 500 m above sea level; in the interior of Yanshan Mountain there are some subsidence basins. The vast plain to the south of Yanshan Mountain is the fault-subsidence region of the Cenozoic era, its surface is covered with Quaternary sediments. The topography of this plain is flat and its elevation is less than 100 m above sea level. The elevation of the lowland along the seashore is less than 5 m. There are several rivers which flow through the mountainous land of Yanshan Mountain from the northwest to southeast and finally into the Bohai Sea such as the Yong Ding River, the Chao Bai River, the Ji Canal and the Luan River. Owing to the fact that these rivers do not agree with the tectonic structure in the area to a certain degree, various types of valleys have been formed, accumulating a great deal of silt in the plain and forming the morphology of the recent plain. The coastal zone was immersed under the sea in the mid-Holocene. The plains in the lower reach of the Hai River and the Ji Canal were the west part of the ancient Bohai Gulf. The tectonic movement in the Beijing-Tianjin-Tangshan area is active. Strong earthquakes occurred frequently both in the historical period and in modern time. The landform of this area reflects the tectonic activity in many respects.

I. Basic Characteristics of the Landform

The Beijing-Tianjin-Tangshan area is located at the intersection of the EW tectonic zone and the NE, NNE tectonic zone. Landform in this area was deeply influenced by the fault activities in different directions. The main geomorphologic units of this area are the mountainous lands of Yanshan Mountain and the Beijing-Tianjin-Tangshan Plain. They have been gradually formed by differential tectonic movements since the Mesozoic era. The structural morphology in this era controls the basic landform pattern of the whole area. Although the bedrock was nearly covered with loose Quaternary sediments in the plain where the fault-subsidence movement was dominant in the Cenozoic era, the active fault belts beneath the sediments and each corresponding block are still controlling the sedimentary process and its geomorphologic appearance to a great degree.

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(1) The mountainous land of Yanshan Mountain

1. The main landform characteristics of the mountainous land

Yanshan Mountain spans the North China plain and the Inner Mongolian Plateau, and the strike of the mountain is almost parallel to the west-east direction. Its topography in the northwest part is higher than that in the southeast part, and the whole mountainous land consists of many NE fault-block mounts and fault-subsidence basins. It is because of the different histories of geology and the different characteristics of the structure that each section of the area has its own geomorphology. To the southwest of the area between Chong Li, Chi Cheng and Mi Yun the mountains are comparatively higher, many of them are over 2000 m above sea level. Fault-block mounts and fault-subsidence basins alternatively appear. To the northeast of the area mentioned above is the main part of Yanshan Mountain.

Most of the comparatively high mountainous lands are about 1500 m. Though the mountainous land is affected by the structures of NE, NW and EW directions as well, the difference of fault-block effects is not striking in geomorphology. The landforms along the two sides of the mountain in this section are not symmetric, its NW side is smooth descending to the Inner Mongolian Plateau, the relative difference of height of the topography is generally about 300-500 m; its SE side gradually descends to the Beijing-Tianjin-Tangshan Plain with a great slope. The main and the branch of the Bai River, the Chao River and the Luan River flow almost parallel to the southeast along the topography of this area. The surface cutting is intensified and the entrenched meander in the valley is highly developed. Although the flowing direction of the rivers is approximately southeast, partial sections of the rivers appear in a zigzag manner owing to the effect of the EW or the NE structures. The height of the mountains in the south part of the Great Wall reduces obviously; low mounts, hills which are about 500 m high; broad valleys and basins distribute alternatively. The basins in Mi Yun County, Ji Xian-Zun Hua County and Qian An County are connected by the Beijing-Tianjin-Tangshan Plain directly.

2. The differential processes of the landform in the mountainous land and the tectonic activity

Formation of the mountainous land of Yanshan Mountain is mainly the result of the interaction of endogenetic and exogenic force of landform, but the long-existing active faults have controlled the development of the mountainous land leading to the regional difference of landform. The north and the south portions of Yanshan Mountain respectively belong to the tectonic zones of Yinshan Mountain and Yanshan Mountain. Though their histories of geology are different they were all seriously influenced by the NE and NW structures during the Yanshan Movement in the Mesozoic era, forming a lot of NE fault-block mounts and fault-subsidence basins. In these basins Jurassic and Cretaceous layers were accumulated, and at the same time, some magma movements took place along the fault belts. During the period from the end of the Mesozoic era and the beginning of the Cenozoic era, tectonic movements were relatively smooth and after a long time of erosion the surface was gradually smoothed to be a peneplain. At that time the areas where the present Yanshan-Inner Mongolian Plateau and the north part of the Beijing-Tianjin-Tangshan Plain are located, were peneplains connected with each other basically.

