ISSN 8755-6839

SCIENCE OF TSUNAMI HAZARDS

Journal of Tsunami Society International

Volume 40 Number 2 2021

THE GREAT TANGSHAN EARTHQUAKE OF 28 JULY 1976 IN CHINA - Analysis of Tsunami Generation in the Bohai and Yellow Seas

George Pararas-Carayannis

Tsunami Society International

ABSTRACT

No other earthquake in the 20th or 21st centuries was as catastrophic or claimed as many lives as that which struck the city of Tangshan in Northern China on 28 July 1976. Tangshan, a thriving industrial city of 1.6 million people in the Province of Hebei is located about 95 miles east and slightly south of Beijing and about 280 miles southwest of Haicheng of Liaoning Province. The main magnitude 7.8 earthquake was followed some 15 hours later by a 7.1 magnitude major event and numerous aftershocks. The first two events were mainly responsible for the destruction or severe damage of 93 percent of unreinforced houses, multistory residential buildings, and other structures in Tangshan and its southern suburb along the Beijing-Shanhaiguan railway. According to government records, the earthquake killed 242,769 people and severely injured another 169,851. However, based on the density of the population and the extent of the destruction, these figures have been disputed. The death toll has been estimated to have been three times greater than reported. The present study reviews the seismotectonics of the region, the aftershock distribution, the strike-slip ground motions of major existing faults along the YanShan and the Cangdong fold-fault zones, the Shanxi fault depression structural belt, the Taihang piedmont fault zone, the Guangdong and Tangcheng-Lijiang fault zones and the 1976 TangShan earthquake's intensities and ground motions, as well as the downward tilting and crustal displacements of sedimentary layers along the coasts of Bohai Bay**.** Based on this review and analysis, the present study examines the reasons why only a small tsunami was generated in Bohai Bay, even though earthquake intensities were high, ranging from VI to VIII.

Keywords: *Tangshan earthquake, Liaoning Province seismicity, YanShan Cangdong fold-fault zones, Shanxi structural belt, Taihang Piedmont fault zone, Bohai Sea tsunamis*

1. INTRODUCTION

Tangshan is a major city in the Hebei Province of China bordering Bohai Bay and Sea in the upper Yellow Sea. Two earthquakes on July 28, 1976, in the Hebei Province of northeastern China struck and totally destroyed the city of Tangshan – a city of 1.6 million inhabitants (Pararas-Carayannis, 2007; 2008a). The main quake had a magnitude of M 7.8 and an epicenter at 39.4 N. 118.0 E. (Fig. 1). It was followed by a major 7.1 magnitude destructive aftershock, some 15 hours later, that had a magnitude of M 7.1. The earthquake took a heavy toll on infrastructure and agriculture. Although not adequately documented, given the intensities of ground motions near the coast, a small tsunami was generated in the Bohai Bay of the Yellow Sea.

Fig. 1. Epicenter of the Tangshan Earthquake of 28 July 1976 in the Hebei Province of Both events were shallow (15 km) and occurred near the coast of Bohai Bay. *China.*

There were no foreshocks or clear precursory phenomena prior to the Tangshan earthquake - as there had been in other earthquake-stricken areas of China. However, half a month earlier there had been a series of abnormal signals observed in the regions of Beijing, Tianjin, Tangshan, Bohai and Zhangjiakou. Also, just prior to the earthquake, many unusual phenomena were observed in the immediate Tangshan region. There were observations of large amplitude variations of groundwater level and of strange animal behavior - – indicating that something was going to happen.

As early as July 12, it was reported that gas began to discharge from a well in a village. On July 25 and 26, this discharge increased. The day before the earthquake, well water at another village reportedly rose and fell three times and other wells showed signs of cracking of their lining. The night before the earthquake, many people in Tangshan reported seeing strange lights in the sky and hearing loud sounds. Some people reported seeing lights of multiple hues and fireballs traversing the skies. Unfortunately, these were isolated incidents that were spread over a large area in a heavily populated region of China, thus no special significance was given at the time. The anomalous precursory phenomena were widely scattered and inconclusive. They occurred too late to be of usefulness for short-term prediction and warning purposes. The only community that paid attention to the precursory phenomena was that of Qinglong County. Special emergency meetings for preparedness were held in the three days just prior to the earthquake – and this may have contributed to the greater survival rate in this County. Based on such signals the State Seismological Bureau had correctly concluded that a significant earthquake could be expected between July 22, 1976, and August 5. However, the precursory phenomena differed from those of other earthquakes. Because of the scattered distribution of the signals, there was no determination of the location where this earthquake would strike.

The following sections present more details on the Tangshan eartquake of 29 July 1976, on their aftershock distribution, earthquake's intensities, and ground motions, on the downward tilting and crustal displacements of sedimentary layers along the coasts of Bohai Bay, on the seismotectonics of the region, the strike-slip ground motions of major existing faults along the YanShan and the Cangdong fold-fault zones, the Shanxi fault depression structural belt, the Taihang piedmont fault zone, the Guangdong and the Tangcheng-Lijiang fault zones**,** as well as on the downward tilting and crustal displacements of sedimentary layers along the coasts of Bohai Bay and Sea**.** Based on this review and analysis, the present study examines the reasons why only a small tsunami was generated in Bohai Bay and Sea, even though the earthquake intensities were high.

2. THE GREAT TANGSHAN EARTHQUAKE OF 28 JULY 1976 IN NORTHERN CHINA

The great Tangshan earthquake with magnitude M 7.8 (later revised to moment magnitude Mw 7.6) and focal depth of 15 km occurred on July 28, 1976, at 19:42:53.8 UTC (local date and time: July 28, 1976, 03:42) in the Hebei Province of northeastern China. Its epicenter was at 39.60° N 118.20° E39.4 near the coast of the Bohai Sea (Fig. 1). The earthquake was felt in fourteen provinces of China, and as far as Xian, about 470 miles (756 km) away, in Beijing (about 140 km to the west), and in Tientsin (60 miles to the

southwest). Fifteen hours later, it was followed by a major 7.1 magnitude destructive aftershock in the Northeast, with an M 7.1 magnitude and epicenter at 39.7 N., 118.5 E. (Wang 1976; Mei, 1982; Yong et al 1988; Pararas-Carayannis, 2008a). Ground intensities in the area ranged from VI to VIII. Both events were shallow (15 km). Many strong aftershocks followed the larger earthquakes, two of which had magnitudes of 6.0 or more.
In the following days, there were many more aftershocks ranging in magnitude from 5 to 5.5 (Fig. 2). Several months later, on 15 Nov 1976, a magnitude 6.0 earthquake struck again in the same region (Pararas-Carayannis, 2008c).

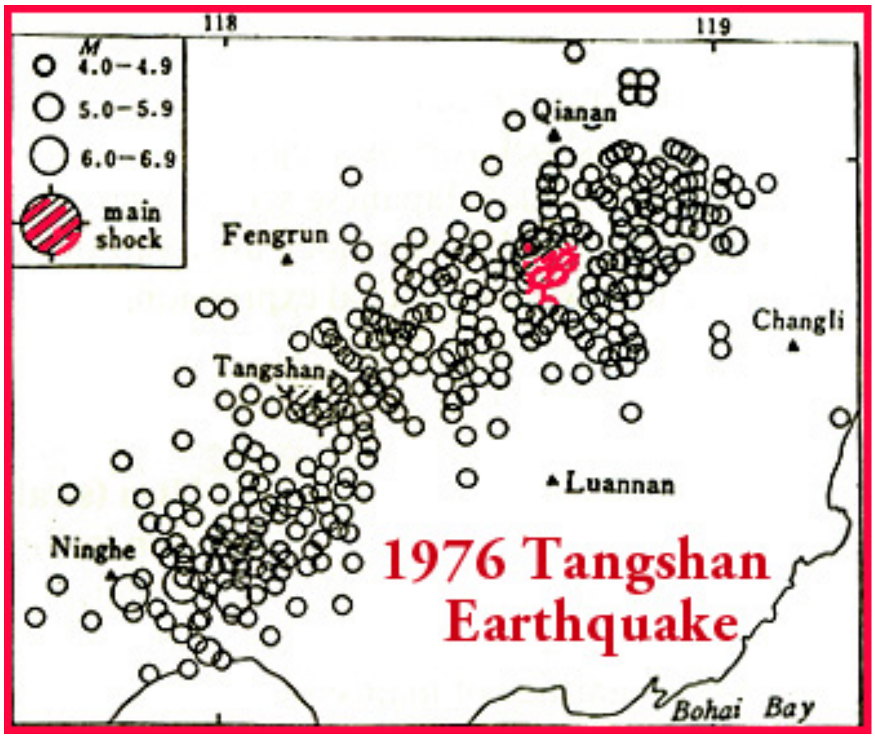

Fig. 2. The Epicenter and major aftershocks of the Earthquake of July 28, 1976 near Tangshan.

