Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (15): 2714-2724, 2009
ISSN 1812-5654

The 1976 China, Tangshan Earthquake M_w = 7.8 Mechanism in Retrospect

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Abstract: The aim substance of this study was to discuss the complexity of the seismic genesis of this earthquake. To meet the objectives of the study, data from both field and previous studies was collected, the most significant due to the aim was analyzed deeply, in this study 3 famous seismic models proposed by Chinese scientists to explain the cause of the occurrence of Tangshan earthquake were discussed and compared with the view of sharing ideas with other models, these models are (1) the tectonic magma thermo-seismic model, (2) the multi-dynamical processes and local weakening of the crust model and (3) the dilation creep model. The results of this study showed that the area of Tangshan earthquake was driven by multi-stress field sources, the geological context of this earthquake was predominated by shallow brittle crust and the earthquake had a close relation with tidal force, the main result of the study was a new deduced model called: various stress sources, local shallow brittle crust and tidal force triggering effect. A perfect identification for the mechanism of Tangshan earthquake needs the collaboration of several scientists in different fields of earth sciences.

Key words: Magnitude, fault, seismic genesis, seismic models, tidal force

INTRODUCTION

The Tangshan earthquake which occurred in Northeast China on July 28, 1976 at 3:42 am; location 39, 6°N, 118, 0°E, M_s 7.8 (USGS) stands in terms of loss of life as the greatest earthquake disaster of modern times, before the earthquake Tangshan had 1000.000 inhabitants and it had been estimated that quarter were killed (George and Xie, 2002). Tangshan earthquake has been the subject of several geophysical and geological studies by both Chinese and foreign scientists (Liu *et al*., 2007; Li, 1986; Guo *et al*., 1977; Jiang, 2007a, b; Patricia *et al*., 2006; Jian *et al*., 1998; Rhett *et al*., 1979). It may be one with the largest number of studies of any single seismic event up to now. There were 530 studies up to 2006 about different features of Tangshan earthquake (Yao and Jiang, 2006). After this event, a comprehensive investigation on the Tangshan earthquake was carried out, including the seismic precursors, intensity distribution, source mechanism, aftershocks (Fig. 1a,b) as well as the deep and shallow structures beneath the Tangshan and adjacent regions (Fig. 2a, b, 3a, b). However, till now, researchers are trying their best to give a perfect identification about the seismic genesis of the Tangshan earthquake, more than 30 years has passed yet, some research are still on the cause (Liu *et al*., 2007; Jiang, 2007a, b; Wang, 2001), it is far from the end. It is worth considering that such an event in an intensively active tectonic area could not be suppressed, but why earthquake of such a high magnitude in the Paleo-Craton Area in North China far from the plate boundary, this has been one of the incomprehensible problems. There are various ideas about the genesis of the Tangshan earthquake in the early studies. However, according to Liu *et al*. (2007), they can be basically attributed to two different opinions: one is the emphasis on the horizontal interactions between different crustal blocks (Fig. 4) and another is the emphasis on the vertical crustal deformation caused by the exchange of the crust-mantle materials. The former studies on earthquake geology demonstrated that the Tangshan earthquake was located on the occlusion area composed of the Tangshan fault and another concealed faults (Guo *et al*., 1977) and its tectonic genesis was attributed to the activity of deep faults with different strikes (Li, 1986). Using numerical modeling methods, several researchers investigated the brewing process and the genesis of the Tangshan earthquake, for example by using the 2-D Finite Element Method (FEM), Zheng *et al*. (1984) investigated the brewing process of the Tangshan earthquake under the horizontal compression between different blocks. On the basis of the 2-D Maxwell Viscoelastic model, Mei and Liang (1989) carried out numerical simulations of the brewing process of the Tangshan earthquake and proposed the so-called seismogenic hard body model. On the basis of the reinterpretation of data obtained from the deep seismic sounding study in the Tangshan area, Zeng *et al*. (1985) proposed that the Tangshan earthquake could be caused