In the period of the Himalayan Movement in the Cenozoic era, as the continuous development of block faulting and structural disintegration took place in the peneplain of the
Paleocene and the peneplain was separated to form the Inner Mongolian Plateau, the Yanshan mountainous land and the North China plain. The undulation of the topography was intensified continuously in the differential movement of the block fault in the Yanshan mountainous land. The variation of landform in the middle period of Tertiary not only developed the wide-spread lava land due to the eruption of basalt near the fault belts in the areas of Zhang Jia Kou and Wei Chang, but also led to the fault-block displacements along many other fault belts. In the NW Zhang Jia Kou-Ning He fault belt and its southeast area, the differential movement of the block fault was comparatively intensive. Here, the thickness of the Cenozoic of the Huai Lai-Yan Qing and Yu Xian fault subsident basins is 1000-2000 m. The block fault mountains in the vicinity of the basins uplifted tremendously. In the uplift process of the block fault the formation of the surface of the Paleocene peneplain was accompanied by large-scale lifting, tilting, and shifting, thus controlling the topography inclining to the southeast and the river systems parallel to each other in a NW-SE direction. Since the Quaternary the block fault movement had been intensified again, the Yanshan mountainous land was further uplifted, the inner subsidence basins sank successively and received several hundred meters of sediments at the same time. With the rising of the mountainous land many meandering rivers were formed. To the south of the line connecting Chi Cheng, Fening Ning and Lung Hua, the main rivers and their branches such as the Bai River, the Chao River, the Luan River, and the Yong Ding River below the Guan Ting became entrenched meanders. Because of the intermittent uplifting and the erosion in the Quaternary, terraces of 4-5 levels generally were developed in the river valley and basin, with the terrace of the second level forming an integrated accumulation surface with the pluvial-alluvial plain on the piedmont. The uplifting of the Yanshan mountainous land led to the change of the river system. The abstraction of the Shan Dian River in the upper reach of the Luan River, the abandonment of the ancient channel from Qian Xi to Feng Run in the middle tract of the Luan River, the rearrangement of the river system of the Yong Ding River in Yan Qing-Huai Lai Basin and the discarding of the ancient valley from Ba Da Ling to the Nan Kou section, all these phenomena reflect the tectonic activity in the Pleistocene.

(2) The Beijing-Tianjin-Tangshan Plain

The Beijing-Tianjin-Tangshan Plain is a fault-subsidence plain, it was formed by the differential tectonic movement since the Tertiary. Under the faulting effect in the NE, NNE, NW and nearly EW direction, the bedrock beneath the plain was cut into many NE-NNE block-fault uplift and depression areas, nearly parallel to each other. They are northwest to southeast, respectively: the west Beijing uplift, the Beijing subsidence, the Da Xing uplift, the Da Chang-Wu Qing subsidence, the Bao Di uplift, the Tangshan subsidence and the Laoting subsidence, with a fault as a boundary. The thickness of the Pleistocene sediments in the subsidence areas is great, and in general, the Tertiary and the Quaternary are comparatively developed indicating that the fault-subsidence movement was relatively strong in these areas since the Tertiary; but the situation of sedimentary in the uplift areas is not exactly the same. They are either lacking of the Mesozoic, and the Tertiary, or the Mesozoic and the Tertiary only appear locally in these areas. This phenomenon shows that they suffered uplift and erosion in the Mesozoic era and the Tertiary to different degrees, but in the Quaternary period because of the acceptance of sediments of different thickness they formed the Beijing-Tianjin-Tangshan Plain with the subsidence areas. Each structural unit mentioned above intercepted with the NW and the nearly EW faults, leading to the sedimentary difference, especially the belt through which the Zhang Jia Kou-Ning He Fault passed, not only influenced the development of geologic morphology of the
Yanshan mountainous land but also influenced that of the Beijing-Tianjin-Bohai Sea region. The underlying NE, NNE tectonic structure in the south part of the Beijing-Tianjin-Tangshan Plain is also restricted by the EW tectonic structure, so that the orientation of the connecting zone with the NNE Ji Zhong subsidence and the Cang Xian uplift in the North China plain is roughly in the direction of EW (Deng Qidong et al., 1980). Though the active fault-blocks buried under the Beijing-Tianjin-Tangshan Plain have no direct relationship with the modern ground surface they also, more or less, reflect the tectonic activity in the combination of regional landforms and the characteristics of the major forces of geomorphology.