Figure 3 below is an aerial photo of Tangshan showing the degree of almost total destruction. According to local government accounts the 1976 earthquakes killed 242,769 people and severely injured another 169,851. However, based on the density of the population in the area and the fact that the earthquake destroyed ninety three percent of all residential buildings, the death toll was estimated to be three times greater than what had been reported, and to have ranged from 655,000 to 779,000 people.

The earthquake struck at 3:42 a.m. when most people were at home asleep. The timing contributed to the great death toll. What made matters worse, was the fact that the city of Tangshan is located in the center of an area surrounded with major faults. Most of the structures in the region were extremely vulnerable because they had been built on unstable, alluvial soils. Consequently most these structures were destroyed. Only a few of the city's structures and building were earthquake-resistant but even the well built structures suffered serious damage.

Fig. 3. Aerial photo of a section of Tangshan showing degree of destruction

The zone of maximum destruction was estimated to be is about 47 square kilometers. It included the city of Tangshan and the southern suburb along the Beijing-Shanhaiguan railway. The earthquake's destruction was beyond description. Over a four-by-five mile area the devastation of the city was nearly total. Everything was completely leveled. About ninety-three percent of residential buildings and seventy-eight percent of commercial and industrial buildings in Tangshan were destroyed. Highway bridges and at least two dams collapsed. All roads, except for one were closed. Rails were bent causing the derailment of seven commercial trains. Homes and factories were leveled to the ground. There was a total destruction of the region's infrastructure. Electric power, water supply and sewer systems failed. All telephone and radio communications systems stopped functioning. Almost all of the irrigation wells became inoperative. Sand and water gushed from the ground and spread over large tracts of farmland. Mud volcanoes of up to 3 meters in diameter sprung up.

What made matters worse, was the fact that the city of Tangshan is located in the center of an area surrounded by major faults. Most of the structures in the region were extremely vulnerable because they had been built on unstable, alluvial soils. Consequently

-ost of these structures were destroyed. Only a few of the city's structures and buildings were earthquake-resistant but even the well-built structures suffered serious damage. The damage was not restricted to the Tangshan region only. Damage was reported from as far away as Qinhuangdao, Tianjin, and Beijing.

2.1 Earthquake Intensities and Ground Motions

There were substantial ground movements along the segment of the fault that ruptured. Along the west side, the ground moved laterally for about five feet (1.5m.), in a north/northeast direction sub-parallel to the major axis of the microseismic zone. However, in some areas, horizontal ground displacements of up to 7 meters were subsequently measured. On the eastern side of the rupture, the ground block tipped upward near the south end and downward at the northern end.

The intensities of the 1976 earthquake and its ground motions were extensively surveyed and reported (Figure 3). In the epicenter area, the intensity was estimated at XI (State Seismological Bureau). The region with intensity X was reported as being elliptical in shape, and covering a total area of about 370 km2. According to eyewitness reports, the shaking lasted for about 90 seconds. Ground motions were so strong that people reportedly were thrown in the air. The region of intensity of IX was reported as being rhombic in shape, trending in a northeast direction and covering an area of about 1,800 km^2. In this area, most of the homes were damaged and about 40 percent of them collapsed. The region of the,intensity VIII extended in a southeastward direction, and covered an area of about 7,300 km^2. The region of intensity VII was reported to cover an area of about 33,000 km^2.

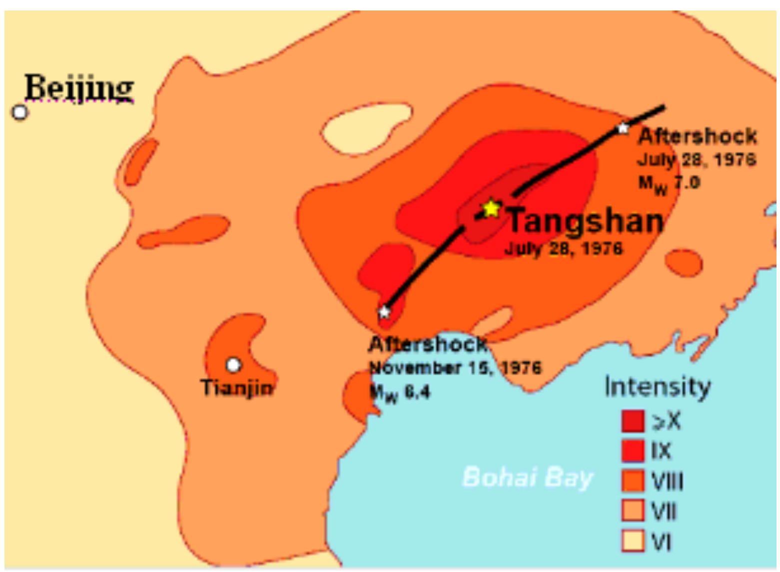

Fig. 4. Map of intensities of the earthquake in Tangshan and surrounding areas bordering Bohai Bay (after Wang Fang 1976, State Seismological Bureau of China)

The zone of maximum destruction was estimated to be about 47 km^2. It included the city of Tangshan and the southern suburb along the Beijing-Shanhaiguan railway. Over a four-by-five mile area, the devastation of the city was nearly total. About ninety-three percent of residential buildings and seventy-eight percent of commercial and industrial buildings in Tangshan were destroyed.

2.2 Loss of Life and Damages

The actual death toll from this earthquake may never be known with certainty. According to official government accounts the earthquake killed 242,769 people and severely injured another 169,851. However, based on the density of the population and the extent of the destruction, these figures have been disputed. As mentioned, Tangshan was a city with 1.6 million people. Combined the two earthquakes of 28 July 1976 destroyed ninety three percent of all residential buildings, and the death toll was estimated to be three times greater than what was reported - ranging from 655,000 to 779,000 people. At least 700,000 more people. At least 700,000 more people were injured, and property damage was extensive, reaching even Beijing. The extremely high death toll makes the 1976 Tangshan event the second worse earthquake disaster in recorded history. The most destructive earthquake ever occurred four centuries earlier in 1556 in Shaanxi, China. It is estimated that the 1556 earthquake killed 830,000 people. Another earthquake in the Gansu region in 1920 had killed about 200,000.

2.3 Tsunami Generation in the Bohai and Yellow Seas

Given the high intensities of the earthquakes near the coasts of Bohai Bay and Sea, a tsunami was generated and must have been responsible for deaths and damages. However, the devastation from the earthquake was so great, that no distinction was made of the effects of the tsunami in Bohai Bay and Sea or further away in the Yellow Sea. Figure 5 indicates earthquake intensities of VI, VII, and VIII along Bohai Sea's coastal region and the postulated source area of tsunami generation, even though crustal movements were predominantly of the strike-slip type, although the ground block tipped upward near the south end, thus contributing to tsunami generation.

Subsequent sections 3, 4, and 5 of the present report examine the neotectonics of the Bohai basin region, the impact of past historical events, and the postulated tsunami generated by the Great Tangshan earthquake of 28 July 1976, as indicated by the upward tipping of the southern ground block and the lateral compressive motions on consolidated sedimentary layers. Based on a previous analysis of the unique conditions of the Bohai Basin (Pararas-Carayannis, 2009), the present study examines and re-evaluates the potential for local tsunami generation from a variety of direct and collateral source mechanisms triggered by intraplate earthquakes such as the Tangshan event in the northeast region of China (Pararas-Carayannis http://tsunamisociety.org/281GPCC.pdf

More specifically, section 5 of the present study examines such collateral mechanisms of tsunami generation by the folding and en-echelon bookshelf failures of the consolidated sedimentary formations near the coasts of the Bohai Sea, as well as the very possible earthquake impact on the destabilization/dissociation of existing structural accumulations of gas hydrate deposits within the basin's thick, sedimentary stratigraphic layers. In brief, the potential for tsunami generation in the Bohai Sea was exacerbated by the thick accumulation of sediments (in different states of consolidation) and the multi-layered stratigraphic distribution of sediments with different shear strengths, densities, and rigidities. Following an earthquake, en-echelon, bookshelf type of failures occur with oblique directivity to the general strike orientation could impart greater tsunami energy and alter tsunami directivity. Thus, any mathematical modeling study must consider such complexities of source inputs for such environments of extreme sedimentation.

