Reconstruction of the 869 Jogan earthquake, the predecessor of the 2011 Tohoku earthquake, by geological evidence combined with tsunami simulation



M. Shishikura, Y. Sawai & Y. Namegaya
Active Fault and Earthquake Research Center, AIST, Geological Survey of Japan

ABSTRACT: We reconstructed the tsunami inundation area of the 869 Jogan earthquake by geological evidence such as tsunami deposit, and inferred fault source model by tsunami simulation. From analysis of nearly 400 geological core samples obtained from the Sendai and Ishinomaki Plains, it is inferred that the 869 Jogan tsunami inundated to 3-4 km further inland from shoreline and was generated from subduction mega-thrust fault which has 200 km long and 100 km width off Miyagi and Fukushima. Magnitude and source of the Jogan tsunami is very similar to the 2011 Tohoku earthquake.

1 INTRODUCTON

The 2011 Tohoku earthquake (M 9.0) was generated from plate interface along the Japan Trench where the Pacific plate subducts beneath the North American plate. Source fault lies from off Sanriku to off Ibaraki with length of 500 km (Fig. 1). Coastal lowlands were damaged by large tsunami which inundated to 3-4 km inland. Not only the general public but even most of seismologist did not imagine that such giant earthquake and tsunami

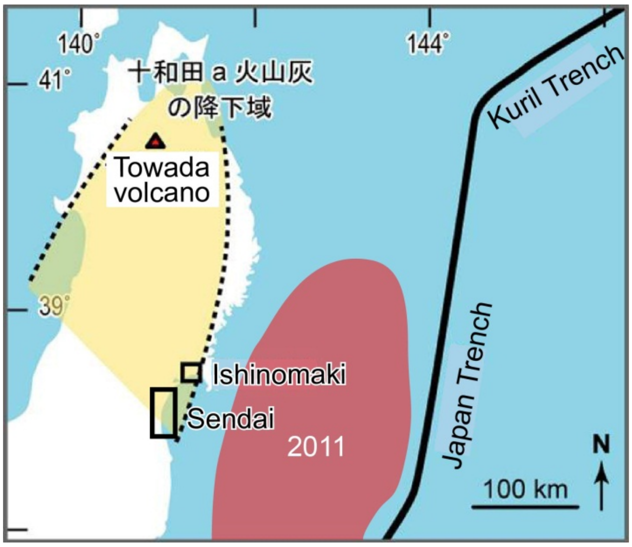

Fig. 1 Location of the survey sites and source area of the 2011 Tohoku earthquake.

would occur off Tohoku. However some paleoseismologists had already revealed the possibility of giant tsunami almost as large as the 2011 event.

Back to over 1100 years ago, the 869 Jogan earthquake accompanied with large tsunami was recorded into historical documents and coastal sediments. In this paper, we introduce our research results of the Jogan earthquake reconstructed by combination of geological evidence and tsunami simulation in the Sendai and Ishinomaki Plains.

2 DISCRIPTION OF THE HISTORICAL DOCUMENT

The written history of tsunamis near Sendai begins with a possible predecessor of the 2011 extraordinary large tsunami which was over 1,000 years ago. It is known from series of historical documents (*Nihon Sandai Jitsuroku*) for the Heian era (AD 794-1192). The documents mention a large earthquake and a tsunami on July 9, AD 869, in the Julian calendar.

3 GEOLOGICAL EVIDENCE

Past large tsunami events have been recorded in Holocene coastal deposit along the Pacific coast in Tohoku. We conducted coring survey in the Sendai and Ishinomaki Plains by using Geo-Slicer which

Fig. 2 Working scene of coring survey by using Geo-Slicer.

can take undisturbed and continuous geological core sample (Fig. 2). The survey areas are well-known as a rich production area of rice and are therefore mostly cultivated by paddy field. Before reclamation, such areas were marshy environment where peaty materials have been deposited. Several sand sheets which consist mainly of massive (sometimes laminated), poorly-sorted and graded sand are intercalated into the marsh deposit. Because they contain marine microfossils and distribute further inland, we consider that the sand sheets were transported from around beach by tsunami. One of the widely distributed sand sheets covered by volcanic ash (To-a tephra) erupted from Towada volcano during AD 915 is identified to be derived from the 869 Jogan earthquake (Fig. 3).

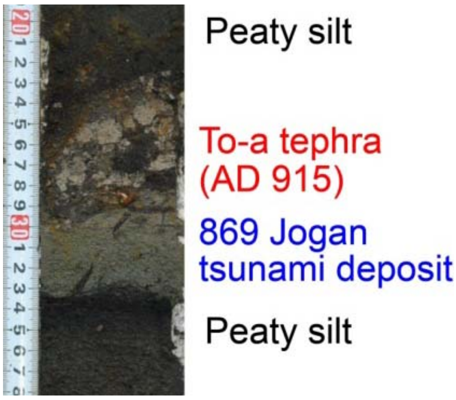

Fig. 3 Photo of sliced core showing the historical volcanic ash and tsunami deposit intercalated into marsh deposit.

3.1 *Ishinomaki Plain*

We found at least five layers of tsunami-originated sand in the Ishinomaki Plain by coring at over 50 sites along five survey lines (Shishikura et al., 2007). The tsunami events are pre- or post-dated the To-a tephra. The sand layer just below To-a, which is widely distributed in the plain, is correlated to the 869 Jogan tsunami (Fig. 4). Analyzing this tsunami deposit, it is inferred that the Jogan tsunami inundated 2.5-3 km inland from paleo-shoreline, which was about 0.8 - 1.3 km inland of present shoreline. Two older and one younger sand layers than the Jogan tsunami were radiocarbon-dated to be 2800-3100 cal yBP, 2100-2300 cal yBP and 14-15th century, respectively. The youngest sand layer was possibly deposited during the 1611 Keicho tsunami, though it was observed in only one site.