The landform of the Beijing-Tianjin-Tangshan Plain was developed by the interaction of rivers, lakes and the epeiric sea during the Quaternary based on the structural subsidence. The main types of landform from the foot of the Yanshan Mountain to the coast of the Bohai Sea basically represent the development process of the plain landform since the end of the late Pleistocene and the beginning of the Holocene. The plain surface accumulated in late Pleistocene has experienced down-cutting erosion in the piedmont areas and a new type of landform has been created in the cut areas. In the areas far away from the foot of the mountain the accumulated surface of late Pleistocene has been covered with later sediments. Especially in the Holocene, because of the changing and blockade of river channels and transgression and regression of sea water, the plain surface has been changed continuously. The Beijing-Tianjin-Tangshan Plain mainly consists of the following types of landform (Fig. 1).

(1) Pluvial-Alluvial Plain. This plain is distributed approximately at the piedmont area of Yanshan Mountain to the north of Da Xing, Xiang He, Bao Di, Feng Nan, and Luan Nan. The surface of the plain is extensively covered with the loess-like sediments of late Pleistocene and bedrock hills are only found along the fault belts at the foot of the mountain, such as the Ba Bao Shan hills west of Beijing, the 20-Li Chang Shan hills near Ping Gu County, and the hills in the area of Luan County. The plain extends to mountainous areas and is connected with the first or the second level of the valley terrace. In many places animal fossils and tree fossils are found in the gravel layer buried below the plain surface for 10-20 m. These animals and trees had lived in the cold climate in the late Pleistocene (Huang Wanpo, 1979). Because of the down-cutting erosion of the Yong Ding River, the Chao Bai River, the Huan Xiang River, the Dou River and the Luan River, a broad flood plain has been formed on both sides of the modern river channel, especially, in the zones between the southeast part of Luan County and Luan Nan County and the southwest part of the lower course of the Luan River, developing a broader embedded alluvial fan-delta plain. At present, the difference of height between the modern flood plain and the pluvial-alluvial plain is 3-5 m, or even 7-8 m. Besides the modern rivers, there are some comparative ancient river channels in the pluvial-alluvial plain, such as the old Qing River channel of the Yong Ding River north of Beijing city and the old Lei Shui River channel south of Beijing city, and the old channel of the Sha River which is to the east of Geoye, Tangshan and the Luan River. On this plain, especially on some flood plains, the sediments are generally of the Xiao Jia He group, the Yin Ge Zhuang group and the Liu Bin Tun group (Chia Lanpo et al., 1977). These sedimentary groups belong to the early, mid, and late Holocene, respectively. Most of the buried Holocene peat layers in the plain before Yanshan Mountain are located on the alluvial plains such as Xiao Jia He, in the west suburb of Beijing in the vicinity of Qing He, in the north suburb of Beijing, Xi Fu of Shun Yi County and Yin Ge Zhuang of Tong Xian County, etc.
(2) **Alluvial Plain.** This plain mainly includes the alluvial fan plain or the alluvial plain formed by the Yong Ding, the Chao Bai and Luan He rivers in the Holocene period. Its location is roughly between the pluvial-alluvial plain in front of the mountain and the coastal plain. The front part of the modern alluvial fan accumulated by the Yong Ding River south of Marco Polo (Loo-Gu-Chao) Bridge extends south up to Xiong Xian County, Ba Xian County and Tianjin. Its west boundary connects with the pluvial-alluvial plain of the Da Shi River and the Ju Ma River, while the east boundary is close to the alluvial plain of the Chao Bai River. This huge modern alluvial fan superimposes on the late Pleistocene accumulated surface of the Beijing Plain and has its own landform, that is, its landform consists of sand belts of ancient river channels and lowland between ancient rivers, which were formed in historical times and has developed into three sub-alluvial fan bodies relatively independent of each other. The first one is in the territories of Da Xing County, An Ci County and Wu Qing County, to the east or north of the present Yong Ding River channel and its apex is near Marco Polo Bridge. It was a flooding area from the 10th to the 14th centuries. The second one is in the area between Gu An County, Xiong County and Ba County southeast of the present Yong Ding River channel and to the east of the Ju Ma River. Its apex is in the vicinity of the Jin Men Floodgate which is on the right bank of the Yong Ding River. This was the flooding area of the Yong Ding River from the 15th century to 17th century. The last one is in the Shan Jiao Dian area between Shuang Ying and Tianjin. It has been the lowest reach accumulated area of the Yong Ding River since the 18th century. The Yong Ding River is a sandy river and its channel has been blocked frequently in recent years. After the construction of the embankment in 1698, the river channel was constrained but the deposition behind the embankment was serious. The alluvial plain of the Luan River is to the left of its present channel, this area is south of Luan County. The alluvial fan plain is mainly made up of two great sand belts which are parallel to an EW direction approximately. One of them is to the north of Zheng Lin Zi and Ni Jing, another one is near Yang Liu Zhuang and Mao He Bei. The apex of the alluvial fan is near Luan County, its front part lies in the neighborhood of the west side of the lagoon of Qi Li Hai. These two sand belts were the ancient channels of the Luan River in the late period of late Pleistocene and the beginning of the Holocene. In its ancient bed, silt and peat are accumulated which belong to the early and mid-Holocene.