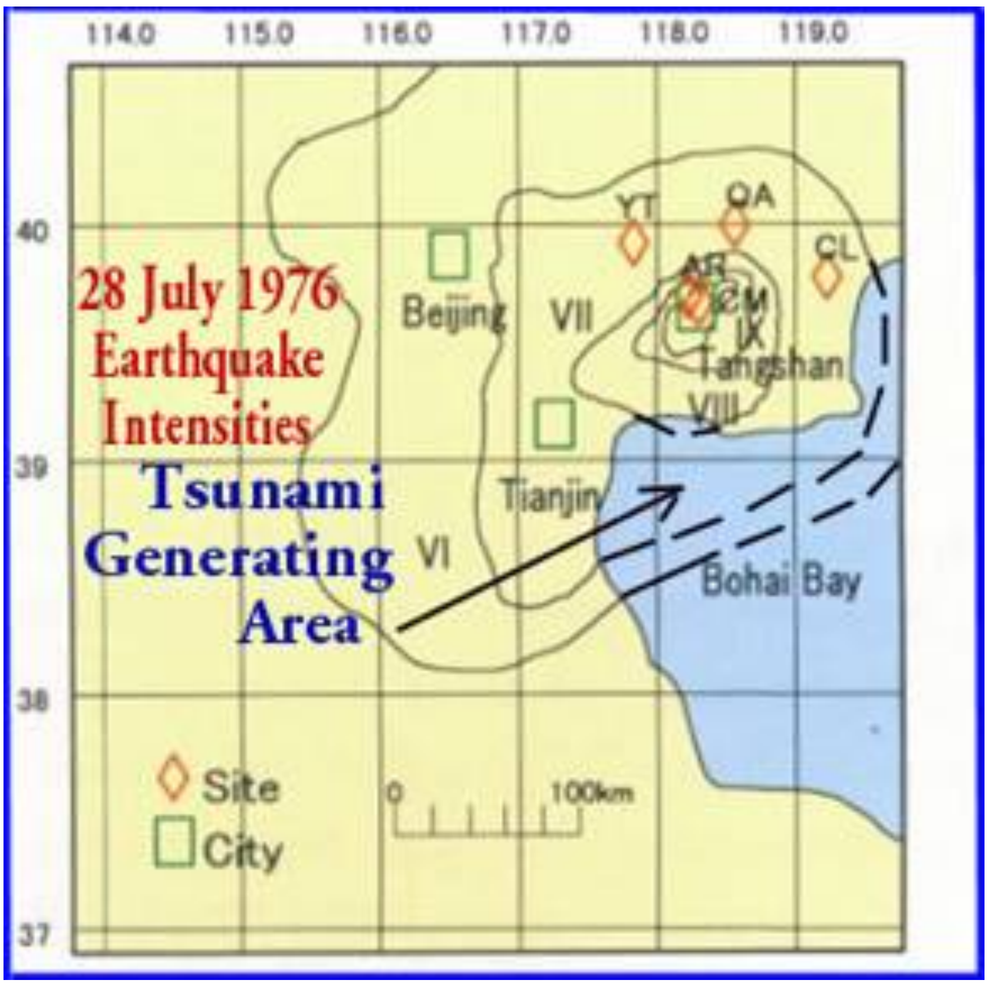

Fig. 5. Intensities of Ground Motions of the Tangshan Earthquake (after Wang Fang 1976, State Seismological Bureau of China). Postulated Tsunami Generating Area.

3.0 SEISMOTECTONICS OF THE TANGSHAN AREA AND OF NORTHERN CHINA

The high seismicity of central and eastern Asia results from the northward collision convergence (at about 50 mm/y) of the India tectonic plate against the Eurasian plate. This active collision - which begun about 55 million years ago during the Cenozoic era (Zhang et al, 1984; Hellinger et al 1985; Ye et al 1985; Yu et al 1995; Xu et al. 1996; Yin and Nie, 1996; Hendrix & Davis, 2001; Castellanos & Mann 2005; Zhao et al, 2005; Pararas-Carayannis, 2007; 2008; 2008b; 2008c; 2008d; 2009) - is the cause of frequent large earthquakes between India and Tibet, throughout Tibet and China. The convergence has uplifted the Asian highlands and the Tibetan Plateau to an average elevation of over 16,000 feet (about 4,880 meters) - the highest and largest plateau on Earth - with hundreds of kilometers of displacement of crustal blocks to the east and southeast in the direction of China. Thus, the high seismicity of China is dominated by this northward collision and convergence (Fig. 7).

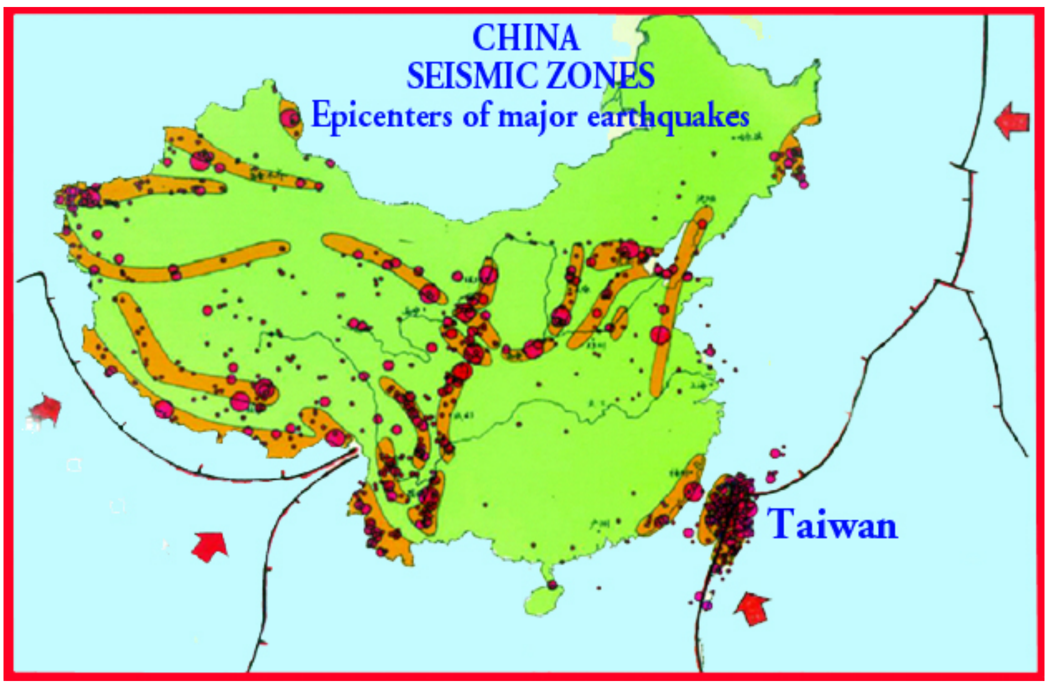

Fig. 7. China's Seismic Zones created by collision and convergence (after Pararas-Carayannis, 2007)

The active collision has resulted in three distinct deformational episodes in China that occurred 200-240 million years ago and resulted in initial thrusting and subsequent vertical extrusion, while later episodes resulted in folding (Li et al. 2007). The convergence has formed the most active and extensive seismic belts in China as shown in Fig. 7, and in the formation of major fault zones. Such crustal displacements along China's seismic zones are responsible for the large destructive earthquakes, which occur with high frequency.

3.1 Major Faults and Rupture in the Tangshan Region

The Tangshan earthquakes of 29 July 1976 ruptured a five-mile (8 km) section of a 25-mile strike-slip fault with a north-northeast orientation that passes through the city Tangshan (Fig. 4). The fault is part of an extensive strike-slip fault system, known as Tancheng-Ljiang, or Tan-Lu. This system extends in a north-northeast direction for more than 3,200 miles from the north bank of the Yangtze River in eastern China to the west across the Russian border.

Specifically, the 1976 earthquake occurred at the junction of the YanShan fold-fault zone and the Cangdong fault zone. The YanShan fold-fault zone runs in an east-west direction and lies north of the Tangshan region. To the south, there are several sub-parallel northeast-trending fault zones known as the Shanxi fault depression structural belt, the Taihang piedmont fault zone, the Cangdong fault zone, and the Tangcheng-Lijiang fault zone. According to the scientific literature, each of these zones has produced several earthquakes. Several episodes of uplift and other anomalous variations along different segments of the fault zones that comprise the Yan Shan Seismic Belt have been reported.

