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Review of the Research of the 2011 $M_W 9.0$ Tohoku-Oki Earthquake[1]

Shao Zhigang, Wang Peng, and Li Haiyan

Institute of Earthquake Science, China Earthquake Administration, Beijing 100036, China

On March 11, 2011, a $M_W 9.0$ earthquake occurred in the Japan Trench, causing tremendous casualties, and attracting extensive concern. Based on the results of related research, this paper analyzes the observations, phenomena and understandings of the earthquake from varied aspects, and obtains four main conclusions. (1) The earthquake, occurring in the subduction zone in the Japan Trench located in the northwest boundary of the pacific plate has two zones of concentrated coseismic slip at different depths, and the slip in the deep zone is relatively small. Though there have been many $M7.0$ historical earthquakes, slips in the shallow zone are large, but there have been few historical strong earthquakes. (2) Constrained by GPS data, the study of fault movement shows that fault movement in the Japan Trench has a background of widely distributed stability and locking (the locking zone is equivalent that of coseismic rupture zone). Perturbation occurred after the 2008 $M8.0$ Hokkaido earthquake, several $M7.0$ events had after slips larger than the coseismic slip, and two obvious slow slip events were recorded in 2008 and 2011. Eventually, the March 9, 2011 $M7.0$ foreshock and the March 11, 2011 $M_W 9.0$ mainshock occurred. The pre-earthquake changing of the fault movement in the Japan Trench is quite clear. (3) Traditional precursory observation show no obvious anomaly, possibly due to monitoring reason. Anomaly before earthquake consists of high stress state in focal zone reflected by some seismic activity parameters, short period anomaly in regional ground motion, etc. (4) The analysis of physical property in focal zone aroused more scientific issues, for example, is there obvious difference between physical property in focal zone and its vicinity? Does frictional property of fault determine seismogenic ability and rupture process? Whether pre-earthquake fault movement include pre-slips? Could deep fluid affect fault movement in focal zone? Experience is the best teacher, and authors hope this paper could be a modest spur to induce others in basic research in earthquake forecast and prediction.

Key words: The 2011 $M_W 9.0$ Japan earthquake Earthquake prediction Seismic monitoring Earthquake research

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INTRODUCTION

On March 11, 2011, a $M_W9.0$ earthquake occurred in the Japan Trench on the Pacific western subduction. The earthquake is the strongest one in scale of the Japanese earthquake records. Like many disastrous earthquakes, this $M_W9.0$ earthquake led to a lot of discussions on subduction earthquake prediction (Stein S. et al., 2012). We are much concerned about these discussions and analysis meanwhile we pay special attention to the layout issues of many seismic instruments in Japan before the earthquake such as geodetic instruments, strong motion seismographs and seismographs. The study of the roles of these observations in fundamental seismic research helps improve our understanding. Based on the related research results, the paper attempts to review studies of coseismic focals, structural background and medium models, fault movements, fault frictions, earthquake precursory and earthquake effects with a view to get some insights into the fundamental research of earthquake prediction.

1 COSEISMIC FOCALS

Japan has very good foundations of earthquake monitoring: geodesy related GPS and InSAR, coseismic displacements in sea floor deformation observation, accelerations observed by strong motion seismographs, seismic wave form observations, tsunami data, gravity variations observed by gravity satellites, and inversion bound data of the coseismic dislocation and rupture processes of the 2011 $M_W9.0$ Tohoku-Oki earthquake.

American USGS originally selected focal mechanism solution to generate fault surface and used body waves and surface waves to inverse fault ruptures. The coseismic dislocations focus on the two zones on the southern and northern sides above the epicenter: Hayes G. P. (2011) selected trench where fault surfaces determined by Slab1.0. For a more reasonable spatial distribution and better quality of wave form data observation, the value range of inversion parameters is extended with the moment magnitude changed from 9.00 to 9.06, maximum dislocation from 18m to 32m, and coseismic dislocation in spatial distribution changing to deep and shallow dislocation zones.

After the 1992 $M7.3$ Landers earthquake, InSAR played a very good constraint role in coseismic dislocation inversion and fault movements between the earthquakes. But in the case of the coseismic dislocation inversion of the 2011 $M_W9.0$ Tohoku-Oki earthquake, the dislocation inversion result of various data constraints by geodetic instruments reveals that the inversion results (Feng Guangcai et al., 2012) of sole InSAR constraint is worse, because post-earthquake displacement may be included and the GPS precision is poor. On the other hand, we also notice that the same author used the same methods but obtained greatly different results because of the different constraint data. For example, Diao Faqi et al. (2011) used only strong motion seismographs for GPS displacement constraint inversions and obtained the maximum dislocation of 23.3m, but with an increase of 5 seabed observation constraints, the maximum dislocation is 45.8m in seismograph (Diao Faqi et al., 2012). The similar situations also appeared in Wang Chisheng et al's (2012) geodesy coseismic dislocation inversions. We therefore believe that the constraint capacity of the near site sea floor deformation observations is far greater than that of the coseismic displacements observed by GPS in the zones distant from the focal of Honshu, Japan. On the other hand, it should be noted that the constraint spot number determined by InSAR is far greater than that of GPS, but its area of coverage does not extend beyond Honshu, Japan. This could be the reason why InSAR displacement constraints have a worse result. Thus, the inaccurate acceleration of the Japan Trench fault in the constraint inversions of the Japanese islands data should not be used to deny the spatial advantages of InSAR fault inversions (Avouac J. P., 2011).

Combined with the waveform observation, strong earthquake observation, high frequency GPS, static GPS displacement, sea floor displacement and tsunami records as constraints, the inversion results can show that coseismic dislocation is greater in shallow parts and smaller in deep parts. There are at least 3 large coseismic dislocation concentrations in the shallow parts. We calculate the coseismic stress drops on the fault surface. The concentration zones of large stress drop values and the spatial distributions of high speed anomalies of the velocity V_P show consistency with the tsunami (Bletery Q. et al., 2014). The initial gravity satellite model of Shao Guangfu et al., (2011) consults the fault surface of the focal mechanism solution and uses the body waves and surface waves and the invertded dislocations concentrated around 300km above the epicenter. The rectified model uses the body waves, surface waves and displacements in GPS observations. The dislocation spaces are distributed in deep and shallow dislocation concentration zones with the largest dislocation of 59.8m and gravity (Shao Guangfu et al., 2011). With the waveforms and strong earthquake observations as constraints for coseismic rupture inversion, the static dislocation distribution shows that there are two dislocation concentration zones in the shallow and deep parts of the epicenter, with the shallow one larger and deep one smaller (Yoshida Y. et al., 2011).

The feature of using surface waves to determine the coseismic ruptures is that the ruptures of the earthquake extend from the epicenter along both sides of the shallow part, with N60°E and N127°E along both sides, and 276km and 231km (Hwang R. D., 2014) in dislocation respectively. We use the wave form data from the global 50 broadband seismograph observations as the constraint, and invert the spatial and temporal evolution of the coseismic ruptures of the earthquake. The result shows that the main ruptures occurred mainly within 100s before the earthquake. There are two dislocation zones: a shallow one and a deep one. The ruptures 40s after the earthquake mainly occurred in the deep zone. The ruptures 60s – 70s after the earthquake mainly occurred in the shallow zone and the ruptures 90s after the earthquake mainly returned to the deep zone. The ruptures 100s after the earthquake appeared as smaller ruptures along the both sides of the fault going south in Honshu, Japan (Ide S. et al., 2011).