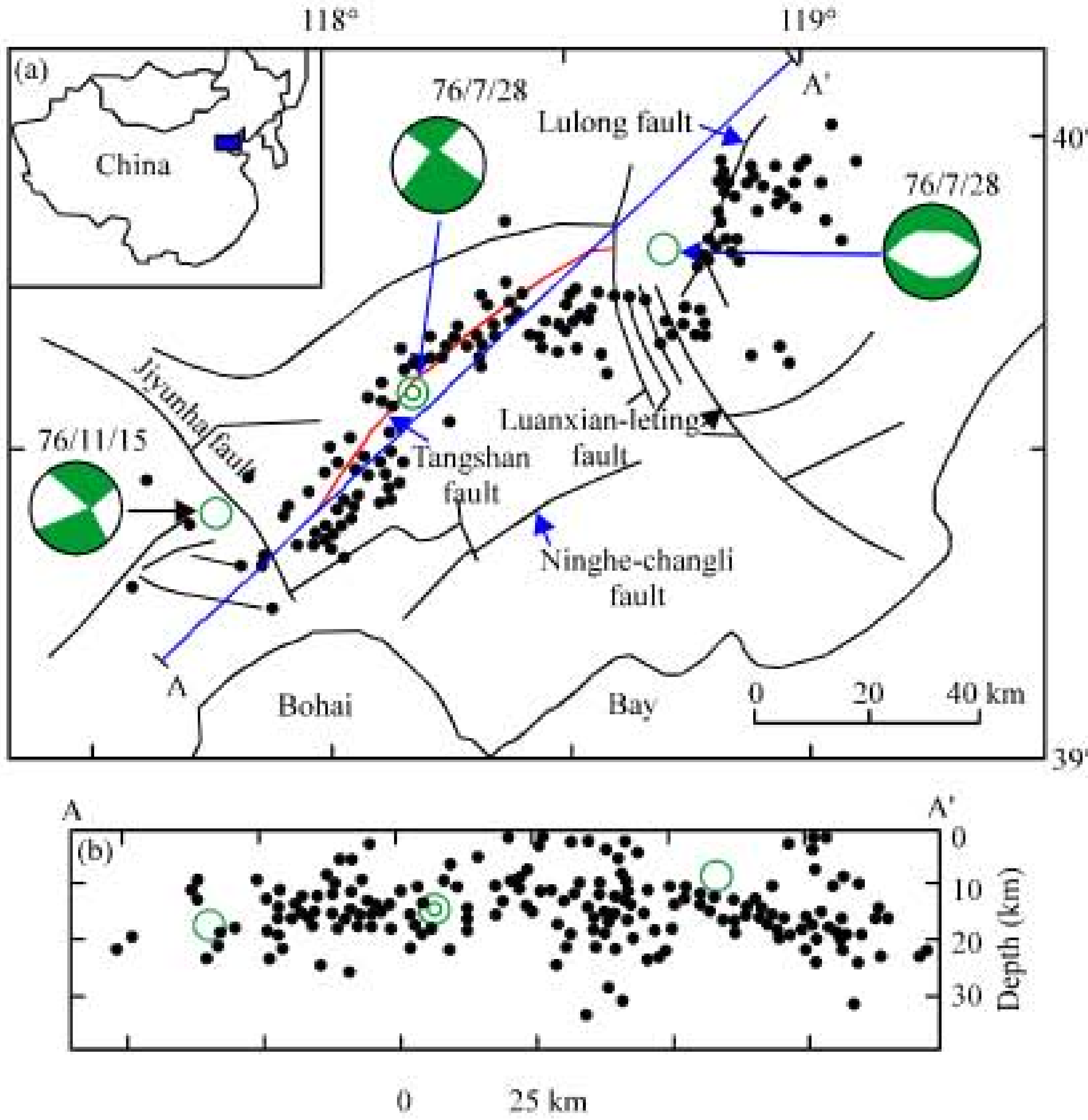


Fig. 1: (a) The wpicenter dister distribution of the aftershocks (solid circles) with M1 = 4 of the tangshan earthquake from 28 July to 30 December 1976 (modified from Shedlock *et al*., 1987). The major tectonic faults and the lower hemisphere projection of the fault-plane solutions of the mainshock (double