3.1a The Yan Shan Seismic Zone

The Tangshan earthquake occurred at the junction of the Tangshan fold-fault zone and the Cangdong fault zone. The YanShan fold-fault zone runs in an east-west direction and lies north of the Tangshan region. To the south, there are several sub-parallel northeast-trending fault zones known as the Shanxi fault depression structural belt, the Taihang piedmont fault zone, the Cangdong fault zone, and the Tangcheng-Lijiang fault zone. According to the scientific literature, each of these zones has produced several earthquakes. Several episodes of uplift and other anomalous variations along different segments of the fault zones that comprise the Yan Shan Seismic Belt have been reported. The significance of these anomalies remains to be further investigated as to the potential for future destructive earthquakes in the Beijing-Tianjin area, and for tsunami generation near the coasts in the Hebei Province and the Liaoning Province, north of Bohai Bay.

3.2 Ground Movements, Crustal Displacements and Fault Rupture of the Great 1976 Tangshan Earthquake

There were substantial ground movements along the segment of the fault that ruptured as a result of the Great Tangshan earthquake. Along the west side, the ground moved laterally for about 1,5 m in a north/northeast direction, sub-parallel to the major axis of the microseismic zone. However, in some areas, horizontal ground displacements of up to 7 meters were subsequently measured. On the eastern side of the rupture, the ground block tipped upward near the south end and downward at the northern end. As previously mentioned, the earthquake's intensities, the aftershock distribution, the crustal displacements, and the downward tilting at the southern end must have included a good portion of the Bohai Sea and the generation of a local tsunami.

The earthquake ruptured a five-mile (8 km) section of the 25-mile long fault that passes through the city Tangshan. The Tangshan Fault is a strike-slip fault with a north-northeast orientation. The fault is part of an extensive strike-slip fault system, known as Tancheng-Ljiang, or Tan-Lu. This system extends in a north-northeast direction for more than 3,200 miles from the north bank of the Yangtze River in eastern China to the west across the Russian border

4.0 HISTORIC EARTHQUAKES AND TSUNAMIS IN THE BOHAI BASIN REGION OF NORTH-EAST CHINA

The complex intra-plate earthquakes in Northern China have been extensively studied in the past by US institutions funded by the National Science Foundation's PIRE (Partnerships for International Research and Education) in close collaboration with numerous Chinese institutions. The studies included integration of seismic imaging of earth structure, geodetic measurement of crustal deformation, paleo-seismic reconstruction of earthquake histories, and geodynamic computer simulations. Such studies provided a better understanding as to the causes of large earthquakes in Northeast China, such as the destructive 1976 Tangshan event that leveled the city and caused the greatest death toll in recent history.

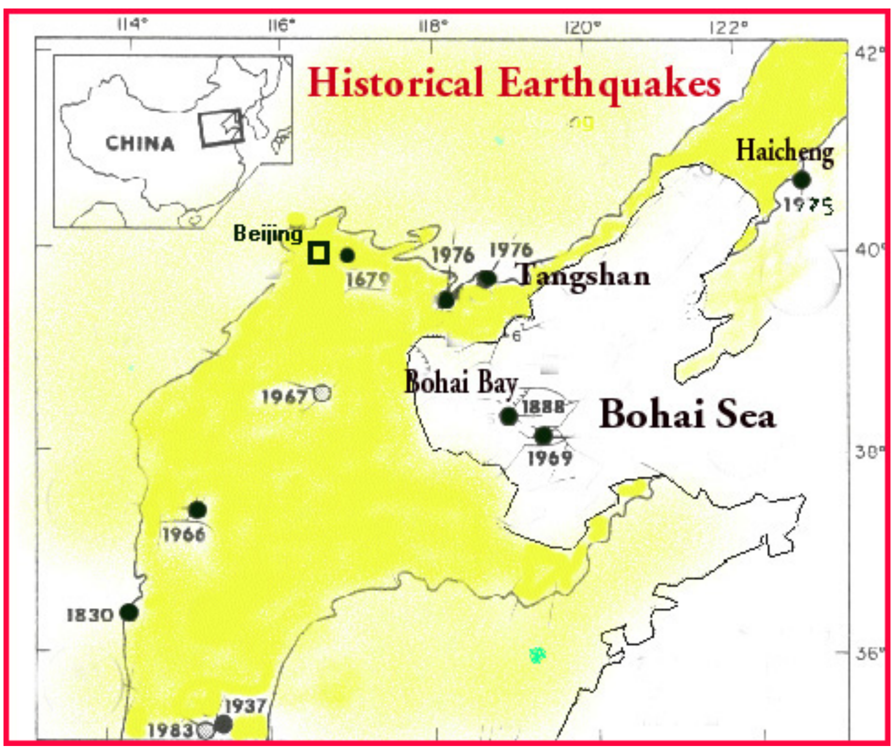

Fig. 8. Historic earthquakes in the Bohai Sea in the Northeastern Margin of China.

According to historical records, there have been six great earthquakes of Ms 8 magnitude and 16 major earthquakes of Ms 7 magnitude in the area of Northeast China, in the past 2000 years7 (Gu, 1983; Ma, 1988, Pararas-Carayannis. 2007). Earthquakes with Ms >7 have occurred in this region between 1966 and 1976 (see Fig. 8 above). Economic losses caused by these earthquakes were estimated to be about 10 billion yuan, but Tianjin city alone suffered about 7.5 billion Yen in direct and indirect damages, therefore even this figure is probably inaccurate. Historically, the Shaanxi Province massive earthquake of 23 January 1556 in northern China, with an estimated magnitude of M 8.0, is believed to be the deadliest ever recorded. It struck Shansi, China killing 830,000 people.

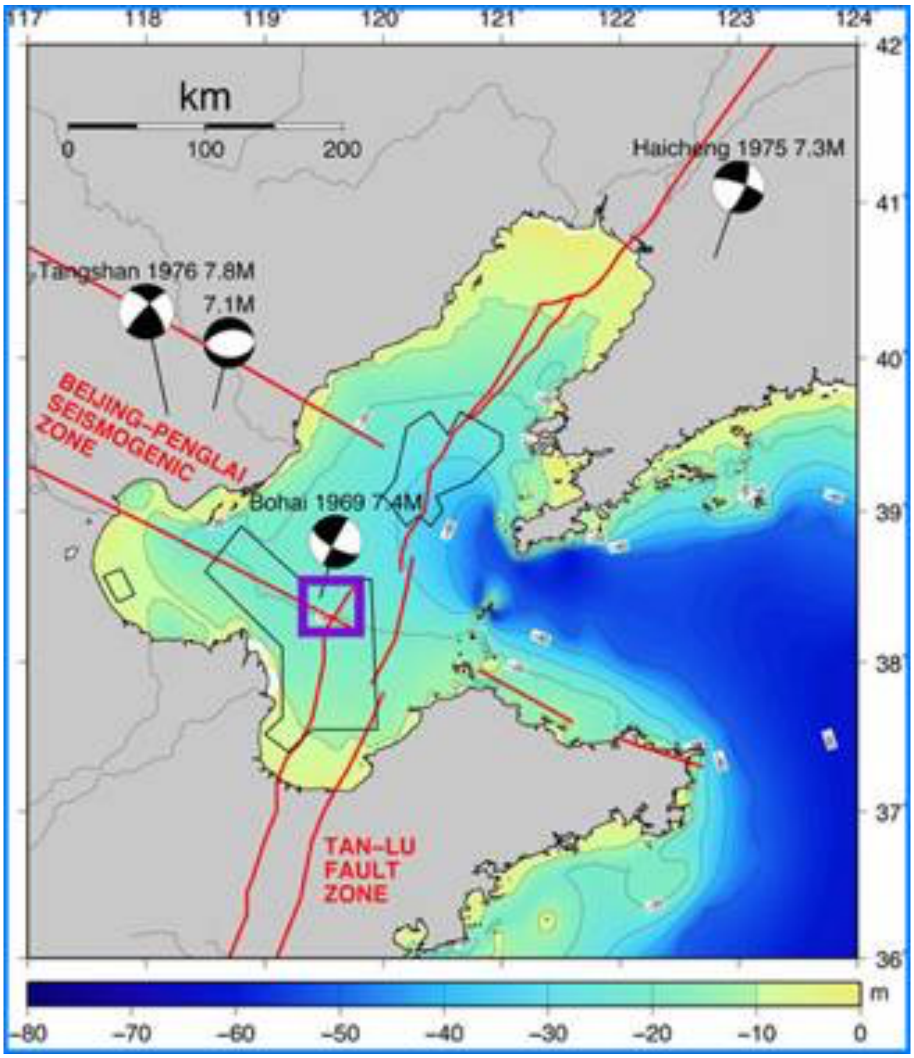

Fig. 9. *Major seismotectonic and seismogenic fault zones in the Bohai Basin and Sea. Earthquake epicenters and focal mechanisms of recent earthquakes. Bathymetry based on GEBCO digital data base* (after Pararas-Carayannis, 2009) (*modified graphic, after Yang & Xu, 2004 and Xu et al, 2004).*

The more recent earthquakes also resulted in hundreds of thousands of casualties and in significant economic damage. As mentioned, the worse of all recent events was the July 28, 1976, Tangshan earthquake. Generally, and as shown in Fig. 9, these large earthquakes have occurred along the major active faults that bound the Bohai Basin, but even within the Bohai Sea in 1888 and in 1969. Numerous strike-slip and normal faults on land in the Liaoning and Hebei Provinces are the predominant active structures where such very destructive earthquakes occur more frequently.

