Interplate megathrust earthquakes and tsunamis along Japan Trench offshore Northeast Japan

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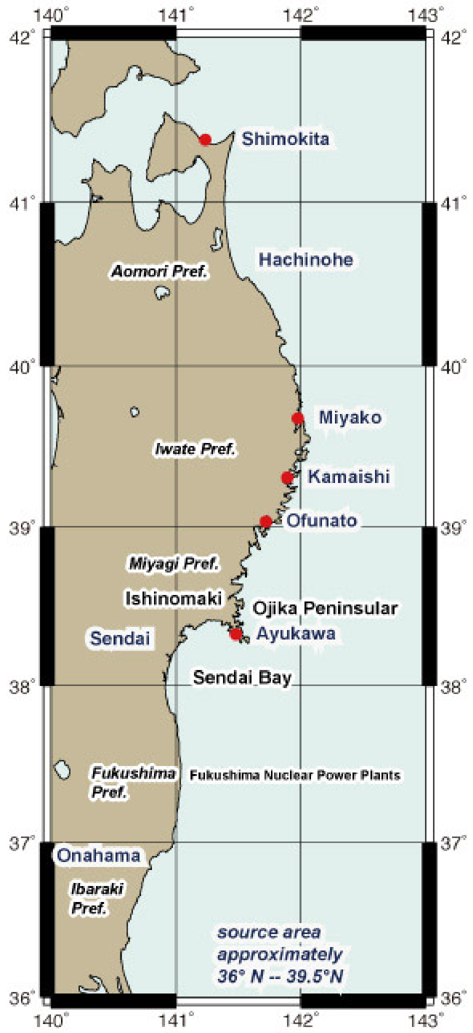
A M 9.0 (JMA: Japan Meteorology Agency) or Mw 8.9 (U.S. Geologcial Survey) gigantic earthquake occurred at 11:46 AM (JST) on March 11, 2011 on the interplate megathrust interface between Northeast Japan and Pacific Ocean. The seismogenic fault plane 500 km long along the trench and 200 km wide toward under Northeast Japan ruptured by three sub-events in 5 minutes (according to JMA) generating the largest known earthquake in and around Japan.

The earthquakes expected in the source area had much smaller magnitude of M 7.4 to M 8.2 from 6 smaller fault segments based on historic seismicity (HERP: Headquarters for Earthquake Research Promotion, 2009a). The March 11 earthquake ruptured all 6 segments in a single earthquake. This conjunctive gigantic earthquake seems to be far beyond seismologists' imagination as the 2004 Sumatra-Andaman earthquake. The segments are shown in online annex documents based on HERP (2010, p. 27 and p.28; 2009a).



The first tsunamis reached to the coast from Choshi (36° N) to Miyako (40° N) simultaneously within 10 minutes as minor (10s of centimeter) backwash in three tide-gauges. Then, about 30 to 40 minutes after the earthquake huge (3 m+) run-up first attacked coastal lowlands. The short time between earthquake and the first wave indicates sea-bottom deformation by underlying seismogenic fault reached very close to the coastline. The simulutaneity of first arrival at Choshi (36° N) to Miyako (40° N) demonstrate the both ends of the fault plane are located offshore of these two tide gauges. See the online annex documents based on tide-gauging by Maritime Safety Agency.

The Sanriku coastal areas between Ayukawa and Hachinoe have suffered repeatedly from recent tsunamis by 1896 subduction earthquake, 1933 outer-rise earthquake under east slope of Japan Trench, and distal 1960 Chile earthquake. The preparedness has certainly reduced fatalities but banks and watergates did not stop tsunami run-ups. During recent tsunamis, tsunami height in Sanriku aeas in Iwate prefecture exceeded 10 meters and enormous damages took place. On the other hand, tsunami height in Miyagi prefecture to the south was mostly less than 5 meters and damages were relatively light. Further south in Sendai area and Joban coast of Fukushima and Ibaraki, only few locations experienced tsunamis more than 2 meters (Watanabe, 1985).

Tsunami hazard assessments in Miyagi and Fukushima prefectures were based on those recent tsunamis above and nobody has ever expected such high tsunamis as 4 to 7 meters or more of March 11. However, historic records of tsunamis have indicated much higher tsunamis in 1611 (Keicho in Japanese imperial period as Showa and Heisei) and 869 (Jogan period). In 1611, 6 to 8 meter high tsunamis devastated Sendai plain and Northern Fukushima areas, and in 869 entire coastal plain was inundated beneath Tagajo in present Sendai city. The paucity of quantitative data probably have discouraged researchers and practicians to take these ambiguous indication into hazard maps. However, the inundation and tsunami height of the March 11 tsunamis very well match with those data.

In the past a few years, geological studies of the 869 Jogan tsunami brought remarkable information on past huge tsunamis in Sendai Bay coast and further south. Sawai et al. (2007) and Shishikura et al. (2007), HERP (2009b) studied surface geology of coastal lowlands in Ishinomaki Plain and Sendai Plain on Sendai Bay and found tsunami deposited being distributed over almost entire coastal plains. They used geoslicer, a sampling tool that collect planer soil sample of 10 cm wide, 2 cm thick, and up to 200 cm long, very intensively to get closely spaced boring transect across coastal plain to reveal the position of coast line in 869, and extent of tsunami deposits both horizontally and vertically. The Towada-a volcanic ash that erupted in 915 and lies just above the 869 tsunami deposits helped recognition and correlation of the deposits.