The rupture velocities of the two main ruptures of the Sumatra earthquake are 1.5 – 1.8km/s, equivalent to that of the initial rupture of the 2004 M_S9.0 earthquake. The rupture velocity of the 2010 M_S8.8 Chile earthquake was only 2.25km/s (Koketsu K. et al., 2011). This could be a common phenomenon of subduction, inducing large thrust earthquakes. However, this earthquake rupture is very complicated (Koketsu K. et al., 2011; Meng Lingsen et al., 2011). The high frequency components in the coseismic digital waveform records come from the deep coseismic rupture, and the low frequency components come from the shallow ruptures (Yao Huajian et al., 2011; Yagi Y. et al., 2012; Nakahara H., 2013). This could be related to the pre-earthquake fault closure. The strong closure zones may have higher stress levels, and may produce higher frequency ruptures in the coseismic time. The 2010 M_S8.8 Chile earthquake demonstrated horizontal variations rather than deep and shallow variations (Wang Dun et al., 2011).

The Japanese earthquake had three M7.0 aftershocks within 40 minutes with a spatial range of 500km × 200km. The aftershocks above M5.0 are obviously more seismically active than the 2010 M_S8.8 Chile earthquake and the 2004 M_S9.0 Sumatra earthquake. The foreshock activities were started by the February 16 M5.5 earthquake and the largest foreshock was March 9 M7.3 earthquake. These were all activities occurring spatially around the epicenter of the main shock. After the earthquake, the seismic activities in the Japanese islands were all enhanced (Hirose F.

et al., 2011). The side tensile $M7.6$ earthquake was induced after the plate subduction belt, the thrust $M7.4$ and $M7.8$ earthquakes along the northern and southern sides, and the $M7.1$ thrust earthquake under the epicenter (Hirose F. et al., 2011).

Summary: The coseismic dislocation and rupture of the 2011 Japan $M_W9.0$ earthquake are based on a large number of coseismic data, but there are still many inconsistent research results. However, the coseismic focal process of the $M_W9.0$ earthquake is clear. Generally speaking, the coseismic dislocations can be divided into deep and shallow zones. There is a large number of coseismic dislocations in the shallow dislocation concentration zone, but the strong earthquake activities are historically weak. There is a relatively smaller number of dislocations in the deep dislocation concentration zone, which is historically the $M \geqslant 7.0$ strong earthquake activity zone. On the other hand, the coseismic ruptures of the deep and shallow dislocation zones show different characteristics. The higher frequency ruptures occurred in the deep dislocation zone while the lower frequency ruptures occurred in the shallow dislocation zone, which demonstrates the difference in fault physical characteristics of the deep and shallow zones.

2 STRUCTURAL BACKGROUND AND MEDIUM MODELS

The Japanese islands are located in a zone under the joint actions of the Pacific, Eurasian, the North American and Philippine Sea plates (Kanamori H., 1977; Taira, 2001). The zone has strong plate structural movements and has active volcanoes and earthquakes (Department of Earthquake Monitoring and Prediction, CEA, 2007). The Pacific plate dives in the west of the Japan Trench under the Eurasian plate with a speed of about 8 – 9cm/a. The earthquakes on the subduction belt includes shallow, medium and deep focal earthquakes (Chen Pofei et al., 2004). The focal depths increase gradually to 600km – 700km from the trench area westward to Northeastern China with very active shallow-focal and deep-focal strong earthquakes (Department of Earthquake Monitoring and Prediction, CEA, 2007; Kanamori H. et al., 2006).

Kanamori H. (1977) proposed a dynamic model of the different plates on the subtractive belt on the round pacific plate. The model is based on the gravity instability induced by the gradual cooling of the oceanic plates. This is an example of the subtractive plate profile of the northwestern border of the Pacific plate. There are different stages of the actions of the plate subduction from the Bering strait counter clockwise to the Mariana trench: (1) The meeting state of the oceanic plate and the continental plate, i. e. the early stage of the plate subduction. Because of the joint role of the temperature, density and continental dynamic sustainment, the oceanic plate thrusts repeatedly with a low angle against the bottom of the continental wedge. The subtractive belt of the Bering strait plate with the joint actions of the Pacific plate and the North American plate is in such a stage and this is the reason why the seismic activities in the area are shallow and medium-depth earthquakes. (2) Early stages of the plate subduction; The friction heat between the oceanic plate and the continental plate causes the melting of the local lower crust in the continental plate which leads to relatively strong volcanic activities between the plates and provides energy for volcanic activities. The subtractive belt of the Kurile Islands is in this stage. (3) Intermediate stage of the plate subduction. The melt blocks reduce the dynamic sustainment for the heavier oceanic plate and accelerate the sinking of the oceanic plate. If the strain goes beyond the strength of the plate, tension ruptures may occur in the bent trench of the plate (e. g. 1933 $M8.4$ Sanriku-Oki in Japan Trench). The subtractive belt of the Japan Trench is in this stage. (4) Late stage of the plate subduction; after the tension rupture, the bottom part of the oceanic plate sinks increasingly and the dips become larger than before. Deep and intermediate depth earthquakes continue to take place, but as the smaller interactions between the oceanic plate and the continental plate, there are few strong shallow focal earthquakes. The activities of the Isuzu-Mariana Islands arc belong to this type.

The earthquake activities on the plate subduction belt are controlled by the stress of the interaction between the plates and the stress is further controlled by the plate subduction age and convergent rate. The b-value is used to describe the regional stress of the background zone and the result shows that the stress could be related to the tectonic age and subduction depth and is independent from the convergent rate and the upper movement velocity. The tectonic activities of the plate subduction of the Japan Trench started earlier than 100Ma and the width of the plate subduction may determine the turning of very strong earthquakes (Yamano M. et al., 2014). The plate subduction zone of the Japan Trench is a typical duel seismic belt region (Nishikawa T. et al., 2014). According to the relocation results, the bandwidth of the dual earthquakes in the Japan Trench is about 40km, and the distances between the intermediate surface and the upper and lower seismic belts are close to each other (Herrendörfer R. et al., 2015).

Land heat current monitoring shows that there are obvious anomalies in the land heat current values within 150km on the eastern side of the Japan Trench, much higher than those on the two sides of the Japan Trench and the Pacific Ocean floor. The reason may be the vertical channel of the effective hydrothermal exchange between the shallow and deep crusts, the region being the land heat current observation anomaly zone as the result of plate bending (Kita S. et al., 2010). The area is also an extensive strong earthquake area. On the other hand, the dip of the plate subduction of the zone is as small as 28°. The plate subduction interaction distance is long and the deep earthquakes in Northeastern China are from the plate subduction.