open circle) and the two largest aftershocks (large open circles) determined by Nebelek *et al*. (1987) are also shown (b) projestion of the hypocenters (solid circles) on a vertical plane along the line AA' as shown in (a)

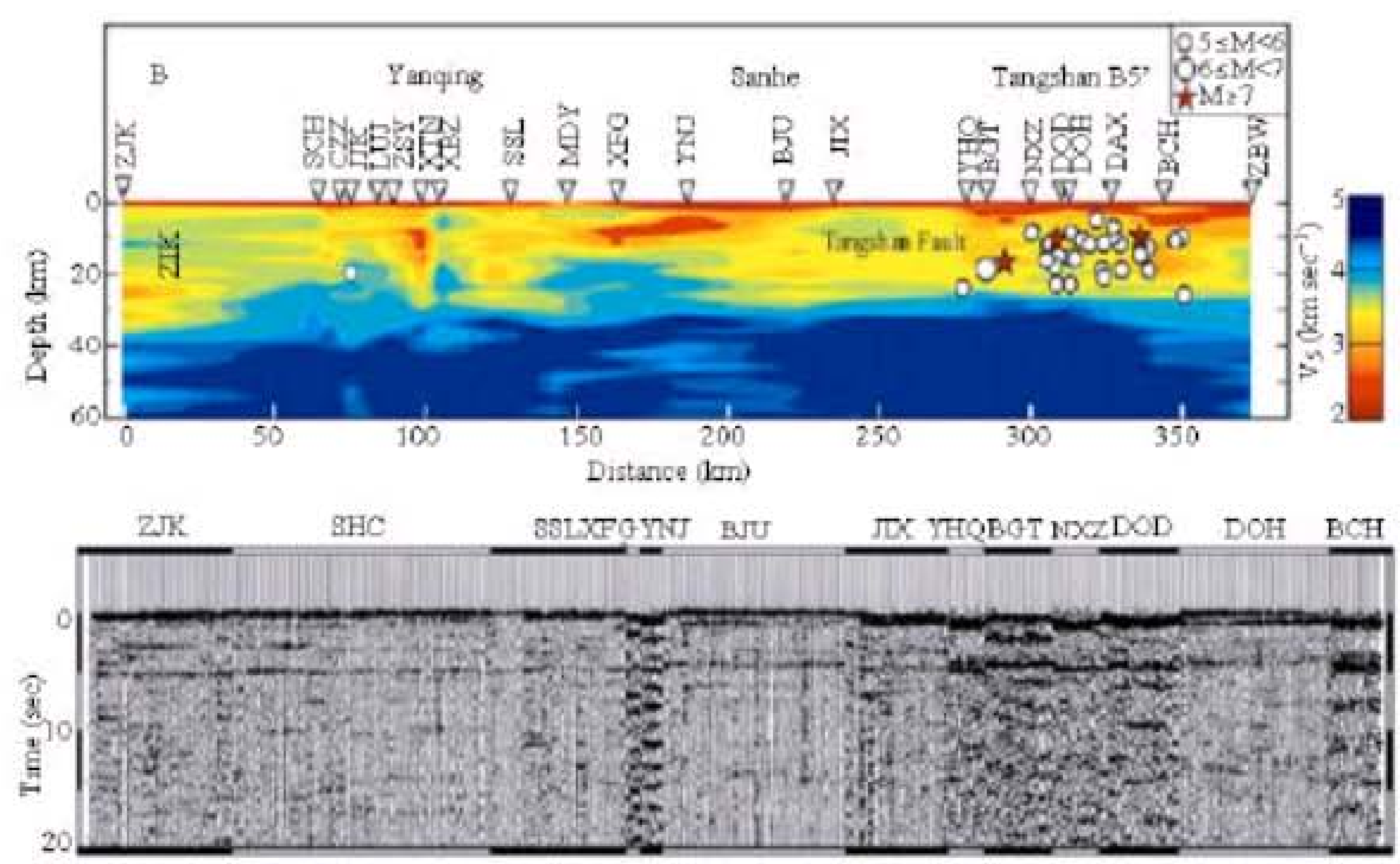
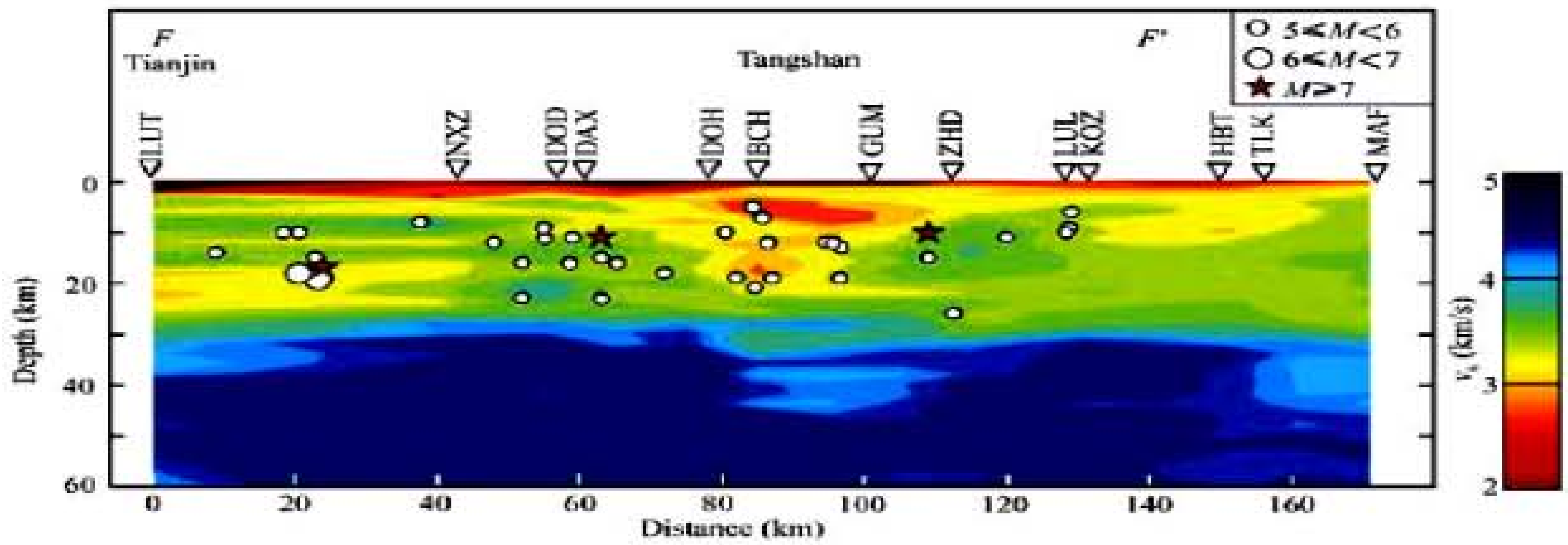
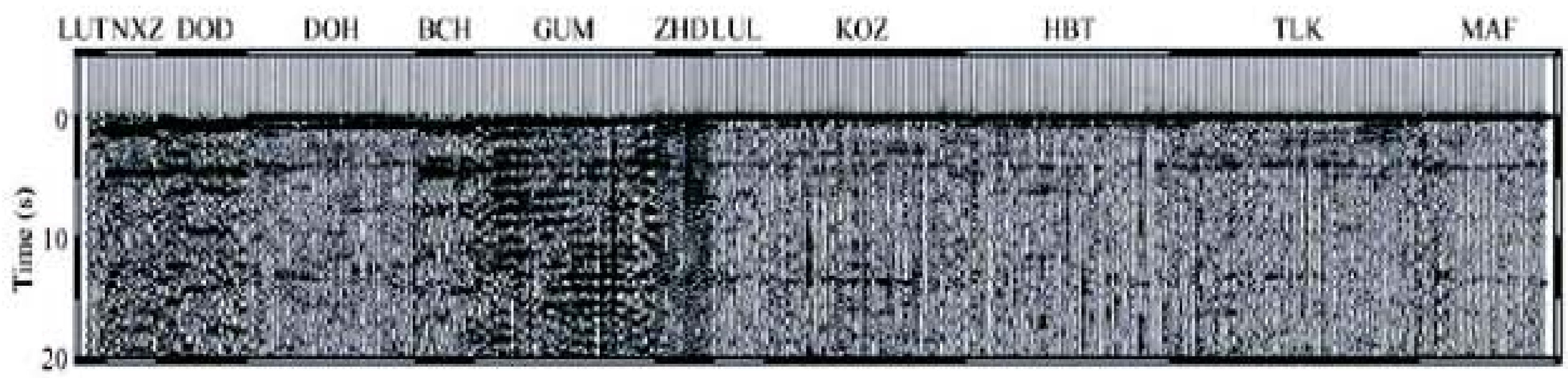