As previously indicated, the fault-plane solutions of historic earthquakes in the Bohai Basin area usually show right-lateral strike-slip with prominent NE orientation, although some had NW orientation with a normal dip-slip component. Recurrence frequencies in this region also have varied. Although earthquake recurrence intervals along any individual fault in the Bohai Basin are relatively long (usually in the range of several thousand years), the composite recurrence interval for the whole region is in the order of a few decades (Ma et al., 1989; Ma & Gao, 1996).

4.1 The 4 February 1975 Haicheng Earthquake and Tsunami

A previous major earthquake in the region occurred at 19:36 CST on 4 February 1975 South-Southeast of Haicheng, a town of approximately one million inhabitants in China's southern Liaoning Province (Fig. 9) The Haicheng earthquake and tsunami have been extensively studied (Chen, Y-T et al., 1976; Shou, 1999. Chen et al. 2007; Cipar 1979; Davis et al. 2001, Earthquake Administration of Liaoning 1975; Wang et al, 2006; Wang 2007; Pararas-Carayannis, 2008b). The quake had a shallow depth and M_s magnitude of 7.5. In addition to damage in Liaoning Province and its surroundings, minor damage was also reported in Seoul, South Korea. The quak was felt in Primorsky Krai, Russia, and in Kyushu, Japan.

Although the quake caused total destruction of Haicheng's infrastructure and property, it did not result in many deaths because the earthquake had been successfully predicted and most inhabitants had evacuated the city earlier that day. The decision to evacuate was based on reports of continuing changes in groundwater and soil elevations over a long period, as well as widespread accounts of unusual animal behavior. The unusual animal behavior was observed earlier in December 1974. According to reports, rats and snakes appeared "frozen" on the roads. Also, starting in February 1975 reports of unusual animal behavior increased greatly. Cows and horses looked restless and agitated. Rats appeared "drunk", chickens refused to enter their coops and geese frequently took to flight . (Anonymous, 1977).

All these observations placed authorities on high alert, and earlier in the day on the 4th of February, ordered the evacuation of the city. Though this particular prediction of the earthquake was initially believed to be just the latest in a recent string of false alarms that had occurred in the preceding months, including one case of an earthquake swarm being caused by filling of a reservoir (Wang et al, 2006) the evacuation of Haicheng proceeded anyway and eventually paid off. Local authorities ordered the evacuation of Haicheng early in the morning of 4 February. Nonetheless and in spite of the massive early evacuation that day, when the earthquake struck later at 7:36 p.m., 1,328 (some say 2,041) people died, over 27,000 were injured, as thousands of buildings collapsed. However, it was estimated that the death toll would have been at least 150,000 if there had been no evacuation at all.

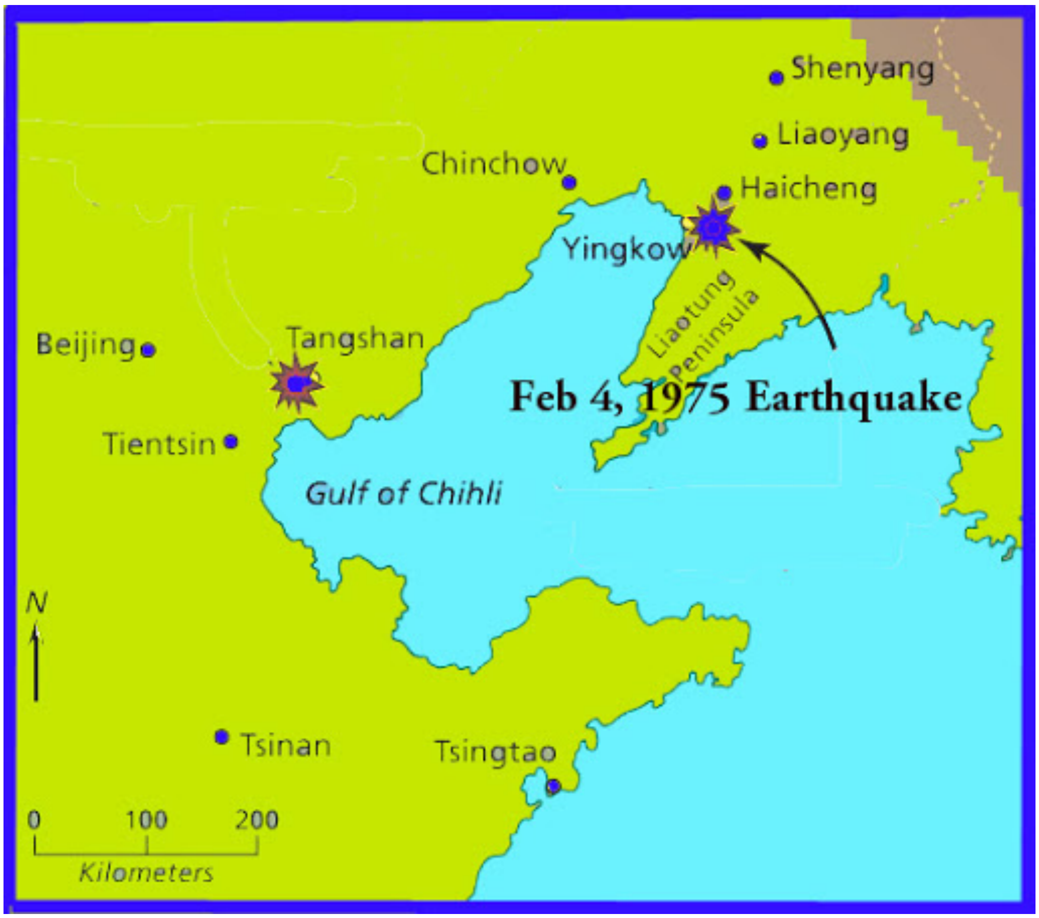

Fig. 9. The 4 February 1975 Earthquake in Haicheng. Liaoning Province

In recent years, the success of the earthquake's prediction has come under scrutiny (Ma, L. and Gao, X., 1996; Yin et al, 2000; Keilis-Borok & Soloviev, 2003). Seismologists have agreed that the Haicheng earthquake can't be looked to as any sort of "prototype" for predicting future earthquakes, as the foreshocks that played a huge role in leading to aprediction of this earthquake are not regular, reliable occurrences before all earthquakes. However, Qi-Fu Chen, a professor at Beijing's China Earthquake Administration, explained that this earthquake at least "showed the importance of public education," prompting a further discussion about the necessity of making the public aware of the dangers, of preparations, and of warning signs related to earthquakes (USGS, 2015 Historic Earthquakes)

5. TSUNAMI GENERATION IN THE BOHAI SEA FROM THE GREAT TANGSHAN EARTHQUAKE OF 28 JULY 1976

Infrequent earthquakes along active tectonic structures that crisscross the Bohai Basin near or within the Bohai Sea have generated local tsunamis in the past by a combination of direct and collateral mechanisms that involved not only strike-slip mechanisms but also tilting and upward or downward movements due to the folding of existing thick sedimentary layers, or the destabilization of gas hydrates deposits. Although most of the earthquakes in the Bohai Sea and the adjacent region, involve mainly lateral strike-slip components that do not contribute significantly to the generation of tsunamis, en-echelon structural failures and destabilization of existing gas hydrates deposits in the Bohai Sea have been postulated as being responsible for local tsunami generation (Pararas-Carayannis, 2008). Such mechanisms of the 28 July 1976 earthquake contributed to local tsunami generation as discussed in the following section.

5.1 Collateral En-Echelon Structural Failure Mechanisms of Tsunami Generation by the 28 July 1976 Earthquake - Partial Upward Block Displacement

As indicated by a previous study (Pararas-Carayannis, 2008), stress and tectonic displacements caused by an earthquake along a fault - whether strike-slip, normal, or inverse - in a multi-layered sedimentary environment such as that of the Bohai Sea - can cause structural failures that may be oblique to the overall fault orientation and thus result in collateral displacements, en-echelon structural failures, and bookshelf faulting of the seafloor, all of which could contribute to tsunami generation.