(3) **Marine-Alluvial Plain.** The marine-alluvial plain is located southeast of Tianjin-Wu Qing-Bao Di-Feng Nian-Luan Nan, which is not only low and flat but also has many lacunae scattered everywhere. The Hai River, the Ji Canal and the Luan River flow from here into the sea. Generally speaking, the elevation of the plain is less than 5 m, or even 2 m or so. In the mid-Holocene this plain was invaded by sea water, and with its regression and siltation the coastline extended continuously so that the plain was gradually enlarged. Except for the coastal area, the sedimentary layers of shallow sea facies or coastal facies were buried under the ground, the shallow ones were only 2-3 m, the deeper ones were from 7-8 m to 10 m. On the low and flat ground a lot of shallow depressions and lacunae are separated by the deposited high lands along the banks of rivers, the most famous of them are Huang Zhuang Wa Lacuna, Da Huang Pu Wa Lacuna, Li Zi Gu Wa Lacuna and Qi Li Hai Lacuna, which are in the area of Bao Di, Wu Qing and Ning He. The apex of the alluvial fan-delta plain in the lower reach of the Luan River is near Ma Cheng south of Luan County. The present Luan River channel inclines to the northeast side of the alluvial fan-delta plain. In the past, the Luan River changed its channel repeatedly, and in the recent six hundred years its channel has basically shifted from the west to the east. Because of the deposition of sand embankments in the mouths of the rivers the front part of the delta has repeatedly extended into the sea.
II. Change of the River Systems in the Plain

Because of the continuous change of channel of the Yong Ding River, the Chao Bai River, the Ji Canal and the Luan River in the plain, a lot of river facies sediments have been developed, influencing the landform of the plain.

(1) The historical change of the Yong Ding River

After its departure from the mountainous land near San Jia Dian, the Yong Ding River deposited a great deal of accumulation in the plain. Traces of its movement can be found to the south of the Wen Yu River, to the west of the Chao Bai River and to the north of the Baiyangdian Lake-Wen An Wa Lacuna. As the river flows to the south, the river channel of different times becomes younger. There are at least two ancient channels of the Yong Ding River, which have a broad alluvial flat and incisions from the accumulated surface of the late Pleistocene. One flows from the west of Ba Bao Mount to the northeast. After passing through Hai Dian, Qing He and Sha Zi Ying and connecting with the Wen Yu River, it finds its way to the Chao He and the Bai River system. Its location is near the Ba Bao Mount-Gao Li Ying fault on the northwest side of the Beijing subsidence. The gravel layer of the ancient river channel is buried under the ground shallowly. The $^{14}$C dating of peat, ancient tree and silts in the ancient alluvial flats is generally 15000-2000 years BP (the $^{14}$C Lab in Archaeology, Institute of Chinese Academy of Social Sciences, 1980). It shows that at least in the late Pleistocene the Yong Ding River passed through this location. It would be probably that in the early Holocene the Yong Ding River gradually gave up this channel and the riverbed was buried continuously, and the Qing River took the place of the ancient channel of the Yong Ding River. The other extends from the south of Ba Bao Mount to the southeast. This channel passes through Nan Yuan and Cai Yu and flows to the old Wu Qing town directly. A broad valley north of Cai Yu Village remains at present, the ancient gravel layer of the riverbed are still scattered on the ground surface. According to the historical record, at least in the Han Dynasty i.e. more than 2000 years ago, the Yong Ding River had shifted there. At that time the Yong Ding River was called the Lei Shui River. By the end of the Tang Dynasty (618-907 AD) the tributary of the Yong Ding River occurred in the Beijing Plain. Its branch was located in the area between the Lei Shui River and the present Yong Ding River. In the Liao Dynasty in the 11th century the Lei Shui River was abandoned completely and changed its channel to the south in the vicinity of its present channel. The silt and sand in the Yong Ding River have increased since the Jin and the Yuan Dynasties with its channel frequently blocked and broken. However, its flowing area was located mainly in the area between the Lei Shui River and the present channel. Many sand belts were left in the flooding channel in the present Da Xing County and An Ci County. In the period between the Ming (1368-1644) and the Qing (1644-1911) Dynasties, the Yong Ding River flowed in a southwest direction to the areas of Gu An, Yong Qing, Xiong Xian and Ba Xian. The front of the fan-shaped belt of the ancient river channel in this area reaches the north side of the Baiyangdian depression.