Fig. 2: (a) S-wave velocity structure of the crust and upper mantle along the B-B' profile and (b) receiver functions (Liu *et al*., 2007)



(a)



(b)

Fig. 3: (a) S-wave velocity structure of the crust and upper mantle along the F-F' profile and (b) Receiver functions. The circles and the red stars represent the events (Liu *et al*., 2007)

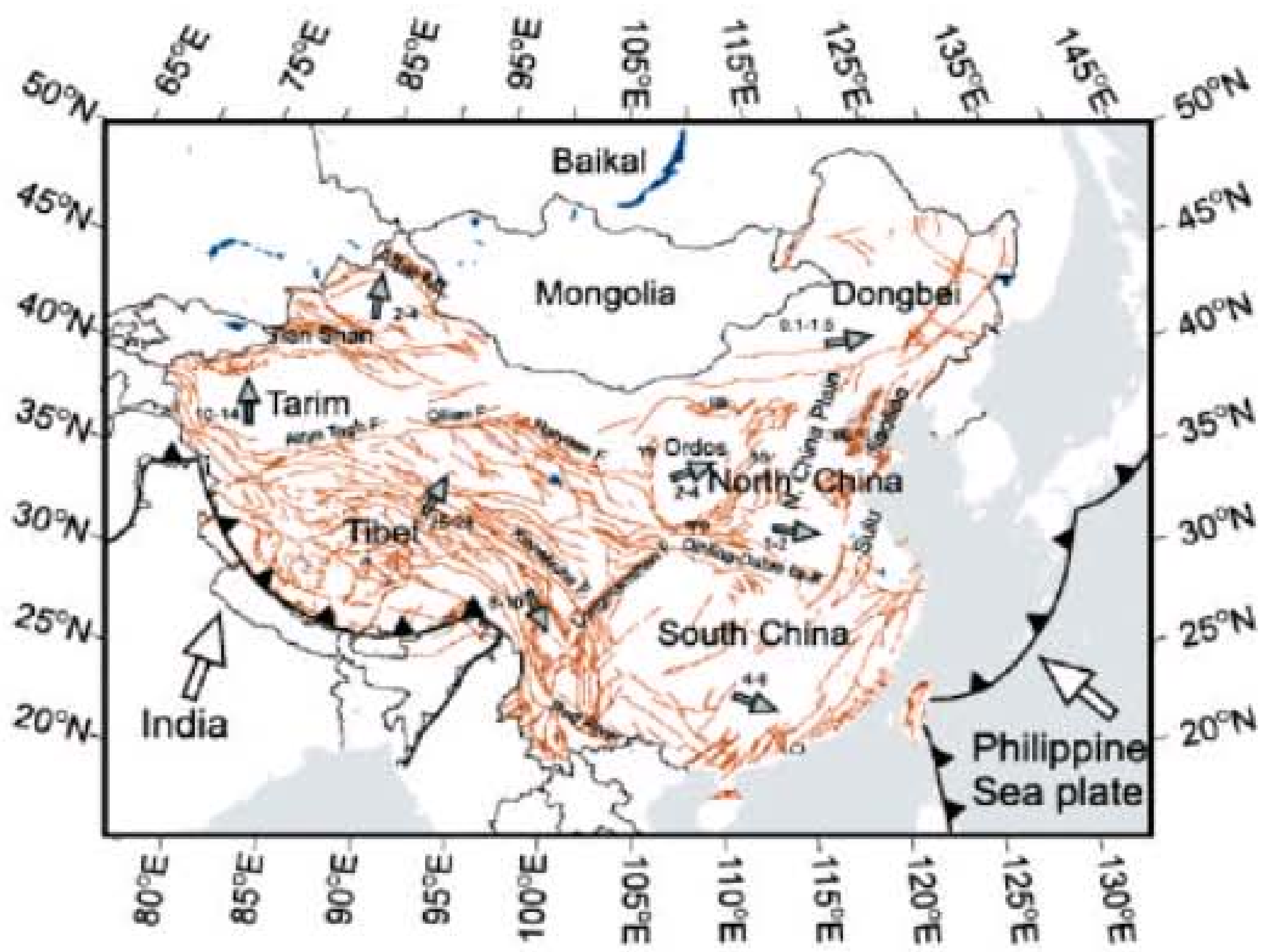


Fig. 4: Simplified map of major geological units in continental China and their relative motion (mm year^{-1}) with respect to stable Siberia, based on Quaternary fault-slip rates and other neotectonic data. Thin lines are active faults. WG: Weihe graben, SG: Shanxi graben, YR: Yinchuan rift, HR: Hetao rift, BB: Bohai Basin. Solid cicle representes Tangshan region (Mian *et al*., 2007)

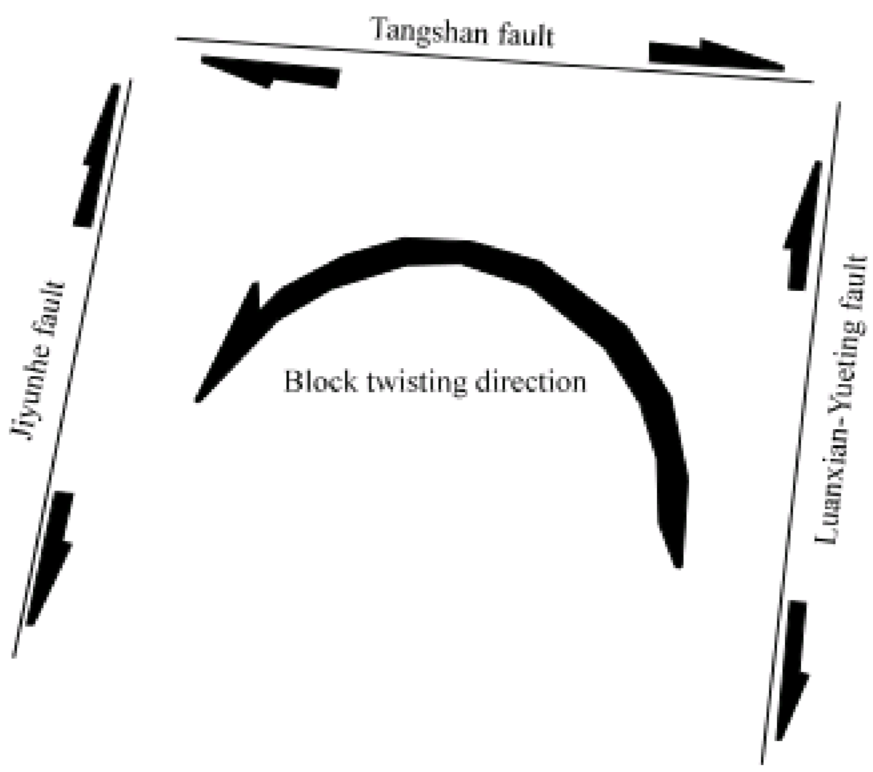


Fig. 5: Causative structure schematic diagram of Tangshan earthquake (Li, 1986)

by transferring the upper mantle materials into the lower crust. By using the FEM, Song *et al*. (1982) investigated the stress field on the source fault of the Tangshan earthquake and proposed that the Tangshan earthquake was caused by the joint effects of the vertical and horizontal forces. Here, we introduce three famous models about the seismic genesis or the cause of the Tangshan earthquake.

The tectonic magma thermo-seismic model by Li (1986): It is based on the synthetic analysis of geological background, the characteristics of some precursory anomalies, distribution of seismic fissures and focal mechanism. Li (1986) suggested that Tangshan earthquake be the result of the combined effect of horizontal compressive-stress due to westward subduction of pacific plate and the upward compressive-stress due to mantle uplift and magma-intrusion. It has led to the counterclockwise twist of Tangshan massif which is confined by several faults (Fig. 5).

There are some points of suspicions about this model: the model is based on fault activity and does not provide any convincing proofs about the dynamics of the Tangshan earthquake (Liu *et al*., 2007). How different scale faults with varied depths cut the region to form the block? The other is that, if such block exists, it seems smaller than not only the extent of seismic denseness area of the $M_l = 4$, but also smaller than the area of aftershocks (Wang, 2001). Li (1986) attributed the stress triggering the Tangshan earthquake to the mantle uplift, intrusion of the magma and the westward subduction of pacific plate. In fact the stress field before Tangshan earthquake came from another phenomenon such as a seismic slip at the Jiyunhe fault during 1972-1973 (Shao and Shuzo, 1999), tidal forces (Kai, 1988) and the interaction of different blocks in Northern China (Zhang *et al*., 2003).

Multi-dynamical processes and local weakening of the crust model by Wang (2001): The main content of the multi-dynamical processes and local weakening of the crust model is: just before Tangshan earthquake in 1976, the plates around the Chinese mainland had experienced strong movements in almost same time interval, which brought multi-dynamical processes and had undergone very complex stress movement and stress concentration. Affected by multi-dynamical processes in different directions, stress increase in Tangshan was balanced; in such case micro-cranny in all directions could not develop easily, so there were no prominent foreshocks. Under the increased stress, inherent crust structure in Tangshan region was gradually weakened accompanied with $M_l = 4$ seismic denseness. Because the crust was relatively brittle in Tangshan Region. As the stress accumulated the extent of local weakening was enhanced, resulting in heavy breakup in the center area above and the occurrence of Tangshan earthquake, finally, the epicenters of two main shocks of Tangshan earthquakes were just located in the center area. As the depth of the brittle layer was relatively shallow, the hypocenters of the two main shocks were also shallow, the center broken up corresponded to the aftershock area. Wang (2001) thought that, by using this model of multi-dynamical processes and local weakening of the crust to explain the cause of Tangshan earthquake, we can connect dynamical source of Tangshan earthquakes with dynamical circumstances of the Chinese mainland. And explained the occurrence reason and the occurrence regions of $M_l = 4$ seismic denseness from 1973 to 1975; we can also explain the complexity of Tangshan earthquake sequence and without foreshocks; we can as well explain why the two main shocks occurred at relatively shallow depth. However, there are some comments on this model, Wang (2001) did not take into account a lot of precursors which can help to get reliable evidences about the seismotectonic genesis of Tangshan earthquake, such as precursors of gravity anomaly (Rui *et al*., 1997; Wei *et al*., 1985), deformation of the Tangshan fault zone and the increasing fault activity outside this zone (Xie and Ren, 1987), level of ground water in the Tangshan fault block region (Mei, 1985), tendency anomalies of radon before Tangshan earthquake, anomalous variation in hydrochemistry in the epicentral region of the Tangshan earthquake and anomalous of earth-resistivity (Qian *et al*., 1983). Wang (2001) has introduced the term of multi-dynamical processes and suggested that these processes were brought by the strong movement of the plates around the Chinese mainland, but in our opinion. Wang (2001) did not adequately clarify the nature of these multi-dynamical processes, the explanation seemed very general and allow several assumptions about these multi-dynamical processes. As we discussed in the first model, Wang (2001) has also overlooked a lot of stress field sources which were supplying the Tangshan earthquake region before the occurrence of the earthquake.