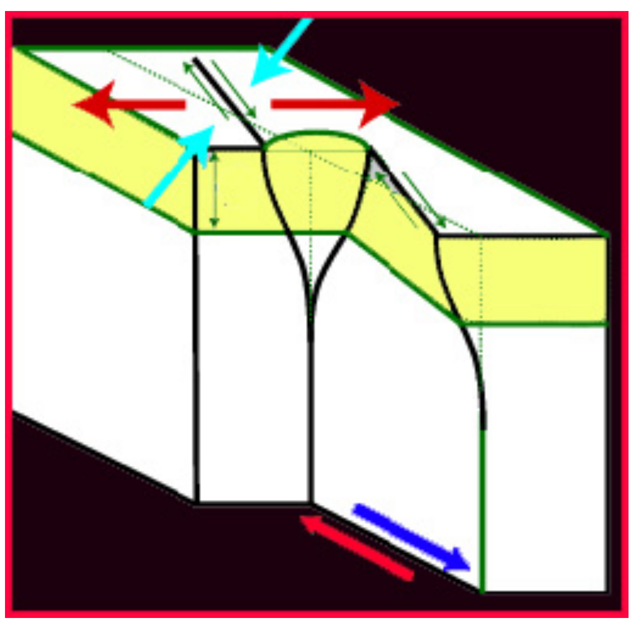

Fig. 10. Stress concentration induced by strike-slip faulting across layer interfaces. (Modified Graphic http://hraun.vedur.is/ja/prenlab2final/img114.gif)

The combination of high intensities of the 28 July 1976 earthquake, and of a localized upward block movement along the southern region of the affected source region, apparently contributed to folding of the thick sedimentary layers and to local tsunami generation in the Bohai Sea and adjacent region.

Fig. 10 above is an illustration of stress concentration which can be induced by strike-slip faulting across layer interphases of consolidated sedimentary layers. Shear cracks along a fault may be vertical and planar, but may also result in splits into two or more interacting sections at a stratigraphic interface with different density and stress drop - depending on rigidity contrasts between the adjoining media. Furthermore, the deeper sediments along faults in the Bohai Sea may be characterized by different elastic parameters, depending on the degree of hydration, particle size distribution, and compaction densities.

Also, a series of bookshelf type of structural failures may occur which will be oblique in orientations to the overall faulting trend. Oblique, en-echelon type of failures could result in multiple ruptures that could also affect the sediments of the upper layers - thus changing the spatial geometry and characteristics of the source area and the mechanism of tsunami generation. Slower rupture rates with different azimuthal orientation can be expected within these layers. Furthermore, net seafloor displacements can be expected to vary and the tsunami's directivity to be different from what may be inferred from fault orientation or focal plane solutions (Pararas-Carayannis, 2008).

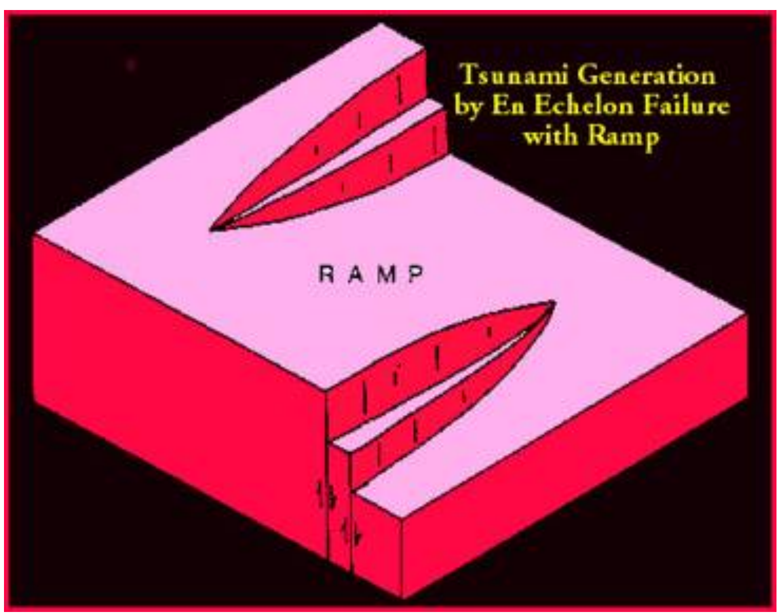

Fig. 11. Tsunami Generation by En Echelon Step Fault Displacement and by Sea Floor Changes with Elevated and Depressed Ramp Structure (After Pararas-Carayannis, 2008).

For example, the simplified mechanical/geometrical effects left by a model earthquake within a transform fault plane at the sedimentary discontinuity interphase have been extensively investigated by employing the "displacement discontinuity method" (Bonafede & Neri, 2000). Figure 11 illustrates a simple case of such stress-induced displacement discontinuity and the potential changes in the geometry and characteristics of the tsunami source. Additional investigations have dealt with the two-dimensional dynamics of yhe shallow reverse type of faulting upon discontinuity interphases (Madariaga, 2008).

However, in an actual multi-layered sedimentary environment such as that which exists in the Bohai Sea, the geometrical complexities and stress drop values can be expected to vary along planar strike-slip or reverse faults. Faulting in such an environment cannot remain planar. Strike-slip faulting at depth may be accompanied by en-echelon surface breaks in a shallow sedimentary layer - where the stress drop may be lower at the discontinuity interphase, while ductile deformation at depth may be accommodated by antithetic faulting in the upper brittle layer - enhanced with lower rigidity but higher stress - thus resulting in bookshelf faulting that can augment tsunami generation and alter tsunami directivity (Fig. 11), as indicated by earthquakes elsewhere. For example, bookshelf failure of sedimentary layers is believed to have resulted in the augmentation and apparent directivity from the north (rather than from the west) when the tsunami of December 26, 2004, struck Aceh, in Sumatra. It is believed that similar bookshelf and en-echelon failures within subducted sediments were also associated with the September 2, 1992 earthquake off the coast of Nicaragua and enhanced the tsunami run-up (Pararas-Carayannis, 1992). Indeed, studies of aftershock distribution of earthquakes around the world indicate an extensive concentration of their focal depths along sedimentary bedding planes - which would also support that such failure mechanisms contribute to tsunami enhancement and differences in azimuthal tsunami source parameters (Fig. 12).

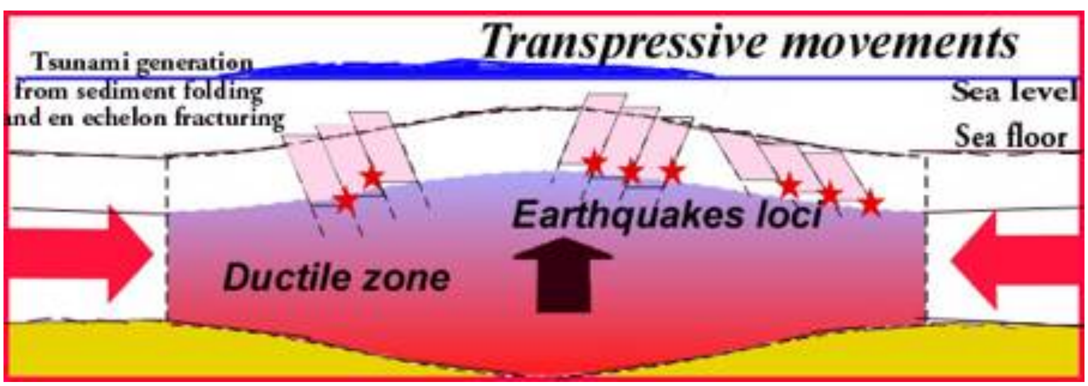

Fig. 12.Transpressive Movements and Tsunami Generation from Sediment Folding and en-echelon fracturing.

Therefore, we may conclude that such distribution of aftershocks of the 28 July 1976 earthquake - localized along with sedimentary discontinuity layers - not only indicates the asymmetric interactions between the original fault plane of the earthquake and the shallower sedimentary layers, but also indicate that significant residual, compressive or tensile stresses remained over the shallower portion of the fault surface on the southern section, after the major shock and fault rupture. Thus, the strong aftershocks of the earthquake in the existing sedimentary environment of the Bohai Sea Basin contributed to local tsunami generation In brief, tsunami generation in the Bohai Sea was exacerbated by the thick accumulation of sediments (in different states of consolidation) and the multi-layered stratigraphic distribution of such sediments, with different shear strengths, densities, and rigidities. En-echelon, bookshelf type of failures with oblique directivity to the general strike orientation imparted greater tsunami energy and altered its directivity.