(2) The historical change of the Luan River

The Luan River is the largest river in the Tangshan Plain. Its pluvial-alluvial fan plain which accumulated in front of the Yanshan Mountain was cut by erosion at the end of the late Pleistocene, then, a new incised alluvial fan plain was accumulated on it. The ancient river channel in the sand belt south of Chang Li and northeast of the present Luan River is a part of this alluvial fan. The old riverbed in the sand belt has already been filled with silt and peat in
which there are also some stone axes, deer horns, and bronze dagger axes of the Yin Dynasty as well. In the old river channel of the sand belt in the Mao He Bei Village of Chang Li County the silt layer under the peat layer is 3.5 m from the surface, its $^{14} \text{C}$ age is 9535 years BP. These circumstances show that this new alluvial fan was developed at the end of the late Pleistocene and the beginning of the Holocene. In the most part of the Holocene the Luan River had stopped its movement in this area.

The movement of the Luan River occurred in the area between the fan plain of the late Pleistocene and the sand belt of the new alluvial fan during the Holocene and the historical time. Topography in this area is obviously low so many branches of the old river are located everywhere. The formation of the incised alluvial fan-delta plain in the area of Luan Xian and Laoting is the result of the siltation of the Luan River and the continuous development of the delta in the river mouth. During historical times the Luan River swayed from the east to the west continuously on the fan surface in the south part of Luan County.

In recent several hundred years the migration tendency of the Luan River channel in the downstream was from west to east. Table 1 gives the outline of the change of the Luan River channel.

(3) The historical change of the Chao Bai River

The lower reach of the Chao Bai River and the Ji Canal is a depressed plain which extends from the northwest to the southeast. It had been a sea gulf several thousand years ago. Sometimes the Chao River, the Bai River and the Yong Ding River combined and sometimes separated from each other here so the river systems here are very chaotic. The Chao River and the Bai River flow separately in the Yanshan Mountainous land. After their departure from the mountain they cut the Beijing Plain accumulated in the late Pleistocene in the areas of Shun Yi and Tong County. They not only developed a wide lowland of alluvial flat but also changed their channel in the alluvial plain repeatedly. In ancient times the Chao River was called the Bao Qiu Shui River, while the Bai River was called the Gu Shui River. About 2000 years ago the Bao Qiu Shui and the Gu Shui flowed into the sea separately. At that time the Chao River and the Bai River flowed parallel to the southern part of today's Huai Rou County with the former in the east and the latter in the west. The Wen Yu River was then a branch of the Chao Bai river system while the Yong Ding River (Lei Shui River) joined the Chao Bai River system in Wu Qing County as well. After the Tang Dynasty (618-907) the Yong Ding River began to be away from the Le Shui River channel, and even had no relationship with the Chao Bai River system. The plain in the lower reach of the Chao Bai River and the Ji Canal not only has a chaotic river system but also is the transgression area of the Holocene. Sea and land alternatively appeared and the river system merged and separated, leading the landform evolutionary process of this area to be very complicated.

III. The Transgression of Holocene and the Ancient Gulf

In the Quaternary, the Beijing-Tianjin-Tangshan Plain suffered transgression of different degrees many times but each transgression in the late Pleistocene occurred a long time from the present and its sea facies layer has been deeply buried under the ground. The most recent transgression happened in the mid-Holocene. Its sedimentary layer of sea facies was only a few meters to more than ten meters. On the west coast of the Bao Hai Gulf the remaining shell ridges
on the ground after the most strong fluctuating regression process indicated the ancient coastlines of different periods. Although the low plain in the lower reach of the Hai River and the Ji Canal is the main confluence area of the north system of the Hai River, the effect of modern siltation is not strong enough to cover the traces of the transgression completely. Both the macro-configuration and the micro-topography show that the history of the low plain of the Bo Hai Gulf away from the influence of the sea is not very long. The ground where the ancient gulf was once located still possesses low and wet features at present. With the regression of sea water and the siltation of the rivers, areas between the rivers in this plain were divided into many depressions or lacunas. The huge lake-marsh area of ancient Yong Nu Shu, which appeared after the sea retreat in the lower reach plain of the Chao Bai River and the Ji Canal, has disintegrated gradually.