Dilation creep model by Niu (1985): The dilation creep model of earthquake source development is usually abbreviated DC. Inelastic volumetric dilation of rock masses and fault creep are considered as two basic physical processes in the DC model. The physical mechanism of precursors of the M_l = 7.8 Tangshan earthquake has also been analyzed and discussed in this model. The results showed that the precursors of the Tangshan earthquake were not caused by only one factor and the precursors observed in and around the epicentral area prior to this earthquake can be grouped into 3 types:

- Precursors may be related to rock dilatancy
- Precursors resulted from fault creep
- Precursors may be associated with some sort of upward migration of mass in the crust or the upper mantle and/or may be attributed to large scale stressing process accommodated by some combination of stable slippage and discontinuous brittle rupture (namely small earthquake) along the faults

Niu (1985) suggested that repeated dilation and discontinuous creep occurred during the process of source development of the Tangshan earthquake can be divided into the following 6 phases:

- Elastic stress accumulation (from 1954 to 1967)
- Early inelastic dilation (from 1968 to 1969)
- Early fault creep (from 1970 to 1973)
- The second dilation (from the end of 1973 to the first half of 1975)
- The second evident fault creep (from the second half of 1975 to the end of April, 1976)
- Fault creep just before the main shock (from the end of April, 1976 to the occurrence of the Tangshan earthquake)

Niu (1985) thought that the preparatory process of the Tangshan earthquake, as one of the intraplate events, may be controlled jointly by the upward migration of deep mass and large scale Intraplate stress field. This characteristic is probably different from that of the earthquake along plate boundary. The DC model has been published in Chinese (Niu and Gang, 1976; Niu, 1978) and it is poorly understood outside China. We think that the dilation creep model is a very good model to explain the mechanism of Tangshan earthquake, because, it combines the kinematics with dynamic features of this earthquake. In this model several precursors have been taken into account, however, Niu (1985) contented to explain them according to the theoretical concepts of his model. Tangshan earthquake presents a big complexity in terms of mechanism, so it is a best example for researchers willing to extend their knowledge in Earthquake Mechanism. Tangshan earthquake would have been predicted, if the short and imminent predictions were not neglected, thus it is very useful case study in earthquake prediction field (Bouasla, 2009).

THE NEW MODEL OF VARIOUS STRESS SOURCES, LOCAL SHALLOW BRITTLE CRUST AND TIDAL FORCE TRIGGERING EFFECT

In the last decade, we have learned a great deal about the processes that cause 90% of the world's earthquakes using the model of plate tectonics, the understanding of the geological activities that take place at the boundaries of the earth's major crustal plates has increased tremendously. Yet little is known about the processes at work in the interiors of the plates especially within countries. Most straightforward theories about plate tectonics assume an absence of any deformation within the plates. This is certainly not true when we consider the large and damaging historic earthquakes that have occurred in areas far from the actual plate boundaries (Lynn, 1978), the best example of these is the July 28, 1976 Tangshan earthquake.

The author proposed the model of various stress sources, local shallow brittle crust and tidal force triggering effect to explain the cause of the Tangshan earthquake; this model is elicited by several studies and can be divided into three parts (Bouasla, 2009).

Various stress sources: All the models treating the problem of Tangshan earthquake mechanism mentioned that, there were various stress field focuses supplying the Tangshan earthquake region before the occurrence of the earthquake. These sources are mainly: the uplift of the upper mantle beneath Tangshan region (Liu *et al*., 2007; Li, 1986; Wang, 2001) (Fig. 2, 3), thermal stress (Zhang, 1987), the Chinese scientist Zhang thought that the existence of high tempreture zone, resulting from the upper mantle thermal plume in the Xialiaohe-Bohai-Huanghua Area, with its center in the middle of the Bohai Bay and the horizontal thermal gradient in the vicinity of Cangdong fault led to the concentration of geothermal stress in the Tangshan area, the intrusion of the magma in the crust beneath Tangshan Region (Liu *et al*., 2007; Niu, 1985; Wang, 2001), the effect of the interaction mainly between the pacific and Indian plates against the Eurasian plate which supplies the north of China by a huge amount of stress (Mian *et al*., 2007; Peter and Tapponier, 1977; Clyde *et al*., 1995), the interaction between different blocks in North China (Zhang *et al*., 2003; Shou, 1995) (Fig. 4) and the aseismic movements before the occurrence of Tangshan earthquake (Shao and Shuzo, 1999).

Local shallow brittle crust: This part was concluded based on the studies of Liu *et al*. (2007), Wang (2001), Li (1986) and Guo *et al*. (1977) and the observations during the field work we have done in Tangshan area.

According to Liu (2007), the events in Tangshan area were mainly distributed on the intersecting part of high and low velocity medium, the maximum focal depth reached to the lower crust, this implied that earthquakes generally take place within the brittle hard body of the crust, including its lower part (Fig. 2, 3).

From the model of Wang (2001), multi-dynamical processes and local weakening of the crust, this fact can also be proven, because, Wang (2001) suggested a local weakening of the crust for the Tangshan area, besides, Wang (2001) has also relied on several previous studies mainly on Leland and Zelt (1991) model.

Li (1986) and Guo *et al*. (1977) have given a comprehensive geostructural background of Tangshan area, they thought that the regional structural background of Tangshan earthquake can be regarded as an intersection in Tangshan district of the EW direction Wuyuan-Changcjiakuo (Kalgan)-Tangshan tectonoseismic zone with the NE direction Hebei-Shandong fault block depression seismic zone (especially the East Cangzhou faulting seismic zone). The conclusion of their works gives an idea that Tangshan earthquake zone is tectonically significant.

Tidal force triggering effect: This part is elicited by the following studies by Kai (1988), Sachiko *et al*. (2004) and Amy (1980) and the report of the University of California- Los Angeles (UCLA).