Fig. 4 Distribution of the 869 Jogan tsunami deposit in the Ishinomaki Plain

Fig. 5 Distribution of the 869 Jogan tsunami deposit in the Sendai Plain

3.2 *Sendai Plain*

We also took the study of paleotsunami in Sendai Plain (Sendai, Natori, Iwanuma, Watari, and Yamamoto) (Sawai et al., 2007; 2008). The study was based on forty-nine sliced samples taken from rice paddies (swales) and beach ridges using the handy geoslicers. The deposits consist mainly of massive (sometimes laminated), poorly-sorted and graded sand, swamp/marsh peat, mud, and a historical volcanic ash (To-a: AD915). Two of the sand layers were regarded tsunami deposit judging from fossil records, sedimentary structures, correlation with historical records, and continuous traceability from over a few kilometers (or less than a kilometer) from the present coast to landward. Tephrochronology permit correlation of the sand sheet with a tsunami in AD869 Jogan tsunami that reportedly devastated at least 100 km of coast approximately centered on Sendai (Fig. 5). The other sand sheet above the ash To-a can probably be correlated to the 14-15th century event detected in Ishinomaki or well-known tsunami in AD1611 Keicho. Further deeper part of the cores record a few sand sheets and this may represent that usually large tsunamis repeatedly inundated Sendai Plain during the late Holocene. In Yamamoto Town, radiocarbon dating showed that recurrence interval of sand sheets ranged from 600 and 1300 years.

4 TSUNAMI SIMULATION

Tsunami inundation area was examined by computer simulations. Satake et al. (2008) and Namegaya et al. (2010) tested several types of tsunami source models. They show that tsunami source of the Jogan tsunami was extraordinary larger than usual Miyagioki (off Miyagi prefecture) earthquake which has M 7.0-7.5 in magnitude and mean recurrence interval of 37 years. It requires at least Mw 8.4 (interplate earthquakes with length of 200 km, width of 100 km, upper depth of 15 km or 31 km, and the slip amount of 7 m) to explain tsunami inundation based on distribution of sand sheet. We assumed 14 fault models of the Jogan earthquake (Satake et al., 2008 and Namegaya et al. 2010). They include outer-rise normal fault, tsunami earthquake, interplate earthquakes with various fault depth, width, length, and slip amounts. In addition, an active fault in Sendai bay is modeled. Tsunami inundation areas in Ishinomaki plain, Sendai plain, and Ukedo river-mouth lowland were computed from these models. The computed areas were compared with the distributions of the Jogan tsunami deposit in each area. As a result, two fault models are selected as possible models; interplate earthquakes with length of 200 km, width of 100 km, upper depth of 15 km or 31 km, and the slip amount of 7 m (Mw 8.4).

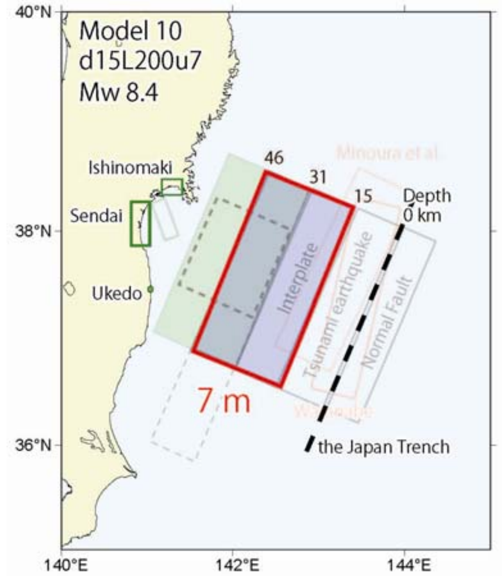

Fig. 6 One of the most probable fault model for the 869 Jogan earthquake

5 RECURRENCE OF LARGE TSUNAMI EVENT

Deeper part of the cores record that usually large tsunamis repeatedly inundated the Sendai and Ishinomaki Plains in the late Holocene. Recurrence intervals were estimated a range between 450-800 years on the basis of a computer program OxCal using radiocarbon ages of samples from 3-4 m geoslicers in Sendai, Yamamoto, and Minami-Soma sites. Considering elapsed time, thus there was high risk of large tsunami just before the 2011 event.

6 RELATION WITH THE 2011 TOHOKU EARTHQUAKE

Inferred magnitude of the 869 Jogan earthquake seems to be smaller than the 2011 earthquake. However the Jogan fault model is based on only detected geological traces in the Sendai and Ishinomaki, and is thus minimum size. If newly evidence of the Jogan can be detected in Sanriku or Ibaraki, the fault model would be larger extent and closer to the magnitude of the 2011 event.

Simulated tsunami inundation limit of the 869 Jogan is almost same position as that of observed 2011 Tohoku. However, the latter shows actual inundation of water whereas the former is estimated by tsunami deposit. To confirm the deference between tsunami inundation limit and distribution limit of sandy deposit transported by tsunami of the 2011 event, we conducted post-tsunami survey, and compared the sandy deposit limit with the 869 Jogan earthquake (Fig. 7). Our survey results show that magnitude of tsunami inundation seems to be roughly same between two events.

Fig. 7 Comparison of tsunami inundation between the 869 Jogan earthquake and the 2011 Tohoku earthquake

7 CONCLUSION

Our study results suggest that it can be forecasted to the magnitude of the 2011 Tohoku earthquake, though it was difficult to predict exact timing. To know the past is very important to evaluate future earthquake and tsunami. Coastal paleoseismology is the best way to reveal past phenomena related to earthquake and tsunami.

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