The lower reach plain of the Luan River is a well-developed fan-delta plain in the Beijing-Tianjin-Tangshan Plain. When the transgression effect in the Holocene was most vigorous, part of the lower reach plain of the Luan River was submerged and the sea water at least reached the vicinity of Laoting County. After the greatest transgression, with the siltation and the change of the river channel of the Luan River and the decrease of fluctuation of the sea level, the marine facies layers in the southern portion of Laoting County were gradually covered with fluvial sediments. There is a shell layer 2 m deep under the ground in Ma Tou Ying Village and the $^{14}$C age of the shells is 3700 years BP. Also, in Tong Jia He and Jiang Ge Zhuang southeast of Laoting there exist some shallow shell layers buried under the ground. According to this, we can estimate that 3000 years ago the coastline was not far away from Ma Tou Ying and Jiang Ge Zhuang. The time for the land formation of the southern area of Ma Tou Ying and Jiang Ge Zhuang is much later. According to the ruins of forts, beacon towers, and the sentry post established in the Ming Dynasty (1368-1644), and the remnants of the shell layer, or, the shell layer embankment, it is believed that 500-300 years BP the coastline in the Ming Dynasty was probably in the vicinity of Can Sha Kou, Hong Fang Zi and Da Miao Zhuang. This ancient coastline connects with the shell embankments in the area of Gao Shang Pu, Hei Yan Zi and Sheng Tou Gu in the west. Through the development of the sand embankment in the river mouth, the front part of the Luan delta and the coastline go forward step by step. The Xiang Yun Island, which is south of Laoting County, was a sand island in the sea during the Ming Dynasty but by the beginning of the Qing Dynasty it had already been near the seashore. After 200 years, by the end of the Qing Dynasty, the Xiang Yun Island had reached the land and had become a part of it. In 1915 the Luan River changed its channel south of Lian Hua Chi. In the recent several decades the newest accumulated body of a small delta has been developed in the river mouth area.

**IV. Reflection of Tectonic Activity on Plain Landform**

The landform of the Beijing-Tianjin-Tangshan Plain has been developed by the exogenic forces of rivers, lakes, marshes, and shallow sea on the background of differential block-fault effects since the Cenozoic era. Therefore, in the vicinity of the active fault belt, not only difference of plain morphology is developed but obvious differences in the sediments and the erosion are also found. Even the hidden active faults in the plain still control the landform development to some degree.

From the macroscopic point of view the plain in the lower reach of the Ji Canal-Chao Bai River is a NW lowland in the Beijing-Tianjin-Tangshan Plain. Many important landform
boundaries such as the mountain foot boundary, the lower boundary of piedmont fluvial-alluvial plain, and the ancient and the modern coastline all corresponds with the strike of the lowlands and extend in a NW direction. And, its peculiar morphology divides the fluvial-alluvial plain of the Luan River, the Dou River and the Huan Xiang River and the fluvial-alluvial plain of the Yong Ding River, the Wen Yu River and the Chao Bai River into two parts. The first part which takes the Tangshan Plain as its main body is in the east, while the second one takes Beijing Plain as its main body is in the west. This lowland is also the depression belt where strong active tectonic movement occurred, that is, the so-called Beijing-Tianjin-Bo Hai Sea depression belt. The thickness of the Pleistocene here is so great that it becomes the deepest subsidence zone in the entire North China fault-subsidence basin. This phenomenon is especially obvious in the joining parts with the NE subsidence where the thickness of the Neogene and the Quaternary has reached 2000-3000 m (Ye Hung et al., 1980). The NW fault belt, that is, the Zhuang Jia Kou-Ning He fault belt which runs through Beijing, Tianjin and the Bo Hai Sea, passes through beneath this lowland zone. Not only are the ruptures in the overlying layer along this fault belt intensive, but also gravity and magnetic forces and the change of morphology in the zone appear to be abnormal. In historical times and recent times earthquakes occur frequently here. Earthquakes of M>6 have occurred 13 times (Zhang Binghua et al., Ma Jin et al., 1980). Corresponding with the tectonic activity the active geomorphologic process is being carried out in the plain of the lower reach of the Ji Canal-Chao Bai River. Most of the rivers in the Beijing-Tianjin-Tangshan Plain are concentrated in this zone. The tail tracts of the Yong Ding River, the Chao River, the Bai River and the Ji Canal migrated frequently and their river systems changed continuously in historical times, yet the river network has remained in a NW-SE direction so far and the longitudinal micro-landform, riverbed and alluvial flat sediments also extended in the same direction as a whole. Under the control of this NW subsidence plain even the Luan River in the mid-Pleistocene passed once through the ancient river valley between Qian Xi and Feng Run to flow to the plain of the Ji Canal along the area of the Huan Xiang River as a whole. The transgression in the mid-Holocene also occurred along the lower reach plain of the Chao Bai River-Ji Canal and pushed forward in a northwest direction. An ancient gulf, concave in the northwest direction, was formed in the vast area between Wu Qing, Bao Di, Yu Tian and Feng Run so that the Beijing-Tianjin-Bo Hai Sea subsidence was more obvious on the surface of the ground.