According to the report achieved by UCLA, earthquakes can be triggered by the Earth's tides. Earth tides are produced by the gravitational pull of the moon and the sun on the earth, causing the ocean's waters to slosh, which in turn raise and lower stress on faults roughly twice a day. Scientists have wondered about the effects of Earth tides for more than 100 years. Large tides have a significant effect in triggering earthquakes; the earthquakes would have happened anyway, they can be pushed sooner or later by the stress fluctuation of the tides (Sir and Turcaud, 2004).

In the present model, we do not mean that the tidal forces of the sun and the moon played the capital role for the occurrence of Tangshan earthquake, but we think that the tidal forces have brought the Tangshan earthquake fault to its threshold limit of withstanding the huge amount of stress. In other words they participated just in triggering the Tangshan earthquake.

Sachiko *et al*. (2004) observed a correlation between the earth tide and earthquake occurrence that is closely related to the regional tectonic stress. They investigated the direction of the tidal compressional stress using shallow earthquakes occurring in 100 subregions of Japan for nearly five years. The azimuthal distribution of the compressional stress obtained for the observed earthquake data is compared with that synthesized for random earthquake occurrence. Statistical analysis confirmed a significant difference between the observed and random catalogs for 13 subregions, which included the areas where unusual seismic activities took place recently and where the possibility of future large earthquake has been argued. For these subregions, earthquakes preferentially occurred when the tidal compressional stress was near the dominant direction of P-axis of focal mechanisms obtained in the corresponding subregions. This suggested that the tidal stress may encourage earthquake occurrence when it acts in the direction to increase the regional tectonic stress.

Amy (1980) had compared the origin times of more than 4,700 aftershocks of the June-July 1976 Susanville (California) earthquake for the period between June 20 and July 1 with the phase of solid-earth tidal components appropriate for normal and shear stress on northeast and northwest trending fault planes. Based on this comparison, approximately 20% more earthquakes occurred at times when the normal compressive stress on the fault plane was decreasing and the shear stress was increasing in the sense of slip on the fault plane. This may be explained by two large bursts of aftershocks that occurred at times when tidal stresses were favorable for motion on the fault plane, rather than continuous triggering of small events during the entire sequence.

Kai (1988) suggested that the occurrence of Tangshan earthquake was due to the tidal force of the sun and the moon. He has confirmed that Hebei (North China) is an area with strong correlation between the tidal force and the occurrences of major earthquakes, the Xingtai earthquake 1966, the Hejian earthquake of 1967 and the Tangshan earthquake of 1976 were triggered by the tidal force, Kai (1988) suggested that the common characteristics of their occurrence times confirmed these facts. The computed times of maximum horizontal tidal force of the semi diurnal solid tide showed that the occurrence times of the above mentioned earthquakes were close to the times of maximum horizontal tidal force of the semi diurnal solid tide at new moon or full moon (Fig. 6, 7).

The Longyao earthquake of M = 6.8, Ningjin earthquake of M = 7.2 and the Hejian earthquake of M = 6.3 occurred tens of minutes after the maximum horizontal tidal force of the semi diurnal solid tides and the Tangshan earthquake of M = 7.8 occurred 16 min before the maximum horizontal tidal force. The tidal forces were directed to the West. The temporal characteristics of the earthquakes indicated that the occurrences of these events were not random, but were controlled by the tidal force from the Sun and the Moon (Fig. 8).

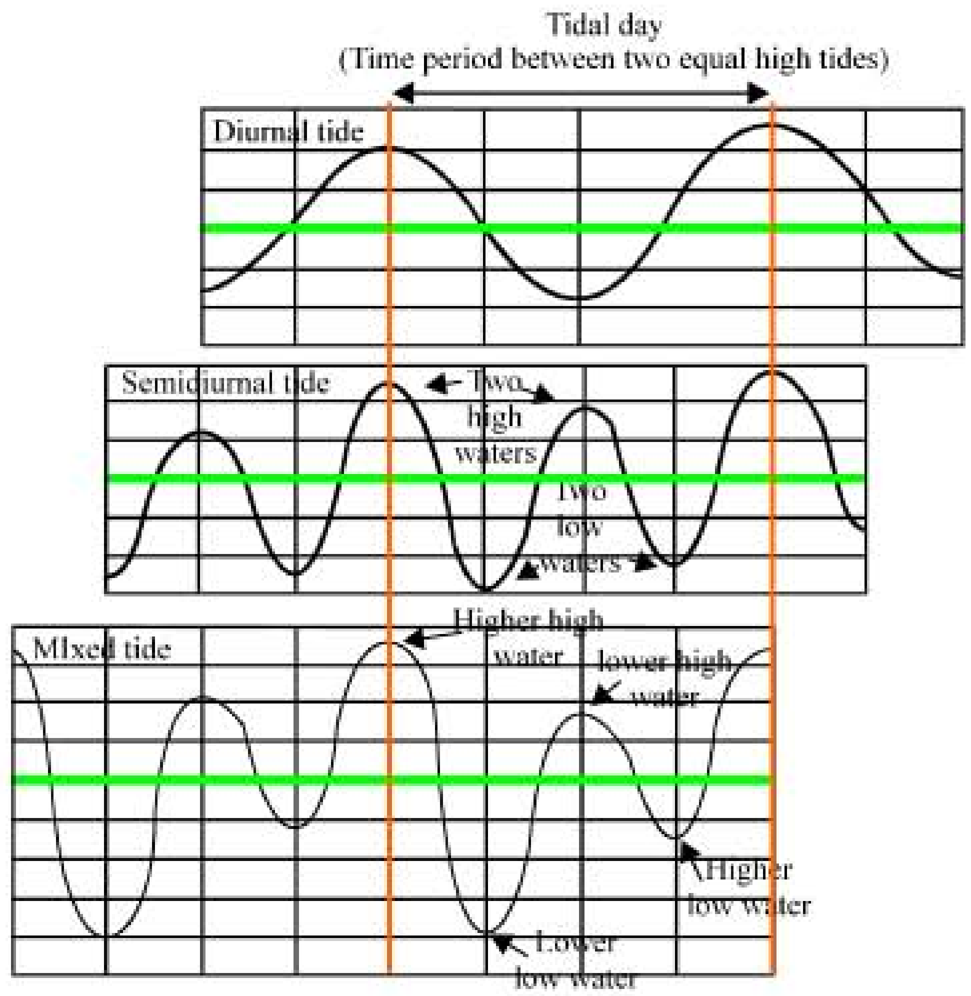


Fig. 6: Types of tides (USGS)