In Ishinomaki plain northeast of Sendai, the 869 tsunami reached 2.5 to 3.0 km inland from the coastline of that time located 0.8 to 1.3 km inside present coastline (Shishikura et al., 2007). In most areas of the Sendai plain 869 tsunami reached about 3 km inside present coastline (Sawai et al., 2007). Further south in Fukushima prefecture at Matsukawaura and Namie, 869 tsunami reached respecteve 2 km and 1.5 km inland. At Namie, tsunami deposits was found at 3.6 m above present sea level (HERP, 2009b). These evidence clearly indicate the inundation area of the 869 Jogan tsunami was similar to the area during March 11 tsunamis. Though tsunami deposits of 1611 Keicho tsunami were identified in a few locations, human disturbance of rather shallow horizon of the deposits and difficulties in radiocarbon dating make it impossible to reconstruct the 1611 inundation areas.

Satake et al. (2008) modeled the 869 Jogan tsunami by computer simulation using above geologic data. They propose two seismogenic fault models on plate boundary megathrust. One is 100 km long and 100 km wide fault plane with 10 m slip, the other is 200 km long and 100 km wide fault plane with 7 m slip both offshore Sendai. The estimated magnitude is Mw 8.1 to Mw 8.4. The extent of the fault plane is constrained only by the limitation of geologic data. Along the Sanriku coast north of Ayukawa and Ojika peninsular, no tsunami deposits of recent tsunamis as well as 1611 Keicho tsunami have ever found. Since historic records clearly demonstrate very high tsunami and extensive inundation by these tsunamis, the lack of tsunami deposits in Sanriku coast does not indicate the lack of big tsunamis in 869.

These studies were about to reveal unknown extreme tsunami disasters like those of 2004 Indian Ocean tsunamis, from which we did learn about paroxysmal hazard far beyond our knowledge and imagination. However, the new information did not help much to reduce the hazards on March 11.

The gigantic interplate earthquake from conjunctive multi segment rupture and consequent tsunami of March 11 together with the 869 Jogan tsunami reminds us about the finding of a paroxysmal earthquake and tsunamis offshore Eastern Hokkaido, North Japan in 17th century. Along the southernmost Kuril trench offshore Eastern Hokkido, Tokachi-oki earthquakes in 1843, 1952, and 2003 at M 8.0 to M 8.2, and Nemuro-oki earthquakes in 1893 and 1972 at M 7.9 and M 7.4 occurred repeatedly at intervals of 50 to 100 years. During these earthquakes and between earthquakes, entire Eastern Hokkaido coastal areas have subsided and minor tsunamis run up on rather small areas of coastal lowland.

In most coastal lowlands in this area, Nanayama et al. (2003) found very extensively distributed tsunami deposits of 17th century. The tsunami deposits reaching 1 to 4 km inside present shorelines and up to 20 m above sea level indicate much larger tsunamis than recent ones attacked the areas in 17th century. The identification and chronological correlation of the deposits was quite certain with volcanic ash layers above and below them. From longer geologic records, similar earthquakes had occurred at about 500 year interval in past 2000 to 7000 years. In order to generate this large tsunamis, conjunctive rupture of Tokachi-oki and Nemuro-oki seismogenic faults and rupture of deeper portion of the interplate megathrust were indispensable.

Sawai et al. (2004) examined fossil diatom assemblages of muddy sediments below and above the tsunami deposits to demonstrate pre-seismic subsidence and post-seismic slow uplift. The post-earthquake slow uplift was inferred as to have caused by afterslip in the deepest portion of the megathrust interface and the interface between mantle wedge and subducting slab. This is the only way to explain the long-term uplift of entire Eastern Hokkaido coast indicated by Pleistocene marine terraces.

The recognition of the 17th century paroxysmal earthquake and tsunamis innovated our knowledge about extreme events in that area. For Japanese earthquake hazard maps, HERP (2004) took these events into account and estimated M 8.3 conjunctive rupture earthquakes in addition to historically known < M 8.0 earthquakes. Our knowledge about the extreme events in the Northeast Japan were close to innovation before the March 11 earthquake, but it was a little short.

References:

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Annex information and figures:

Earthquake Research Institute, University of Tokyo webpage on March 2011 earthquake: http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/

Tide Gauging by Maritime Safety Agency:

http://www1.kaiho.mlit.go.jp/KANKYO/TIDE/real_time_tide/sel/index.htm

Selected tide gauge records by Koji Okumura

http://home.hiroshima-u.ac.jp/~kojiok/110311EQ/tsunami01.pdf

HERP model of the segmentation of Japan trench subduction interface annotation and English explanation by Koji Okumura

http://home.hiroshima-u.ac.jp/kojiok/110311EQ/HERPmapwithnotes1.pdf

http://home.hiroshima-u.ac.jp/kojiok/110311EQ/HERPmapwithnotes2.pdf