The Beijing Plain mainly consists of the fluvial-alluvial fan of the Yong Ding River. Its landform structure is also controlled by the hidden fault belt beneath the plain. Although subsidence was dominant for many NE-NNE uplifts and subsidence in the Quaternary which generally received sediments at the same time, yet, because of the cutting of the NW fault, especially the Zhang Jia Kou-Ning He fault belt, each NE structural unit differed and had an effect on the landform development. The differential movement is more striking in the Beijing subsidence and two uplifts on its both sides. The degree of sinking of the Beijing subsidence in the Tertiary is greater southwest of the NW Nan Kou-Tong Xian fault, but since the Quaternary, sinking of this area northeast of the fault mentioned above became most active and formed a sedimentary center near Shun Yi County. The thickness of the Quaternary is over 700 m. The uplift west Beijing on the west side of the Beijing subsidence relatively uplifted in the Tertiary, but its downthrow side, which is on the southwest side of the Nan Kou-Tong Xian fault, has received sediments since the Quaternary. The thickness of the Quaternary sedimentary center near Sha He is more than 300 m. The Da Xing uplift and the Da Chang-Wu Qing subsidence southeast of the Beijing subsidence all had sediments since the Quaternary, but the subsidence
amplitude of the latter is much greater. The movement characteristics and the sedimentary conditions mentioned above remarkably responded to the ancient and modern change of the river systems and the morphologic characteristics of landform in the Beijing Plain. As for the river systems except for the following rivers such as, the Chao Bai River located at Huai Rou; the Mi Yun and Shun Yi rivers northeast of the Beijing subsidence; the ancient Yong Ding River (e.g. present Qing River) on northwest side of the Beijing subsidence; and the Ju He River north of Ma Fang, Ping Gu County in the northeast part of the Daxing uplift, all belong to the NE-SW river system. Other main rivers basically flow from the northwest to the southeast. Especially in the vicinity of the Nan Kou-Tong Xian fault in the Zhang Jia Kou-Ning He fault belt, a NW confluence belt was formed extending continuously in the southeast direction to the northwest coast of the Bo Hai Gulf. The Chao Bai River and the Wen Yu River-North Canal flow closely and parallel each other in this confluence zone, even a partial river system facing the center was formed in the severe subsidence area of the Quaternary near Sha He. Although the Chao Bai River north of Niu Lan Shan Mount of Shun Yi County and the Ju He River north of Ma Fang of Ping Gu County belong to the NE-SW river system, after passing through the NW fault of the 20-Li Chang Shan Mount, they quickly become a NW-SE river system and strive to join the NW confluence zone mentioned above. Though the Yong Ding River in historical times has changed its channel repeatedly in the Beijing subsidence and Daxing uplift, its overall flowing direction remains approximately southeast. Either the old channel of the Qing River and the Lei Shui River, or the other ones which had once passed through the present urban area of Beijing, took the NW confluence area as their final destination. The departure of the Yong Ding River from the ancient Lei Shui River channel has already been more than one thousand years. Its superimposed fan-like sand belts in the ancient channel, accumulated in the area between Da Xing, Gu An, Ba Xian and Wu Qing in the south part of the Beijing Plain, are the result of siltation from the hydrological point of view but the diverging location or the breach location of the Yong Ding River which formed the front part of the fan plain of the ancient channel, such as the area between Ba Bao Shan Mount to Marco Polo Bridge, the area of Jin Men Floodgate north of Gu An, and the Shuang Ying area east of Yong Qing reflect the tectonic activity to some extent because these locations are all situated in the neighborhood of the NE active fault belt. The gradual migration of the Yong Ding River from the ancient Lei Shui River channel to the southwest not only reflects that the subsidence tendency of the Wu Qing subsidence is stronger than that of the Da Xing uplift but also reflects that the movement of the Da Xing uplift could be accompanied with a slight tilting to the southwest.