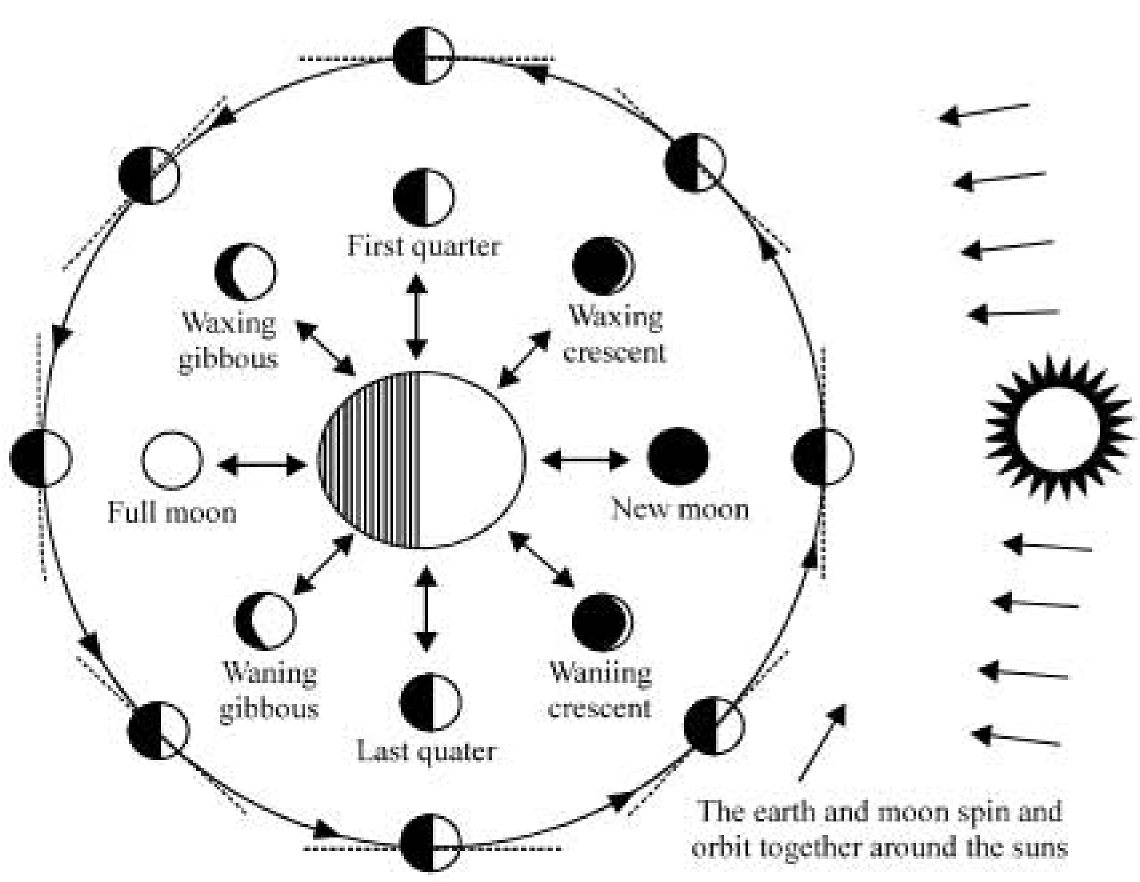


Fig. 7: Moon phases (USGS)

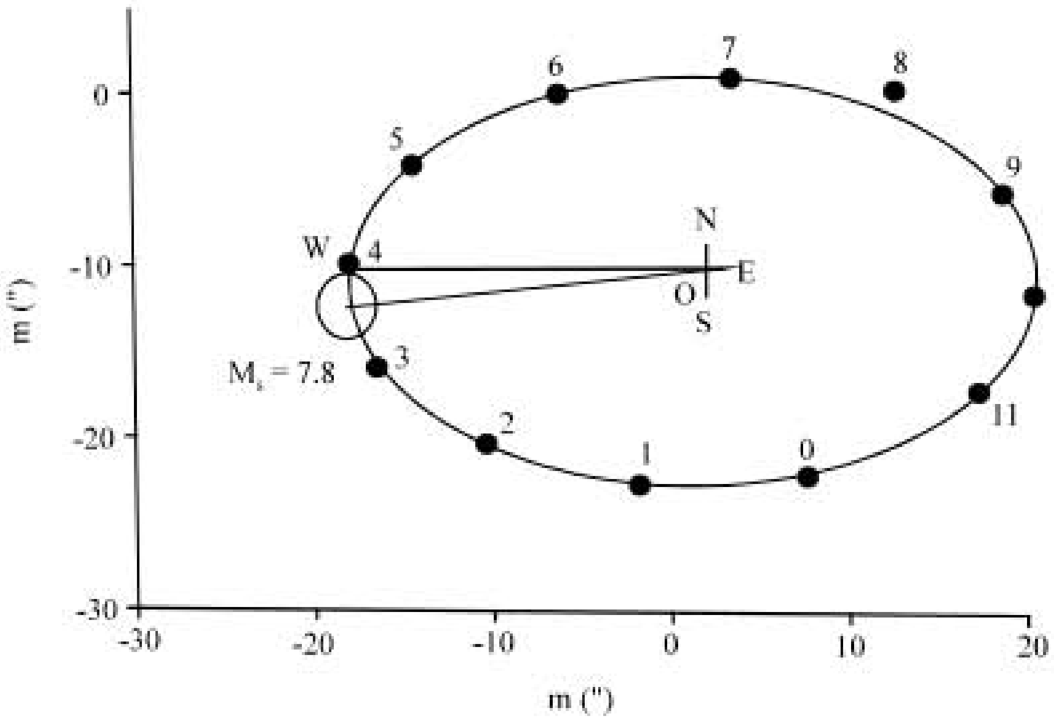


Fig. 8: The horizontal tidal force vector of the semi diurnal tide from 00:00:00 to 11:00:00 on July 28, 1976 for the epicenter of the Tangshan M_s = 7.8 earthquake, where OW is the maximum horizontal tidal force (Kai, 1988)