Finally, Tsunami Society International in 2002 held a Symposium in Honolulu, Hawaii where the existence of gas hydrates in submarine sedimentary formations was extensively reviewed. One of the papers, in particular that was presented pertained to the global distribution and significance in the petroleum industry of naturally occurring gas hydrates as well as of the associated risks (Milkov, 2002). The risks were also expanded in subsequent studies (Watson et al., 1987; Pararas-Carayannis, 2009).

As graphically illustrated by Fig. 13 below, there may have been some contribution to local tsunami generation from the dissociation of gas hydrate within the consolidated sedimentary zone which exists in the Bohai Bay area, where oil and gas extracting platforms did not exist in 1976. However, this is an area of great reserves of oil and gas in China.

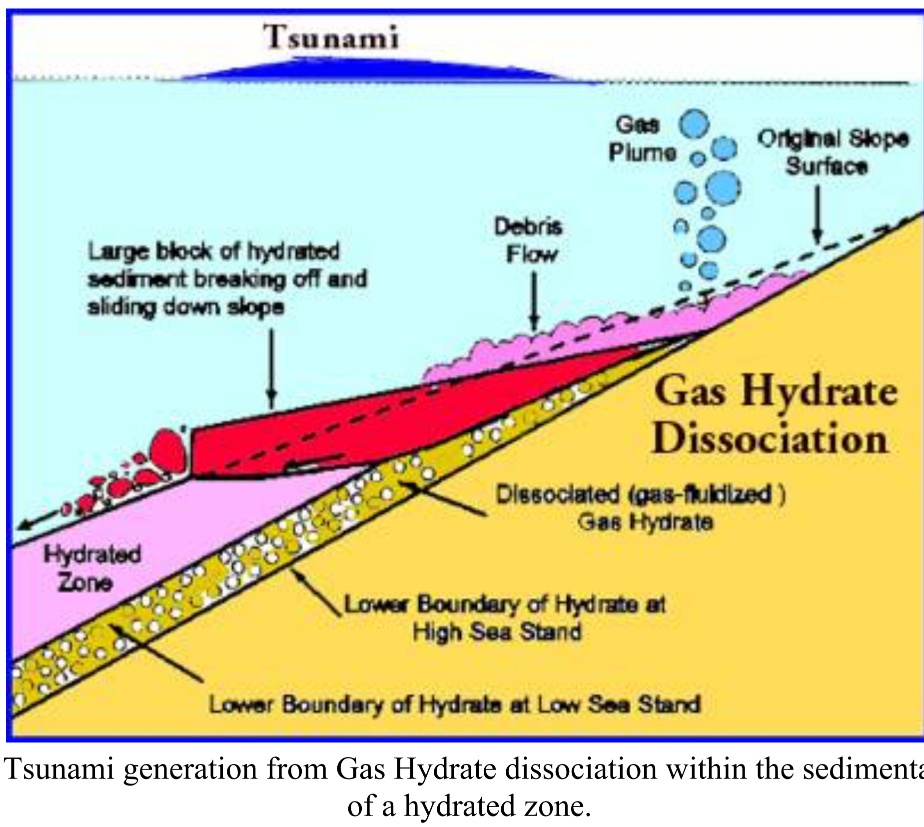

Fig. 13. Tsunami generation from Gas Hydrate dissociation within the sedimentary layers of a hydrated zone.

Presently there are several platforms operating at a water depth of about 90 feet (27.43 meters) in Bohai Bay, about 140 miles from the town of Tanggu and about 85 miles from the town of Dallan. However, and as pointed out, the Bohai Sea is shallow and the slope of its underwater bathymetry is rather gentle, so a massive landslide was unlikely to have occurred in 1976 when the Tangshan earthquake occurred, although future large earthquakes may contribute to tsunami generation and possible damage to such offshore platforms, particularly in winter months when there is an accumulation of ice on the surface of Bohai Bay (Zang et al, 2008) and a local tsunami could carry large pieces of broken ice that could strike and perhaps damage the supporting columns of the now existing oil and gas platforms or even break pipelines and ignite a fire similar to the "Deep Horizon" drilling rig explosion of 2010 in the Gulf of Texas

CONCLUSIONS

The magnitude M7.8 earthquake of 28 July 1976 and its M7.1 major aftershock in the Hebei Province of Northern China were extremely catastrophic in the city of Tangshan and surrounding areas and resulted in more deaths than any other earthquake in recent times. Based on a review and analysis of the seismo-tectonics of the region, of earthquake intensities, of aftershock distribution, and of strike-slip ground motions of the major existing faults along the YanShan and the Cangdong fold-fault zones, the present study provides an explanation as to the extreme impact of this event. Although strike-slip earthquakes involve primarily lateral ground motions and do not generate tsunamis, this particular earthquake involved some downward tilting and crustal displacements of both consolidated and nonconsolidated sedimentary layers along the coasts of the Bohai Sea, which contributed to local tsunami generation within the Bohai Sea.

The Tangshan earthquake of 28 July 1976 involved mainly lateral strike-slip faulting ground motions which do not trigger tsunamis, but high-intensity ground motions associated with such strike-slip events near a coast can often trigger undersea landslides, which may result in significant tsunamis. The Bohai Sea is very shallow, so the 1976 earthquake-generated no significant landslides. However, the coastal geomorphology and the presence of consolidated sedimentary layers in the Bohai Basin region – some of the tilting - support local tsunami generation by the compression of such layers into bookshelf type of failure in a sequential manner by the lateral forces of the strike-slip earthquake. Such mechanism contributing to greater tsunamigenic efficiency was determined for the 2011 Japan earthquake and for the higher degree of that tsunami's destructiveness along Honshu Island's coastlines. The study of the 2011 event in Japan indicated that vertical crustal displacements of more than 10 m due to up-thrust faulting, were augmented by lateral compression and folding of sedimentary layers, thus contributing to additional uplift estimated at about 7 meters - mainly along the leading segment of the accretionary prism of the overriding tectonic plate, and thus contributing significantly to a tsunami of greater height (Pararas-Carayannis, 1983, 1993; 2011; 2013). Therefore, it is concluded that even in the absence of major vertical displacements, the strike-slip motions of the 1976 Tangshan earthquake, the high up to XI intensities near and along the coasts of the Bohai Sea, and an upward crustal movement on the southern block of the area affected did contribute to tsunami generation, although difficult to determine quantitatively.

REFERENCES

Bonafede, M.; Neri, A., 2000. Effects induced by an earthquake on its fault plane boundary element study. Geophysical Journal International, Volume 141, Issue 1, pp. 43-56, 2000.

Castellanos, H., and Mann, P., 2005. Pull-Apart vs. Subduction Rollback Mechanisms For The Cenozoic Formation Of Bohai Basin, Eastern China AGU Fall Meeting, San Francisco, CA. 2005.

Chen, Yun-Tai; Gu, Hao-Ding; Lu, Zao-Xun, 1976. "Variations of gravity before and after the Haicheng earthquake, 1975 and the Tangshan earthquake, 1976", Physics of the Earth and Planetary Interiors, Volume 18, Issue 4, p. 330-338.

Chen Guo-guang, Xu Jie, Ma Zong-jin1, Deng Qi-dong, Zhang Jin and Zhao Jun-meng, 2007. Recent tectonic stress field and major earthquakes of the Bohai sea basin, Acta Seismologica Sinica, Volume 17, Number 4 / July, 2004, pp.438-446, Published by Springer in Earth and Environmental Science, 2007.

Cipar J. 1979, "Source processes of the Haicheng, China earthquake from observations of P and S waves", Bulletin of the Seismological Society of America; December 1979; v. 69; no. 6; p. 1903-1916.

Davis, G. A., Zheng, Y., Wang, C., Darby, B. J., Zhang, C., and Gehrels, G., 2001, Mesozoic tectonic evolution of the Yanshan fold and thrust belt, with emphasis on Hebei and Lianoning provinces, northern China: Memoir - Geological Society of America, v. 194, p. 171-197.

Earthquake Administration of Liaoning Province, Quan Yingdao, "An Earthquake of MS7.3 in Haicheng, Liaoning Province on February 4, 1975", World Data Center for Seismology, Beijing.

Hellinger, S.J., Shedlock, K.M., Sclater, J.G. and H. Ye, 1985. The Cenozoic evolution of the north China basin, Tectonics 4 (1985) 343–358.

Hendrix, M.S., and Davis, G.A., 2001, Paleozoic and Mesozoic tectonic evolution of central Asia: from continental assembly to intracontinental deformation: Boulder, Colo., Geological Society of America, vi, 447 p.

Keilis-Borok, V. I. and Soloviev, A., (Edis.), 2003. Nonlinear Dynamics of the Lithosphere and Earthquake Prediction. Springer-Verlag, Berlin-Heidelberg.