Digital seismic waveform data is used to constraint the inversion of crust-mantle tomography to analyze the medium features of the strong focal zones. This is also an important research field in digital seismology. There is great uncertainty if we use only the stations on the Japanese islands to determine the velocity structure of the Japan Trench zone. The vertical velocity profile of the trench indicates that the zone below the depth of 50km is the ocean crust subduction plate, and the velocity is obviously higher than that of the upper land crust velocity. The 30km – 50km zone is the upper land crust with a higher velocity (Matsubara M. et al., 2011). The tomography shows that the concentration areas of $M_S \geqslant 6.0$ earthquakes in the Japan Trench since 1900 mainly have high velocity, high Poisson ratio, low fault density and high saturation, which shows high fault locking of the Japanese shock focal zones, and the fluid may have already diffused to the high locking zone (Tian You et al., 2013). Based on the 3-D travel tomography of P waves and S waves of the Japan Trench crust-mantle medium structure, it is seen that the area between the north latitude of 37° and the north latitude of 39° is the obviously high velocity zone of P waves. The both sides of the zone are relatively low value zones. The high value zone is the dislocation concentration zone of the 2011 $M_W 9.0$ earthquake (Zhao Dapeng et al., 2011). The foreshock tomography result shows that the moderate and strong earthquakes in history in the Japan Trench are frequently in the range of 50km – 20km depth with the plate subduction belt of high V_P, high V_S and low V_P/V_S. Based on the three-dimensional velocity tomography of the focal zone by the Japanese islands and oceanic floor seismological observations, it can be concluded that there are two V_P/V_S high value zones from shallow to deep in the Japan Trench area (Yamamoto Y. et al., 2008).

The strong motion seismograph recordings of over seven altitudes of earthquakes on Japanese islands in the Japan Trench during 2003 – 2011 shows that the surface motion frequencies caused by these coseismics have a change from high to low: (1) 60km in depth under eastern coast of Honshu, Japan, thrust land form with southeastern tipping within the oceanic plate. (2) Extensive earthquake with northwestern tipping on the eastern side of the trench, over 200km from Honshu, Japan. (3) The fault area of the Japan Trench subduction belt is thrust earthquakes for over 40km, i. e. a historical strong earthquake concentration region in the Japan Trench. (4) Thrust earthquakes with 30km in depth on the fault surface of the subduction belt of the Japan Trench. One of the reasons could be that there is variation in the process of focal coseismic energy release, i. e. the variation of coseismic fault relative motions caused by different fault qualities. Also, there may be variations in the path between focals and observation spots. There are great variations in seismic energy attenuation caused by different propagation paths and medium qualities (Ye Lingling et al., 2013).

Summary: Regional structural characteristics decide the fault deformation features and the temporal and spatial evolution of strong shocks. The regional crust medium and the medium of the strong shock focal zones affect both structures and fault motions. The images show that the foreshock medium characteristics of the focal zone can reflect the fluid activity of the foreshock fault.

3 FAULT MOTION

We used the Japanese islands crust deformation rates provided by GEONET of Japan from 1995 to 2002 as constraints, and inverted the fault motion of the Japan Trench. The $M_W7.7$ Sanriku-Haruka-Oki earthquake occurred in 1994 in the northern part of the Japan Trench. In the coseismic dislocation zone of the earthquake, sealing appeared in shallow faults 3 years after the post shock sliding. The fault motions in most parts of the Japan Trench are in a locked state. The shallow parts are completely locked, and the parts deeper than 80km are totally unlocked (Nishimura T. et al., 2004). There is no possibility of a strong earthquake in the Japan Trench. There are similar conclusions in later research (Hashimoto C. et al., 2009; Loveless J. P. et al., 2010). The observation data of 1995 – 1997 as constraints to invert the fault lock degree reveal that there is a high lock degree of the faults in the Japan Trench shallow earthquake preparation layer, but the highest lock degree appears in the faults of the Japan south sea and Hokkaido, and there is an even distribution in space (Mazzotti S. et al., 2000).

The analysis of the intershock fault lock degree in the subduction belt proves that the shallow faults in large subduction belts should be a speed intensifying zone, i. e., a fault in the intershock stage in the subduction belt should be in a state of shockless sliding. Research on the intershock faults in the Japan Trench is based on this hypothesis for inversion (Loveless J. P. et al., 2010). If we believe that shallow fault intershock stages of a large subduction belt can be in a lockless state, without such a hypothesis, the Japan Trench intershock lock rates through inversion shows two high lock zones; a shallow part and deep part (Loveless J. P. et al., 2011). The seismic profiles of the 1999 earthquake and the vertical trench trend show that there is sediment of 350m deep with a range of 3km in the vicinity sea bottom of the fault. The coseismic rupture has already reached the sea bottom (Kodaira S. et al., 2012), and the comparison of the terrain forms reveals that there are clear fault dips at the sea bottoms (Tsuji T. et al., 2013).

After the 2003 $M_W8.0$ Hokkaido earthquake, a significant change in the crust motion rates appeared in Honshu, Japanese island (Heki K. et al., 2013). With the crust motion rates of Honshu, Japan 15 years before the earthquake as constraints provided by GEONET, the inversion of the lock 3D spatial distribution on the surface of the subduction fault in the Japan Trench reveals that it was stable before 2003, and the finding is consistent with those of Hashimoto C. et al. (2009) and Loveless J. P. et al. (2010). The most obvious feature is that there is a large loss of displacement between north latitude 36° – 40°, with the peak value at about north latitude 38° (Ikuta R. et al., 2012). The coseismic and post-earthquake displacements of a series of earthquakes with magnitude of approximately 7.0 after 2003 led to the significant change of the lock of the Japan Trench subduction faults in time and space. In terms of the distribution of the historical strong earthquake dislocations in the Japan Trench, there were multiple earthquakes with $M \geqslant 7.0$ in the range of 300km between $M_W 8.0$ earthquake in 1938 and $M_W 8.3$ earthquake in 1968, but the maximum coseismic dislocation accumulation in the 80 years did not exceed 5m, which means that there was significant displacement loss in the plate subduction faults in the region (Ikuta R. et al., 2012).

GEONET also recorded the coseismic and post-earthquake displacements of the $M7.2$ earthquake on August 16, 2005, the $M7.0$ earthquake on May 8, 2008, the $M6.9$ earthquake on July 19, 2008, and the $M6.7$ earthquake on March 14, 2010. The values and spatial ranges of the coseismic dislocations of the first two earthquakes were all larger than the post-earthquake slides. However, in the latter two earthquakes, the post-shock slides are not only larger in slide value than the coseismic dislocations, but also larger than in spatial covering ranges (Suito H. et al., 2011). The GPS monitoring of the temporal changes of the crust motion rates, after the removal of the background tendencies, clearly shows that the post-shock displacements changed with the time in the form of index attenuation of the 2005 earthquakes and the crust motion rates gradually returned to the background change. After the 2008 July earthquake, there were increased anomalies with time in the post-shock displacement accumulation (Mavrommatis A. P. et al., 2014).

We use OBP and coastal body strain observation instruments to determine the slow slide events equivalent to $M6.8$ and $M7.0$ around the epicenters of the November, 2008 earthquake, which lasted for a week, and the February 2011 earthquake which lasted for a month. The results showed that these are the concentration areas of the largest coseismic dislocations, and the slow slides in 2011 may have triggered a group of earthquakes of $M \geqslant 5.0$ (Ito Y. et al., 2013). The observation of sea bottom crust motions also showed that before the 2005 $M7.2$ Miyagi-Oki earthquake, the western motion rates of the Japan Trench were 6 – 7cm/a relative to the North American plate, while the rates were 4 – 5cm/a after the earthquake (Sato M. et al., 2013).