The active fault belts also controlled the development of the landform in the Tangshan Plain which consists of the pluvial and alluvial fan-delta plain of the Luan River and the pluvial-alluvial plain of Feng Run area mainly. The NEE Ning He-Chang Li fault, the Ye Ji Tou-Feng Tai fault, the NNE Lu Long-Luan Xian fault and the NNW Luan Xian-Laoting fault are the main hidden faults which influenced the landforms in the lower reach plain of the Luan River, the Dou River and the Huan Xiang River. The areas enclosed by these faults are also the areas where the ancient and modern alluvial fans and deltas have developed. The areas along the faults mentioned above, especially the joining areas of faults of different directions, are not only the important geomorphic boundary or the locations where the nature of the exogenic force of landform is easily changed, but are also the more active areas for the occurrence of earthquakes such as Luan Xian, Tangshan, Ning He, etc. The Luan River is the greatest river east of the Hebei Province and the piedmont plain between Tangshan and Chang Li, at least, has been the accumulated area of the Luan River since the late-Pleistocene. The apex of the pluvial-alluvial
fan is located in the joining location of the Ye Ji Tou fault and the Luan Xian-Laoting fault and its west side is very close to the Dou River, obviously obstructed by the bedrock mounts in the area of Gu Ye and Tangshan and restrained by the NE Dou He fault. The east side of the fan has advanced to the south of Chang Li County and the surface of the whole fan tilts to the south, and its south boundary approaches the Ning He-Chang Li fault approximately. Not only has the thickness of the Holocene south of the fault been increased, but the landform has also gradually changed to be a low coast plain; morphologically, there exist obvious slope changes as well. Since the end of the late Pleistocene and beginning of the Holocene the pluvial-alluvial fan has been incised and eroded. On the east and the west sides of the modern Luan River, which is to the east of the Luan Xian-Luan Nan area, have developed incised alluvial fans of two levels gradually. The one on the east side was formed at the end of the late Pleistocene and at the beginning of the Holocene. At present, it is a longitudinal sand belt in the ancient river channel and its surface is 2-3 m lower than that of the pluvial-alluvial fan of the late Pleistocene. The one on the west side was developed in the Holocene and the traces of the ancient Luan River channel in recent several hundred years are still kept on the surface. Its surface is 5-6 m lower than that of the fan surface of the late Pleistocene. The boundary between these fans of different periods and levels approaches the NNW Luan Xian-Laoting fault. The present Luan River also follows this fault approximately in the SSE direction and flows to the sea. Besides, the NNE Lu Long-Luan Xian fault under the plain continues to extend in the SSW direction to the area of Bai Ge Zhuang. Its existence and activities restrain the extent in which the lower reach of the Luan River swayed to the west in the Holocene and historical times. The incised alluvial fan of the lowest level west of the present Luan River is just located between the NNW fault and the NNE fault. Here is also the strongest subsidence area of the lower reach plain of the Luan River in recent times, especially in the Laoting subsidence to the south of the Ning He-Chang Li fault because its subsidence is so great the transgression of the Holocene could go further in the north direction.

References


(Translator: Xing Jiaming)
Table 1. Outline of the change of the channel in the lower reach of the Luan River.

<table>
<thead>
<tr>
<th>Time (AD)</th>
<th>Partition Location</th>
<th>Flowing Direction</th>
<th>Entrance to the Sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>1324</td>
<td>Ma Cheng</td>
<td>SW</td>
<td>Liu Zan</td>
</tr>
<tr>
<td>1406-1452</td>
<td>Sha Wo Pu</td>
<td>SE</td>
<td>Ji Ge Zhuang</td>
</tr>
<tr>
<td>1456-1622</td>
<td>Sha Wo Pu</td>
<td>SSW</td>
<td>Da Zhuang He</td>
</tr>
<tr>
<td>1622-1752</td>
<td>Sha Wo Pu</td>
<td>SSE</td>
<td>Da Qing He</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>River mouth</td>
</tr>
<tr>
<td>1752-1811</td>
<td>Ting Liu He</td>
<td>SE</td>
<td>Hu Lin Kou Xing Kai Kou</td>
</tr>
<tr>
<td>1811-1846</td>
<td>Ting Liu He</td>
<td>SE</td>
<td>Chao Shui Gou Liu Jia Pu</td>
</tr>
<tr>
<td>1813-1883</td>
<td>Shi Jia Kou</td>
<td>SE</td>
<td>Lao Mi Gou Lang Wo Kou</td>
</tr>
<tr>
<td>1915-present</td>
<td>Shi Jia Kou</td>
<td>SEE</td>
<td>Tian Shui Gou Xin Tian Village Lian Hua Chi</td>
</tr>
</tbody>
</table>
Legend:

1. Bed rock mountainous land and hills
2. Pluvial-alluvial plain in piedmont
3. Alluvial Plain and valley flat
4. Micro-upland of ancient river channel or sand belt
5. Lacuna
6. The Ancient Coastline
I. The probable maximum range of transgression in the Mid Holocene
II. The coastline 4000-3000 years BP
III. The coastline 2000-1100 years BP
IV. The coastline 600-100 years BP

Figure 1. The Geomorphologic Map of the Beijing-Tianjin-Tangshan Area