Ma, L. and Gao, X., 1996. The state of intensive monitoring and prediction at the Metropolitan Area before Asian Game in 1990. He, Y. N. (Ed.), The Selected Papers of Earthquake Prediction in China, Dedicated to the 30 th International Geological Congress, Seismological Press, Beijing, 255-259.

Madariaga, Raul, 2008. Dynamics of shallow reverse faulting in 2D Max, Michael D. 2002, Mass Flow in Marine Sediment: Physical Causes and Possible Examples from the Geological Record, Tsunami Society Symposium, Honolulu, Hawaii 2002.

Mei, S. R. (Ed.), 1982. Tangshan Earthquake in 1976. Seismological Press, Beijing (in Chinese, reviewed abstract in English).

Milkov, Alexei V. 2002, Global Distribution and Significance of Natural Gas Hydrate. Tsunami Society Symposium, Honolulu, Hawaii 2002.

Pararas-Carayannis, G. (1983), *The Earthquake and Tsunami of 26 May 1983 in the Sea of Japan*. http://www.drgeorgepc.com/Tsunami1983Japan.html

Pararas-Carayannis, G. 1993. *The Earthquake and Tsunami of July 12, 1993 in the Sea of Japan/East Sea—The Hokkaido "Nansei-Oki" Earthquake and Tsunami*.http://www.drgeorgepc.com/Tsunami1993JAPANOkushiri.html

---

Pararas-Carayannis, G., 2007. Historical Earthquakes in China. Webpage Article: **http://www.drgeorgepc.com/EarthquakesChina.html**

Pararas-Carayannis, G. 2008.The_Great_Tohoku Oki Earthquake and Tsunami of 11 March 2011 in Japan – A Critical Review and_Evaluation of the Tsunami Source Mechanism. https://www.researchgate.net/publication/257317821

Pararas-Carayannis, G., 2008a, The Earthquake and Tsunami of July 18, 1969 in the Bohai Sea, China. Webpage Article: **http://drgeorgepc.com/Earthquake1969ChinaBohai.html**

Pararas-Carayannis, G., 2008b. The Earthquake of February 4, 1975 in Haicheng, China. Webpage Article:**http://drgeorgepc.com/Earthquake1975ChinaHaicheng.html**

Pararas-Carayannis, G., 2008c. The Tangshan Earthquake of July 28,1976 in China. Webpage Article: **http://drgeorgepc.com/Earthquake1976ChinaTangshan.html**

Pararas-Carayannis, G., 2009. Assessment of Potential Tsunami Generation in China's Bohai Sea from Direct Geotectonic and Collateral Source Mechanisms.Science of Tsunami Hazards. Vol. 18. N.1, 2009. http://tsunamisociety.org/281GPCC.pdf

Pararas-Carayannis, G. (2009), *Earthquake and Tsunami of 3 March 1933 in Sanriku, Japan.* http://drgeorgepc.com/Tsunami1933JapanSanriku.html .

Pararas-Carayannis, G. (2011), *The Great Tsunami of March 11, 2011 in Japan—Analysis of Source Mechanism and Tsunamigenic Efficiency*. OCEANS 11, MTS/IEEE Proceedings, 2011.

Pararas-Carayannis, G. (2013), The Great Tohoku-Oki Earthquake and Tsunami of March 11, 2011 in Japan: A Critical Review and Evaluation of the Tsunami Source Mechanism. Pure and Applied Geophysics, Volume 171, Issue 12, pp.3257, May 2013. DOI: 10.1007/s00024-013-0677-7

Pararas-Carayannis, G., 2007. Historical Earthquakes in China. Webpage Article: http://www.drgeorgepc.com/EarthquakesChina.html

Pararas-Carayannis, G., 2008a, The Earthquake and Tsunami of July 18, 1969 in the Bohai Sea, China. Webpage Article: http://drgeorgepc.com/Earthquake1969ChinaBohai.html

Pararas-Carayannis, G., 2008b. The Earthquake of February 4, 1975 in Haicheng, China. Webpage Article: http://drgeorgepc.com/Earthquake1975ChinaHaicheng.html

Pararas-Carayannis, G., 2008c. The Tangshan Earthquake of July 28,1976 in China. Webpage Article: http://drgeorgepc.com/Earthquake1976ChinaTangshan.html

Pararas-Carayannis, G. 2008d. The Earthquake of May 12, 2008 in the Sichuan Province of China. Website: http://www.drgeorgepc.com/Earthquake2008ChinaSichuan.html

Pararas Carayannis, G. 2009. ASSESSMENT OF POTENTIAL TSUNAMI GENERATION IN CHINA'S BOHAI SEA FROM DIRECT GEOTECTONIC AND COLLATERAL SOURCE MECHANISMS, Science of Tsunami Hazards, Vol.28 No 1. 2009. pp 35-66

Shou, Zhonghao 1999. "The Haicheng Earthquake and Its Prediction", Science and Utopya 65, page 34, November 1999" (in Turkish; Reviewed English abstract)
Science of Tsunami Hazards, Vol. 28, No. 1, page 64 (2009*)*

USGS.gov. 2015. "Historic Earthquakes". earthquake.usgs.gov. Retrieved 2015-11-

Ye, H., Shedlock, K.M., Hellinger, S.J. and J.G. Sclater, 1985. The north china basin: an example of a Cenozoic rifted intraplate basin, Tectonics 4 (1985) 153– 169.

Yin, X. C., Wang, Y. C., Peng, K. Y. and Bai, Y. L., 2000. Development of a new approach to earthquake prediction: Load/Unload Response Ratio (LURR) theory. Pure Appl. Geophys. 157, 2365-2383.

Yin, A., and Nie, S., 1996, A Phanerozoic palinspastic reconstruction of China and its neighboring regions, in Yin, A., and Harrison, T. M., eds., The Tectonic evolution of Asia: Cambridge [England] ; New York, Cambridge University Press, p. 442-485.

Yong, Chen, et al.,1988. The Great Tangshan Earthquake of 1976: An Anatomy of Disaster. New York: Pergamon Press, 1988**.**

Yu Jianguo, Li Sanzhong, Wang Jinduo, Timothy M. Kusky ; Wang Xinhong ; Lu Shengqiang, 1995. Relationship between salt diapirism and faulting in the central structural belt of the Dongying sag, Bohai Gulf basin, ChinaQuaternary International Volume 25, 1995, Pages 13- 17.

Wang Fang, 1976. The 1976 Tangshan Earthquake. State Seismological Bureau of China Beijing, People's Republic of China.

Wang, Kelin; Chen, Qi-Fu; Sun, Shihong; Wang, Andong (2006). "Predicting the 1975 Haicheng Earthquake". Bulletin of the Seismological Society of America. **96**(3): 757–795. *doi*:*10.1785/0120050191*.

Zhang, Z.M., Liou, J.G., and Coleman, R.G., 1984, An outline of the plate tectonics of China: Geological Society of America Bulletin, v. 95, p. 295-312.
Wang, K., Chen,Q.-F., Sun, S. and A. Wang, 2006, Predicting the 1975 Haicheng Earthquake, Bulletin of the Seismological Society of America, June 1, 2006; 96(3): 757 - 795.

Wang Jian, 2007. Historical earthquakes and a tsunami in Bohai Sea. Journal Acta Seismologica Sinica. Publisher Seismological Society of China ISSN 1000-9116 (Print) 1993-1344 (Online), Volume 20, Number 5 / September, 2007.

Wang, T.H., 1988. Genetic types of thrust faults in Eastern China petroliferous regions, Earth Sci. 13 (1988) 627– 634.

Wang Fang, 1976. The 1976 Tangshan Earthquake. State Seismological Bureau of China Beijing, People's Republic of China.

Watson, M.P., Hayward, A.B., Parkinson, D.N. and Z. Zhang, 1987. Plate tectonic evolution, basin development and petroleum source rock deposition onshore China, Mar. Pet. Geol. 4 (1987) 205– 225.

Xu Qinghai, Wu Chen, Yang Xiaolan and Zhang Ningjia, 1996. Palaeochannels on the North China Plain: relationships between their development and tectonics. Studies of the Palaeochannels on the North China Plain, Geomorphology, Volume 18, Issue 1, December 1996, Pages 27-35.

Zhang D., and S. Wang, 2008, Failure modes analyses of ice-resist jacket platforms in Bohai Sea. Dalian University of Technology, Dalian 116024, China (Abstract seen)

Zhao Liang and Tianyu Zheng, 2005, Seismic structure of the Bohai Bay Basin, northern China: Implications for basin evolution. Earth and Planetary Science Letters 231, Issues 1-2 (Feb. 2005) Pages 9– 22.