Very low frequency earthquakes are defined as slow earthquakes. A large number of very low frequency earthquakes have been monitored around the epicenter and the south and north sides of the coseismic dislocations of the $M9.0$ earthquake (Matsuzawa T. et al., 2015). The very low frequency earthquakes on the north and south sides of the earthquake have obviously increased, probably associated with the post-shock slides or stress adjustments. It is noticeable that the very low frequency earthquakes around the epicenter were obvious before the earthquake, but the earthquake profile result shows that there may be fluid layers in the very low frequency earthquake pre-shock areas (Guo Fujie et al., 2002). The lab results show that slow slides may be caused by very weak friction intensity resulting from pore pressure increases, and the fluid pore pressure increase may be the result of fluid movements (Katayama I. et al., 2012).

If we use only the deformation data of the Japan island as constraints, the coseismic largest displacement of the March 9 $M_W 7.1$ earthquake is 0.41m, and there is no obvious static dislocation. In contrast to this is that the released energy of the post-shock slides within 10 minutes after the main earthquake is equivalent to a $M_W 7.08$ earthquake (Munekane H., 2012), and there is a larger coverage range of post-shock slides in different time scales (Munekane H., 2012; Ozawa S. et al., 2011; Diao Faqi et al., 2014). With the addition of the sea bottom OBP data, the magnitude of the March 9 earthquake reached $M_W 7.3$, the coseismic largest dislocation exceeded 1.5m, the largest post-shock sliding value in 51 hours exceeded 0.4m, the coseismic dislocation concentration zone was located under the epicenter, the post-shock slides were concentrated in the epicenter and the south of the epicenter, and the epicenter of the March 11, 2011 $M_W 9.0$ earthquake was located on the southern edge of the post-shock slide concentration zone of the March 9 earthquake (Ohta Y. et al., 2012).

Summary: The spatial and time evolution characteristics of the fault motion can reflect the different stages of the preparation, generation and adjustment of strong earthquakes. In the earthquake preparation, the whole fault motion is comparatively stable, and mainly in the form of lock. The fault motions before the strong earthquakes demonstrate many forms of motions, including post-shock slide inconsistent motions, slow earthquakes, and foreshocks. There can be close relationships between post-shock slides and historical strong earthquakes, fault features and coseismic dislocations. It is noticeable that in terms of observations, inversions and theoretical analysis, the pre-shock time and spatial evolution of the fault moments is a clear physical process, and is a good index for the location and earthquake release capacity of strong earthquakes. Although at present it can only determine the different stages of a strong earthquake on the fault and is not yet operational for time prediction, it already has valuable data accumulation in the process from experience prediction to physical prediction.

4 FAULT FRICTION

In the past 100-year records, $M7.0-8.0$ earthquakes have repeatedly occurred on the Japan subduction belt. How can the $M9.0$ earthquake occur, and what are the activities of the $M7.0-8.0$ earthquakes in the circling process of the $M9.0$ earthquake? The coseismic dislocation value is much larger than the focal dislocation value of a single $M7.0-8.0$ earthquake. The issue involves the physical mechanism of a strong earthquake such as asperity and fault friction.

Shibazaki B. et al. (2011) believed that when the fault was in a state of medium and low speed motion, the critical displacement of the speed weakening or enhancement was small. When in a state of high speed, the critical displacement of the speed weakening was large. Among the 8 asperities on the Japan Trench subduction belt determined by historical strong earthquake ruptures, there is a large asperity with over 20km shallow layers, three asperities with 20km – 30km, and four asperities with 30km – 60km. The large shallow layer asperity has larger fault parameters and critical displacement parameters, and its theoretical recurrence for strong earthquakes of over $M7.5$ is 1000 years. The theoretical recurrence of earthquakes over $M7.5$ of the other smaller asperities is several dozen years. The analogy result shows that the coseismic ruptures of smaller asperities do not extend to the asperities around, and those of larger asperities extend to the asperities around. However, this study does not prove that the phenomenon resulted from asperity spatial size, or from fault friction parameters, and whether it is the key factor for the occurrence of cascade ruptures.

The GPS observation of Japan's GEONET describes the dynamic change of the crust deformation of the Japan Island and the fault thrust motion locked zone on the Japan Trench plate subduction belt based on the crust deformation observation of Honshu, Japan between earthquakes (Hashimoto C. et al., 2009; Loveless J. P. et al., 2010). The length of the fault in the locked state is about 300km. The fault motion lock result based on repeating earthquakes shows that the fault in the focal zone of the 2011 $M_W9.0$ Tohoku-Oki earthquake is in a strong lock state, while the repeating earthquakes, historical $M7.0$ earthquakes and the $M9.0$ earthquake this time correspond to asperities at different layers (Uchida N. et al., 2011), whose spatial sizes are 10km, 100km and 300km – 400km respectively. These asperities of different sizes overlap on the Japan Trench subduction belt. The $M7.0-8.0$ focal zones form a number of asperities, while the $M9.0$ earthquake may lead to dislocations between many asperities and surrounding non-seismic slide zones in an earthquake event. Kato N. and Yoshida S. (2011), based on coseismic dislocation inversion, found a large asperity in the shallow part and a small asperity in shallow part. The analogy result shows that the two asperities may have a cascade rupture with a recurrent cycle of several hundred years, and the small asperity may have had a rupture of small magnitude both before and after the earthquake.

With the deepening of the rock experiments and earthquake process research, many scholars have set up fault dynamic theoretical models and gradually understood that the fault physical characteristics can have different demonstrations in coseismic post-shock and between shocks in the earthquake process (Tse S. T. et al., 1986; Scholz C. H., 1998; Marone C., 1998). The major conclusions are that the fault motion velocity weakening region corresponding to the asperities helps to strengthen the potential strong earthquake zones accumulated by the fault strain between the earthquakes, and the barriers help to stabilize the long term sliding state of the fault corresponding to the fault motion velocity intensifying zone. These models play a key role in the understanding of strong earthquake turns and strong earthquake temporal-spatial evolution, serving as the physical basis for Japanese medium-term earthquake prediction (Yamaoka K., 2007). In related research on the determination of fault seismicity, discussion has included fault characteristics, geometrical scale of the asperity and the possibility of the collapse of joint asperity ruptures. The temporal and spatial evolution of the fault is given qualitatively or semi-quantitatively by numerical simulation. The gap between theory and practice of earthquake prediction may be gradually reduced. However, the 1999 $M_W7.6$ Chi-Chi earthquake and the 2011 $M_W9.0$ Tohoku-Oki earthquake are particularly noteworthy because the two earthquakes may be the epicenter of the fault velocity weakened area of the initial rupture of the adjacent strengthening area caused by serious destructive fault rupture. The results of the numerical simulation of strong earthquakes also show that this phenomenon is entirely possible (Noda H. et al., 2013); that is, the two deep-shallow slip extremes by coseismic rupture of the 2011 $M_W9.0$ Tohoku-Oki earthquake correspond to the asperities and obstacles rather than the two cascade asperity ruptures. This in return calls for the re-examination of the characteristics of fault frictional properties and the geometric characteristics of asperity in the study of cascade ruptures. In particular, in the case of the combination of asperity bodies in many faults in the Chinese mainland, the major function of seismogenics is the impact of asperity friction or asperity geometric properties, and other geological structural factors besides the physical and geometrical properties of the asperities.

