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THE REASONS WHY WE FAILED TO ANTICIPATE M9 EARTHQUAKES IN NORTHEAST JAPAN

Toru MATSUZAWA[1] and Yoshihisa IIO[2]

[1] Professor, Graduate School of Science, Tohoku University, Sendai, Japan, matuzawa@aob.gp.tohoku.ac.jp
[2] Professor, Disaster Prevention Research Institute, Kyoto University, Uji, Japan, iio@rcep.dpri.kyoto-u.ac.jp

ABSTRACT: There were many evidences showing weak interplate coupling in the NE Japan subduction zone: age of the descending slab, background seismicity, existence of small repeating earthquakes, long-term strain in the land area, etc. Thus, almost all of the seismologists did not anticipate that M9 earthquakes could occur there. We should have realized, however, that even a weak plate interface can generate large seismic slip if the width of the coupling region is quite large.

Key Words: Great East Japan earthquake, interplate coupling, earthquake preparation process

INTRODUCTION

Northeastern Japan is located in one of the most investigated subduction zones in the world. The interplate coupling there was thought to be too weak to cause huge earthquakes as large as M9. Therefore almost all of the seismologists in the world were stunned by the occurrence of the M9 Tohoku earthquake (Great East Japan earthquake) on March 11, 2011.

In this paper, we explain the reasons why the seismologists failed to anticipate M9 earthquakes in the northeastern Japan subduction zone and we also try to explain the mechanism that caused the M9 Tohoku earthquake.

EVIDENCES SHOWING WEAK COUPLING ALONG THE PLATE INTERFACE

There were many evidences showing weak coupling along the plate interface in the northeastern Japan subduction zone

Old descending plate

The oceanic plate subducting beneath northeastern Japan is as old as around 130 m.y., which is older than most of the other ocean floors in the world.

Young plates are hot and light, and thus it is not easy to descend beneath the continental plates because of their buoyancy. On the other hand, old plates are thought to descend easily because they are cold and heavy. Therefore, it was thought that the older the subducting plate is, the weaker the interplate coupling becomes (Kanamori, 1977). This was just a hypothesis but it had been accepted by most of the seismologists because its logic sounded very convincing.

Some researchers had casted doubt on the relationship between the M9 potential and plate convergence rate and back-arc spreading proposed by Ruff and Kanamori (1980) after the 2004 M9 Sumatra-Andaman earthquake (e.g., McCaffrey, 2007, 2008; Stein and Okal, 2007), but the dependency on the age of the oceanic plate had not been completely rejected.

High seismic activity

The background activity of small- to moderate-sized earthquakes in the source area of the M9 earthquake (solid oval in Fig. 1) is the highest in Japan. On the other hand, the background seismicity along the Nankai trough, where M8 earthquakes have repeatedly occurred, is very low (dashed oval in Fig. 1). The difference in the background seismicity between the two regions has been explained by the difference in the interplate coupling: if the interface is strongly coupled, it cannot slip usually but eventually slip as a large earthquake.

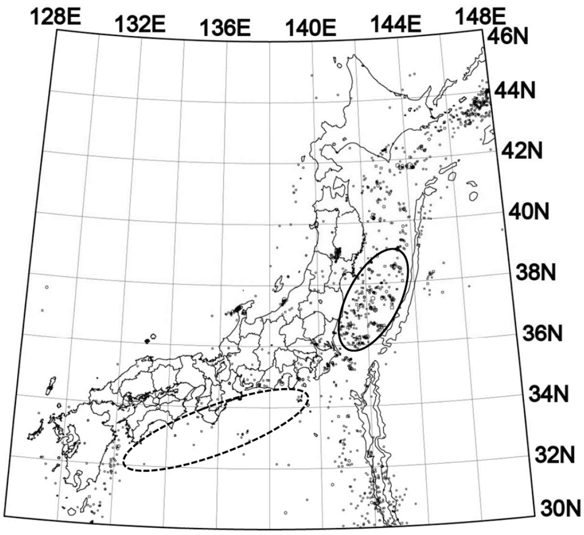

Fig.1 Epicenter distribution of earthquakes of M4 or larger occurring shallower than 60 km for the period from 2006 to 2010. The data are from JMA unified catalogue.

Moreover, small repeating earthquake activity in the northeastern Japan subduction zone is very high (e.g., Igarashi et al., 2003; Uchida et al., 2003). Since the small repeating earthquakes are thought to be caused by the quasi-static slip in the surrounding area, the high activity of small repeating earthquakes indicates that the interplate coupling is weak there.

Dilatational long-term strain in the land area

Around 100 year geodetic survey shows dilatational strain or neutral state is dominant in northeastern Honshu, Japan (Hashimoto, 1990; Ishikawa and Hashimoto, 1999), indicating all the 'locked' areas on the plate boundary might be loosened by M7 earthquakes occurring with repeating intervals of several tens of years.

Some researchers insist that the old geodetic data are unreliable. However, it is hard to explain the reason why such systematic error was generated because no regions other than Tohoku district show such dilatational pattern for almost the same period.

Recent weak coupling estimated from GPS data

Although the analyses of GPS data in the late 1990s indicated a large 'locked' area off southern Tohoku (e.g., Suwa et al., 2006), the data in the late 2000s show weak coupling there (Nishimura, 2011). This weak coupling may be a precursory phenomena of the M9 earthquake (Hori and Miyazaki, 2011), but it can be also interpreted that the strong coupling appearing in the late 1990s was a temporary phenomena.

Seismicity off Fukushima prefecture had been very active until the early 1990s. After the seismic quiescence of around 10 years, the seismicity has again become active since the late 2000s. These indicate that the low seismicity period was exceptional for the off-Fukushima region. Thus, we infer that the coupling before the early 1990s was as weak as in the late 2000s.

Large afterslip

Large interplate earthquakes with M6 or larger are usually followed by large afterslip whose scalar moment is sometimes larger than seismic slip of the main shocks (Suito et al., 2011). Kanamori et al. (2006) pointed out that the seismic slip rate had been low there but we thought that the large afterslip could explain the observed low seismic slip rate.

WHY THE M9 EARTHQUAKE REALLY OCCURRED?

All of the observations mentioned above indicate that the plate boundary was not strongly locked for the long period. Actually, Hasegawa et al. (2011) shows that the stress on the plate boundary before the occurrence of the M9 Tohoku earthquake was as small as ~ 20 MPa.

Then why did the M9 earthquake really occur there? The reason is still under the debate. One of the probable explanations is that the plate boundary had been weakly coupled but the slip of the M9 earthquake was exceptionally large, releasing stress on the boundary almost completely. The Pacific plate descending beneath Tohoku is old and cold but the inclination of the plate is less than around 30 degrees and interplate earthquakes can occur down to 60 km because the plate is very cold. The shallow subduction angle and deep sesimogenic limit made the seismogenic plate boundary very wide (~ 200 km) enough to accumulate slip deficit of more than 50m without large stress increase (Iio et al., 2011). Usually, M6-7 earthquakes release only a part of the absolute stress (~ 3 MPa), but the M9 Tohoku earthquake released almost all of the total stress (~ 20 MPa) because the slip was overshot (Ide et al., 2011) and/or thermal pressurization of pore fluid occurred (Mitsui and Iio, 2011).

CONCLUSIONS

There were many evidences showing weak interplate coupling in the NE Japan subduction zone: age of the descending slab, background seismicity, existence of small repeating earthquakes, long-term strain in the land area, etc. Thus, almost all of the seismologists did not anticipate that M9 earthquakes could occur there. We should have realized, however, that even a weak plate interface can generate large seismic slip if the width of the coupling region is quite large.

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