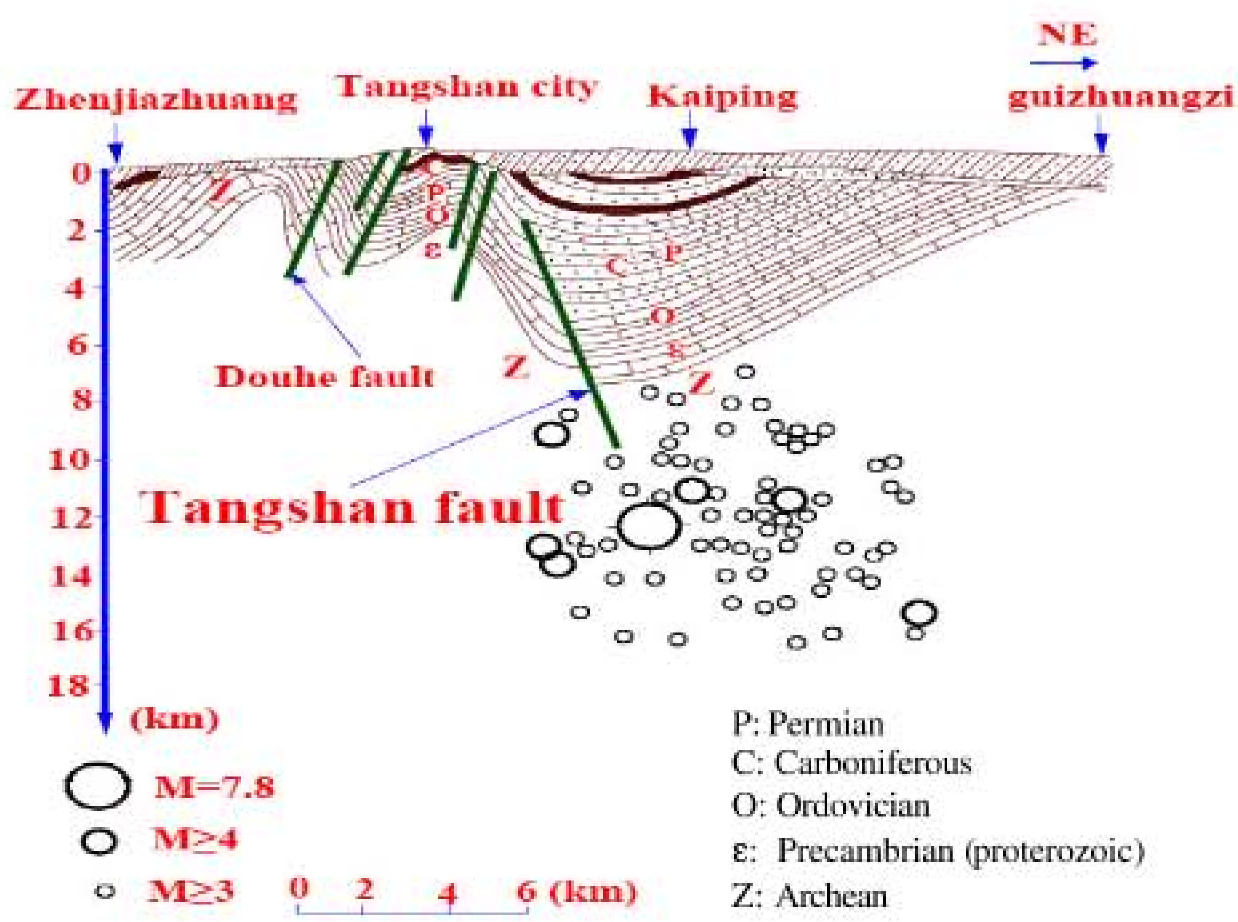


Fig. 9: The inclination of the Tangshan earthquake in 1976 originating fracture, the width of the profile is 24 km (Yang, 2003)

Here, some earthquakes from faraway countries were taken as an example, this does not cause problem, since the space-time correlation of earthquakes has already been proven (Patrizia *et al*., 2008).

The main content of the various stress sources, local shallow brittle crust and tidal force triggering effect is that before the occurrence of the Tangshan earthquake, the Tangshan earthquake region which have a geological and seismotectonic background characterized by shallow local brittle crust and in which the Tangshan earthquake fault is located (Fig. 9). The Tangshan fault received stress field from various sources and the stress accumulation seemed to be considerable since 1972 accompanied with the aseismic slip at the Jiyunhe fault (Fig. 1) which induced significant shear stress concentration at a depth of 20 km close to the conjunction of the Tangshan and Jiyunhe faults and that the Tangshan earthquake hypocenter received a coulomb failure stress of about 4.5 bar. The tidal forces played the role of triggering the earthquake by bringing the Tangshan fault to its threshold limit of withstanding with the huge stress accumulation, since, Hebei (Northeast China) Province is an area with strong correlation between the tidal force and the occurrence of major earthquakes and the Tangshan earthquake happened 16 min before the maximum horizontal tidal force (Bouasla, 2009).

By using the model of various stress sources, local shallow brittle crust and tidal force triggering effect, we can answer why Tangshan earthquake was of huge magnitude? May be because the seismogenic fault of Tangshan earthquake has received over a long time a huge stress from various sources and it happened at shallow depth may be because the brittle crust was of shallow depth (Bouasla, 2009).

DISCUSSION

In this study, the shortages of explanations on the cause of Tangshan earthquake were pointed out. It was anticipated that the new deduced model of various stress sources, local shallow brittle crust and tidal force triggering effect would provide reasonable answers for the incomprehensible questions related to the occurrence of Tangshan earthquake especially the huge magnitude, focal depth and the temporal occurrence. It was found that this model is the most comprehendable model to explain the cause of Tangshan earthquake. There are different hypocenters for 1976 Tangshan earthquakes (Department of Earthquake Disaster Prevention, China Seismological Bureau, 1999). The shallow structure of local crust near Tangshan should be further investigated, to understand clearly the tectonic background of this strong earthquake, including the understanding of the characteristics of surface fracture zone of this earthquake, its activity history during the late quaternary and the paleoearthquake activity in Holocene.

The following researches are propitious to present study:

Gao *et al*. (1995) achieved the analysis on shear wave splitting using digital data in Tangshan region from 1982 to 1984 and their results showed that stress in Tangshan Region was very complex. Using the 3D S-velocity structure and receiver function method of the crust and upper mantle beneath Tangshan area. Liu *et al*. (2007) showed that the earthquakes in Tangshan area were mainly distributed between the upper and lower crust. Hu *et al*. (1993) pointed out that the Tangshan earthquake sequences were mainly controlled by two tectonic belts: one is the main shock fault in NNE direction; the other is the fault located in southwest part of aftershock area in NW direction, except the aftershock of magnitude 7.1, other 3 aftershocks of magnitude greater than 6 were all concerned with the NW fault (Bouasla, 2009).

CONCLUSION

After the occurrence of Tangshan earthquake, seismologists have been puzzled by many questions: why Tangshan earthquake occurred in the place where only small scale ruptures being seen at the earth's surface and where Neotectonic movement is not active and no strong earthquakes were recorded in history? Why there are so many strong earthquakes in the Tangshan earthquake sequence? Why trend and outburst anomalies are distributed so wide? And why some anomalous variations after Tangshan earthquake are even more intensive and complex than that before earthquake (compile group for Tangshan earthquake in 1976, State Seismological Bureau, 1982)? Therefore, this model is helpful in understanding these questions (Bouasla, 2009).

ACKNOWLEDGMENT

I would like to thank the Professors Jin Zhenmin and Qu Guosheng for their direction and help.

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