Different plate subductions show different seismic activity characteristics. The seismogenic faults of the 1964 Alaska earthquake, 1952 Kamchatka earthquake and 2011 Japan $M_W9.0$ earthquake were of ADDS type (along-dip double segmentation) while those of the 1960 $M9.5$ Chile earthquake, 2004 $M_S9.0$ Sumatra earthquake, 2010 $M_S8.8$ Chile earthquake, 1965 $M8.7$ Rat Island earthquake (Bering Strait) and 1957 $M9.1$ Andreanof earthquake (Bering Strait) were of ASSS type (along-strike single segmentation), and the rupture empty segment method commonly used in medium and long term prediction research is effective for the ASSS type. Take the example of the western coast of Chile, strong earthquake rupture plays an important role in the process of long-term strong earthquake prediction but in terms of ADDS type, the forms of the seismogenic fault in deep and shallow sections are complex in different strong earthquake rupture processes. For example, the 2011 $M_W9.0$ Tohoku-Oki earthquake had simultaneous deep and shallow ruptures. Historical strong earthquake rupture evolution shows that a strong earthquake is not of single dimension but multi-dimensional (Koyama J. et al., 2012).

The spatial distribution of historical earthquake ruptures shows that the depth of strong earthquakes in the plate subduction area is about 40km, but regional differences are also larger. The Mexican region is 20km – 30km shallower while the depth of the Japan Trench region is more than 50km. The depth of the lock may be related to the critical temperature, critical temperature, shear stress, continental crust thickness and other regional environments (Tichelaar B. W. et al., 1993).

After the earthquake, Japan launched the Japan Trench Fast Drilling Project (J-FAST). The research on the trench shallow fault mud shows that such fault mud showed a low friction coefficient (< 0.1, the friction coefficient of normal humidity fault mud is $0.1 - 0.35$). The friction coefficient of general room-humidity of fault mud changes with the fault motion velocity, and the significant peak value of friction coefficient is at moderate velocity. The phenomenon is not obvious with the dipped fault mud. That is, the friction coefficient is not sensitive to the velocity of the fault, and the displacement weakening distance is short. This fault property determines that the work done to overcome the friction in the process of displacement weakening is relatively small and is conducive to the propagation of the rupture. This may be the possible cause of the large coseismic dislocation in the shallow fault (Remitti F. et al., 2015).

The 12 seismic sections from north to south along the Japan Trench subduction dive belt show the slope angle and the slip dip. The ratio of the effective foundation friction coefficient and the pore hydraulic pressure can be obtained by the critical cone Coulomb wedge theory. The effective base friction coefficient is significantly larger in the three areas, including the most southernFukushima submarine mountain and the dislocation zone of the 2011 $M_W9.0$ Tohoku-Oki earthquake (Koge H. et al., 2014).

Summary: The frictional properties of asperities and faults along specific fault belts have obvious spatial heterogeneity and can be overlapped in terms of different asperities of different scales on the same fault belt. On the other hand, we are not clear about the complexity of the cascade ruptures by multiple asperities, and the non-asperities can have large dislocation in the coseismic process and thus cause a large gap in the guidance of the focal physical research in the long and medium term strong earthquake prediction. It may be necessary to comprehensively consider the fault friction properties, the asperity geometrical properties, the physical characteristics of the structure and the temperature and pressure environment of the mantle.

5 EARTHQUAKE PRECURSORY

There are many strong earthquakes that show that the regional seismicity state change was a regional earthquake anomaly before strong earthquakes. Based on the 1960 to 2010 earthquake catalogue, the ZMAP seismological software analysis was used to show that there was a quiet anomaly since 1987 (Katsumata K., 2011). At the same time, the ETAS method was used to accumulate the relatively calm phenomena of the seismic activity in the earthquake area before strong earthquakes. Relevant studies in 1992 show that in Japan and the surrounding area, there were no significant quiet anomalies (Ogata Y., 1992). After December, 2001, the medium and strong seismic activity in the Japan plate subduction belt increased significantly. The AMR result shows that there were intermediate scale anomalies of the seismic acceleration moment release in the region 10 years before the earthquake (Xue Yan et al., 2012). According to the spatio-temporal evolution of the seismic activity, the May 8, 2008 $M7.0$ earthquake may be a typical featured earthquake, with a period of about 22 years (Matsumura S., 2010). However, the actual use of characteristic earthquakes to predict an earthquake is very difficult. The seismic activity of the focal zone is in quiescence, but has been active since mid 2009 (Nagao T. et al., 2011), and the relevant seismic activity parameters have many anomalies and the values dropped rapidly to the minimum within a few months before the earthquake (Sarlis N. V. et al., 2013). At the same time, PI hotspots appeared close to the $M9.0$ epicenter (Kawamura M. et al., 2013). The earthquakes of north latitude $> 20°$ on the north Pacific plate border and its vicinity with focal depth less than 50km in 1999 - 2011 were shallow $M \geqslant 6.5$ earthquakes, and the plate edge earthquakes and within plate earthquakes were 31 each. The statistic results show that the seismic activities of the most focal zones of the Pacific plate edge earthquakes showed a significant increase in number several months or days before the earthquake, but the phenomenon was not obvious among the intraplate earthquakes. The possible reason is that there may be a slow slip event in the focal zone before a large earthquake rupture occurs on the contact surface of different plates. In this process, some secondary asperities led to the pre-earthquake series (Bouchon M. et al., 2013).

In related seismology research, the foreshock is an effective short-impending precursory anomaly recognized by the academic community (Xue Yan et al., 2012; Uyeda S., 2015). The JMA catalog calculation helps obtain a b-value of 0.6 for the March 9 foreshock, indicating that the foreshock sequence is in a high stress state (Xue Yan et al., 2012). From March 9, 2011 on, the aftershock activity of the $M7.3$ earthquake gradually migrated to the epicenter in the southwest direction of the main shock (Ando R. et al., 2011).

There is a lot of research on the seismic activity parameters of the b-value of the $M9.0$ earthquake. The b-value of the Japan Trench earthquake catalogue from 1990 to March 8, 2011 shows that the b-value of the active tectonic zones of the Japan Trench's historical strong earthquake are relatively high, and in some places they go beyond 1.0. However, in shallow zones of the trench subduction there is a large range of low b-value areas (Ide S. et al., 2013), indicating that the Japan Trench subduction zone was in a higher stress state before the $M9.0$ earthquake. On the other hand, tidal triggering has continued to be enhanced since 2003, and there had been significant anomalies up to 2007, indicating that the stress was relatively high in the Japan Trench before the earthquake (Tanaka S., 2012). The b-value evolution and the strong earthquakes in different periods after 1998 have obvious spatial correlation. The 2003 $M8.0$ Hokkaido earthquake occurred in the zone with the lowest b-value from 1998 – 2003, and the 2011 $M9.0$ earthquake occurred in the zone with the lowest b-value from 2004 – 2011. The b values of the $M9.0$ earthquake dislocation zone were significantly lower before the earthquake, but those of the $M9.0$ earthquake focal zone were higher 3 months after the earthquake. The b values from 2013 – 2014, however, dropped rapidly (Tormann T. et al., 2015). Although the b values of the $M9.0$ earthquake focal zone dropped rapidly to about 1.0, it does not mean that the stress level of the Japan Trench reached the level of 1998 – 2003, but is still significantly higher than that of the thrust seismic activity (Narteau C. et al., 2009).

Since 1964, the Alaska earthquake in the United States may have had anomalous disturbances from the ionosphere before the earthquake (Leonard R. S. et al., 1965). After this, the method accumulated more and more cases, especially on global satellite positioning system, which analyzed the total electron content TEC value on the signal propagation path. The research on the March 11, 2011 $M_W9.0$ Tohoku-Oki earthquake reveals that there were clear positive anomalies on March 8 lasting for 6 hours. The ionospheric anomalies may be the short-impending precursor anomalies of the earthquake (Yao Yibin et al., 2012). Two months before the earthquake, an ultra-low-frequency electromagnetic anomaly lasting for 10 days was recorded by the Japanese ESA station at 135km from the epicenter, which was the most prominent observation change in the three-year background observation.

The residue displacement of the surface motion rate given by GEONET, as the result of the HHT (Hilbert-Huang) band-pass filter minus the effects of long-term plate motion, short-term noise and frequency-dependent changes, reveals that the residual displacement can infer that the southward movement is consistent with the northeastern coastal seismic fault trend and was particularly evident on the 65th day before the earthquake (Chen C. H. et al., 2014).

Summary: As far as earthquake precursory with a clear time and spatial indication is concerned, the current situation is a lot of aftershock summary work and great difficulty in foreshock application, not to mention quantitatively expressing the significance of earthquake forecast. However, it is clear that the seismic activity parameters show that foreshock stress of the strong earthquake focal zones is relatively high. In addition, it is worth further study of whether the short-term anomaly of the regional surface velocity is related to the pre-earthquake fault pre-sliding.

6 EARTHQUAKE EFFECTS

The tsunami warning started 3 minutes after the earthquake, but the predicted tsunami height was significantly lower, probably due to the initial magnitude of 7.9 by JMA (Japan Meteorological Agency) (Kanamori H., 2012); but the real-time dynamic GPS (RTK-GPS). Timing data could roughly determine within 3 minutes the magnitude of the earthquake as $M_W8.7$ (Ohta Y. et al., 2012). Perhaps high-frequency continuous GPS timing observation in the rapid determination of the magnitude can play a greater role. On the other hand, most of the Japanese dikes, seawalls, sluices and control forests and other infrastructure had not been designed to withstand the tsunami generated by the $M9.0$ earthquake (Suppasri A. et al., 2013), so the tsunami caused many casualties and much economic loss.

In the vicinity of the east coast of Honshu, Japan, 3,477 landslides occurred, of which 80% occurred in the fourth season soil and the Cenozoic rocks, specifically the Cenozoic sedimentary rocks and the lateral expansion of the fourth season sediments, but there is no significant statistical relationship with the recorded peak acceleration by strong motion seismographs (Wartman J. et al., 2013). It is therefore still necessary to carry out research in monitoring and theory on actual earthquake disaster prediction.

The tsunami caused by the $M9.0$ earthquake led to great disasters, and the biggest impact was the near-field regional stress field adjustment. The focal mechanism analysis of the stress field variations before and after the earthquake reveals that the coseismic stress release was more full, or almost completed. The present stress between plates in the Japan Trench is weak. In the vertical section, the maximum principal stress axis is adjusted clockwise 45° – 50°, leading to a large number of positive fault aftershocks (Hasegawa A. et al., 2011). The results of the focal mechanism solution before and after the main shock also shows that the focal zone before the earthquake was dominated by thrust earthquakes, and that the larger aftershocks of more than 40km two months after the earthquake were mainly stretching ones, with SE faults crossing the main fault at the depth of 40km, except for the NW main fault in the Japan Trench. The earthquakes deeper than 40km were mainly thrust earthquakes (Suzuki K. et al., 2012). From the spatial distribution of $M \geqslant 2.0$ seabed earthquakes determined by seismographs in the three months after the earthquake, the 30km and above seismic activities of the main focal zone are relatively weak (Shinohara M. et al., 2012). The maximum principal stress direction converges to the largest area of the coseismic dislocation, and the stress field after the earthquake was completely reversed. The minimum principal stress of the aftershock area points to the plate convergence zone (Hasegawa A. et al., 2012). The maximum and minimum principal stress axes before and after the Tohoku-Oki earthquake in 2011 had a total of 45° of deflection. Similarities appeared in the case of the 2004 $M_S9.0$ Sumatra earthquake and the 2010 $M_S8.8$ Chile earthquake (Hardebeck J. L., 2012).

On the other hand, the Coulomb stress change explains the triggering effect of several significant aftershocks (Hiratsuka S. et al., 2011; Lay T. et al., 2011) and the Coulomb stress change in the main fault zone on the island of Japan, which explains the significant enhancement of seismicity in some areas of the island of Japan (Okada T. et al., 2011; Ishibe T. et al., 2011; Toda S. et al., 2011). Meanwhile the southeastern Hakone volcanic area in southeastern Japan may be a dynamic trigger of seismic waves (Yukutake Y. et al., 2011). The seismic activity in the Kanto area is significantly enhanced, and earthquake frequency greater than 2 times was more than doubled in 2014 (Gardonio B. et al., 2015). The Coulomb stress change caused by the Japanese earthquake in this area was the main reason for the enhancement of seismic activity in the Kanto area (Ishibe T. et al., 2015). For the Tokai earthquake, the Coulomb stress caused by the 9th grade earthquake in Japan is positive, but the magnitude is small, which is less than the trigger threshold. However, it is worth noting that there were five significantly enhanced seismic activities, with enhancement start time from east to west. The Coulomb stress caused by the nine earthquakes in these five regions is greater than the triggering threshold, and the degree of seismic activity enhancement is positively correlated with the increase of Coulomb stress. The magnitude 9.0 earthquake in Japan had little effect on the space, but the increase of seismic activity in the surrounding area should be of concern (Enescu B. et al., 2012).

The $M9.0$ earthquake caused significant near-field and far-field crustal deformation. The multi-beam water depth measurement by active source seismic exploration shows that the earthquake rupture extends to the trench axis, resulting in SE movement of the Japanese trench area of about 50m upward movement of about 7m – 10m (Fujiwara T. et al., 2011), a vertical movement of 5m in the vicinity of the seabed fault, and a horizontal coseismic displacement of 74m. It can be therefore inferred that the shallow fault coseismic dislocations can reach 80m (Ito Y. et al., 2011). The slip that occurred at the front edge of the plate interface reached the seabed of the trench shaft. Based on submarine sonar and GPS, the maximum horizontal measurement and the maximum vertical measurement cumulative and post-earthquake displacement of the Japan Trench seabed for more than three years are 73cm and 45cm respectively, and are located on the south side of the coseismic dislocation zone, which may be the most significant zone of post shock sliding or the most viscous loose zone after the earthquake. The westward movement appeared near the epicenter with about 10cm/a, which is greater than the convergence rate of the Pacific plate. This may be caused by the re-locking of the fault. The northern margin of the dislocation concentration zone has a northward movement, showing that the post earthquake effect extends to the periphery of the focal zone (Watanabe S. I. et al., 2014).

We used the near-field displacement data from 1.5 years after the earthquake as constraints and inverted the distribution of the residual slip after the earthquake, showing that the displacements were mainly concentrated at 20km – 80km depth, exponentially decayed with time, and have cumulative slip of up to 4m. The seismic relaxation energy based on the unseismic sliding after the earthquake is equivalent to the coseismic release energy of $M_W 8.82$ earthquake (Diao Faqi et al., 2014). The equivalent elasticity of the crust in inversion is about 50km and the upper mantle viscosity is 2×10^{19} Pas (Diao Faqi et al., 2014). Satellite gravity also observed significant timing characteristics, such as the 2004 $M9.2$ Sumatra earthquake, the 2010 $M8.8$ Chile earthquake and the 2011 $M_W 9.0$ Tohoku-Oki earthquake. For the upper plate, the coseismic gravity observations were significantly reduced, the short-term gravity observation after the earthquake may be continuously less because of the post-earthquake residual slip and the long term gravity observation after the earthquake may rise because of the viscous relaxation (Tanaka Y. et al., 2014). Of course, the use of relevant information to distinguish between the different physical mechanisms of post-earthquake residual slippery, viscous relaxation and fluid rebound is indeed very difficult.

The Chinese mainland and the Korean peninsula, located about 1000km – 2000km from the epicenter, detected the coseismic displacements as significant coseismic far shock effects (Pollitz F. F. et al., 2011; Shestakov N. V. et al., 2012). The maximum coseismic displacement in the Chinese mainland was 35mm (Wang Min et al., 2011; Zhao Bin et al., 2012), and that in Korea was 57.7mm (Hwang J. S. et al., 2012). The effect may last for hundreds of years in terms of the current analysis of the viscous impact of the $M_W 9.0$ Tohoku-Oki earthquake.

Shestakov et al. (2012) used the far-field GPS coseismic observation inversion to determine the magnitude of the main shock of the $M9.0$ as $M_W8.8$. The comparison of the near-field coseismic displacement observations and their theoretical values shows that far-field GPS observations can be used for tsunami warning systems for strong earthquakes. The northwestern border of the Pacific plate is subducted westward in the Japan Trench, and the ocean plate advanced westward after a depth of 660km. The results of the tomography show that it may reach the Shanxi fault belt in Chinese mainland. The subduction zone includes shallow, medium and deep earthquakes. The focal depth increases westwards from the trench zone to northeast China for about 600km - 700km. The above shows that there is a strong structural connection between the NW edge of the Pacific plate and the eastern part of Chinese mainland. The physical mechanism of these far-field crustal deformations after the $M_W9.0$ earthquake in Japan on March 11, 2011 is worthy of further study, that is, the continuous loading of the northwest edge of the Pacific plate, and the coseismic and post-earthquake loading caused by strong earthquakes play a certain role in the long-term crustal deformation of the eastern part of the Chinese mainland.

The earthquake also led to changes in the ionized stratum. There are three different types of changes in the co-seismic observation of GPS-TEC data: the propagation rate is about 3km/s, which may be caused by Rayleigh surface waves, or partly caused by fault movement. The second change is 1km/s, which may have been generated by the sonic of the earthquake itself, then changed to 255m/s (Rolland L. M. et al., 2011). There is also a rate of 210m/s which may have been caused by the tsunami (Tsai H. F. et al., 2011).

The 2011 $M_W9.0$ Tohoku-Oki earthquake also caused near and far field earthquakes, and volcanic activities in addition to aftershock activities. Compared with the activities before the $M9.0$ earthquake, the magnitude of the repetitive earthquakes in the aftershock residual sliding concentration zones in the 7 months after the earthquake is significantly increased (Uchida N et al., 2015). The earthquake may have accelerated slow slip events on the Boso Hanto peninsula, perhaps because the slow slip events are very sensitive to the transmission of exogenous stress and is likely to be related to the accumulation and release of low stress in its cycle (Hirose H. et al., 2013). The earthquake may have triggered the eruption of Japan's Shinmoedake volcano on March 13 (Wang Fan et al., 2011). The tremors triggered by the 2011 $M_W9.0$ Tohoku-Oki earthquake occurred all over the world, but were concentrated more on the northeast border of the Pacific plate, and are consistent in space with the previously triggered tremors or tremors themselves (Chao K. et al., 2013). The submarine broadband seismograph of the south Japan Sea trough recorded a large number of low-frequency earthquakes in the shallow areas of the eastern part of the south Japan Sea. Compared with previous studies, the low-frequency earthquake events in the south Japan Sea after the 2011 $M_W9.0$ Tohoku-Oki earthquake had smaller magnitudes, shallower depths, and the physical mechanism may have been controlled by the stress state of the fluid and the seismic activities caused by mechanical environment changes (To A. et al., 2015).

Summary: As the monitoring conditions are getting better, the coseismic response observations of the $M9.0$ strong earthquake may become rich. As far as the 2011 $M9.0$ Tohoku-Oki earthquake is concerned, choosing the approach to the study of the internal crust deformation in the Chinese mainland due to plate dynamic boundary loading is need of in-depth study, that is, the need to study the internal crust deformation in the Chinese mainland due to the $M9.0$ earthquake that led to plate dynamic boundary loading, the fault stress accumulation rate and the lasting duration.

7 DISCUSSION AND REFLECTION ON RELATED MONITORING AND FORECASTING

As early as 2002, Aki pointed out that Japan paid special attention to geoscience-related multidisciplinary monitoring and data collection, but did not devote itself to a comprehensive interpretation under the consensus of the scientific community. Prior to the 2011 M_W9.0 Tohoku-Oki earthquake, Japan had 84 F-net Broadband Seismic Station, 1200 GeoNet GPS Permanent Observatories, 1000 K-net strong earthquake observation stations, 777 Hi-net high-sensitivity seismic stations (well installation) with two KiK-net strong earthquake observers for each Hi-net station, and the seabed and seabed seismograph (OBS: Ocean-Bottom Seismometer) and seabed deformation observation instruments.

In particular, the correlation observation on the subduction zone of the plate is very important for the analysis of the M9.0 earthquake. The deformation observation of the seabed (Sato M. et al., 2011) plays a great role in the process of coseismic dislocation inversion. In the same geometrical fault model and the same method, data constraints are the seabed displacement observation based on the original GPS coseismic displacement, but the coseismic dislocation inversion results are quite different (Diao Faqi et al., 2011, 2012). The coseismic dislocation from the joint inversion of the coseismic displacement as constraints from GPS and submarine observations is consistent with the maximum displacement of the coseismic dislocation obtained by digital seismicity (Chu Risheng et al., 2011). The Japan Trench fault locked spactial distribution determined with the crust movement rates as constraints is quite different from the results of Hashimoto C. et al. (2009) and Loveless J. P. et al. (2010). The former shows that the locked spatial distribution of the faults in the Japan Trench is consistent with the coseismic dislocation distribution of the 2011 M_W9.0 Tohoku-Oki earthquake while the latter shows that a strong lock exists only in the deeper zones. The biggest difference between the two is that the latter did not use submarine observations.

Japan's earthquake prediction began in 1965, after the Kobe earthquake in Japan, the actual observation of crustal deformation, seismic network and strong seismic network increased especiallyand continuously in 1995, but no investment was made in non-seismological precursory observations. Some scholars therefore believe that this led to the failure to capture effective precursors, or make earthquake predictions. Since the 1995 Kobe earthquake, Japanese earthquake prediction organizations wanted to abandon short-impending forecast, and the position was reiterated after the 2011 M_W9.0 Tohoku-Oki earthquake. Currently relevant organizations are committed to higher scientific standards, such as the "Japan Earthquake Prediction Society (EQ Prediction Society of Japan)".

The 1995 Kobe earthquake had 6,400 fatalities or disappearances and the collapse of more than 100,000 buildings. After the earthquake, Japan passed the Special Measures for the Prevention of Earthquake Disaster Prevention and established the Earthquake Research Promotion Headquarters in accordance with the Act, which is responsible for seismic investigation and research. The Seismic Research Council collects, organizes and evaluates the relevant seismic survey results and is responsible for promoting the research and dissemination of basic seismic knowledge to achieve the ultimate goal of mitigating earthquake disasters. The Commission has published long-term earthquake assessment and strong surface motion assessment of the faults of the Japanese earthquake activity. The 1999 Earthquake Research Promotion Headquarters included these three research aspects into the Japan 10-year Promotion Earthquake Survey and Research. Based on the above three aspects of basic research, the 2005 Japan Earthquake Research Council released the next 30 years of the earthquake prediction disaster map, and the results include: the earthquake disaster probability distribution map and setting the the focal fault disaster distribution map. The seismic study of the 98 active faults and regional historical strong earthquake statistical studies of Nippon Island and its nearby subduction zones are the main research bases of this prediction study. Of the earthquake prediction research of the same period, many are based on the historical strong earthquake catalog or the ancient earthquake catalog, and use statistical methods to analyze the strong earthquake recurrence cycle and timing process in order to give the probability of prediction (Field E. H., 2007; Working Group on California Earthquake Probabilities, 2003). The results depend too much on the completeness of the historical strong earthquake catalog, and the predicted magnitude is generally not beyond the magnitude of the historical earthquake catalog. As for the 2011 $M_W9.0$ Tohoku-Oki earthquake, the focal activities in the historical earthquake catalog over a hundred years are mainly of $M>7.0$ with occasional $M>8.0$ which are basically located in the west of the $M9.0$ focal zone (Kanamori H. et al., 2006; Engdahl E. R. et al., 1998). Because of the limitation of the historical strong earthquake records, the Japan Earthquake Investigation and Research Promotion predicted that there is possibility of one $M>8.0$ or two $M>7.0$ earthquakes in the Japan Trench in the 30 years from 2005 to 2034 (Headquarters for Earthquake Research Promotion, 2005). Although the predicted location is near the epicenter, the estimation of earthquake occurrence in the Japan Trench is obviously too low.

Japan launched the Observations and Research Program (2009 – 2013) for Earthquake and Volcanic Prediction in 2009, with the aim of quantitatively predicting earthquakes. CSEP (Collaboration for the Study of Earthquake Predictability) is a global earthquake prediction research program (Jordan T. H., 2006). Earthquake Research Institute of the University of Tokyo, Japan set up the Japan Testing Center in 2008, which was run as a national laboratory in Japan and began experimenting in 2009. Nanjo K. Z. et al. (2011) reviewed the first test, with 91 models, 3 test space ranges, and 4 different time ranges (1 day, 3 months, 1 year, and 3 years). The model itself contains multiple integrated models that should provide more information than a single method. On the other hand, some methods include more a physical basis such as coulomb stress changes (Toda et al., 2011). Many models are mostly based on the $M \geqslant 5.0$ frequencies as predictive targets (Lombardi A. M. et al., 2011; Nanjo K. Z., 2011; Tsuruoka H. et al., 2012), but it still needs further study in terms of $M \geqslant 9.0$ or $M \geqslant 7.0$ earthquakes.

Summary: The March 11, 2011 $M_W9.0$ Tohoku-Oki earthquake research shows that the basis of seismic research and forecasting practice is an effective observation, and it is because of Japan's large-scale deployment of physically definite observation instruments of high accuracy such as GPS, strong motion observers and seismographs in addition to continuous observations that reliable research results can be possible and understanding can be improved. On one hand, it is not advisable to abandon some kinds of observation in the reality that the earthquake prediction problem has not yet been solved. However, physically definite observations and observation quality is still the basic prerequisite for all earthquake prediction and forecasting and exploration.

8 DISCUSSIONS AND CONCLUSION

The March 11, 2011 $M_W9.0$ Tohoku-Oki earthquake is the greatest earthquake ever recorded in Japan. The coseismic dislocation of the earthquake shows two concentration zones, shallow and deep. The shallow dislocation zone has a larger coseimic value, but with weaker historically recorded strong earthquakes. The deep dislocation zone has a smaller dislocation value, but is the active zone of $M \geqslant 7.0$ strong earthquakes in historical records. The result shows the limitation of the historical earthquake catalog and that present earthquake prediction can not depend only on statistics.

The regional tectonics determines the characteristics of fault deformation and temporal and spatial evolution of strong earthquakes. Moreover, the properties of the crust media and strong earthquake focal media can be influenced by tectonic action and fault motion. A large amount of the continuous geodesy observation of the spatiotemporal evolution process of the subduction zone in the Japan Trench is beneficial with the background stable lock, pre-earthquake fault movement disturbance and foreshocks. In particular, the pre-earthquake slow shocks and low frequency shocks can be controlled by the fault fluid. The imaging results show that the pre-earthquake medium properties of strong focal zones may reflect the fluid activity in the fault. Although this research still can't accurately describe the three basic elements of time, space and magnitude, and even some are still qualitative work, we can see the possibility of earthquake prediction based on experience or physical prediction.

In view of the current seismic research and the level of earthquake prediction, the inspiration from the 2011 $M_W9.0$ Tohoku-Oki earthquake is that monitoring is the basis of all work, and so the physical meaning of monitoring must be clear and monitoring quality must be guaranteed. This is the prerequisite condition for all earthquake prediction and exploration. On this basis, the richer and more effective monitoring methods such as fault motion, stress state, seismicity, crust medium features, the more solid the foundation of seismic research and forecasting. At the same time, for large-scale, multidisciplinary, continuous, or migratory precursory observations in the Chinese mainland, there may be many things that need to be defined. For example, whether the observed items are clearly physically defined, whether the monitoring specification can ensure the realization of monitoring objectives, and whether the monitoring quality evaluation can ensure that the data effectively meet the needs of earthquake research and forecasting. On the other hand, it is necessary to focus on comprehensive research, especially on the basis of a comprehensive analysis of scientific consensus, to systematically analyze observation data and research results of each subject, which may be basic research work in earthquake prediction from experience to physical prediction.

Of course, the 2011 $M_W9.0$ Tohoku-Oki earthquake has brought along more scientific questions worthy of further study. For example, whether the short-term anomaly of the regional surface movement rate was related to pre-earthquake fault sliding, or what the main effect of the plate dynamic boundary loading on the Chinese mainland internal crust deformation is; how we can achieve a consensus among the scientific community about seismic research and earthquake prediction practice, what other physical forecasting, besides the current statistic forecasting, requires further study and practice, whether there is any generality in the strong focal zone medium environments, what the role of fluid activity in the pre-earthquake fault motions is, and how earthquake precursory monitoring can play a more effective role in the practice of earthquake prediction.

There are many articles on the 2011 $M_W9.0$ Tohoku-Oki earthquake. Because of the limitation on the part of the authors, there are many shortcomings and inaccuracies in this paper. However, we hope to arouse more discussion on the aspect and more thought about China's earthquake monitoring in order to have more suggestions, plans and measurements for Chinese earthquake relief.

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About the Author

Shao Zhigang, born in 1977, is a research professor at the Institute of Earthquake Science, CEA. He was granted his Ph. D degree by the University of Science and Technology of China in 2007. He is engaged mainly in the study of seismicity and geodynamics. E-mail: shaozg@seis.ac.cn