Chapter 3

The Science of Tsunami History

Field of expertise: Geology

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Summary

Tsunami deposit research deciphers the history of past tsunamis from sedimentary records and benefits to improve our understanding on the recurrence intervals of tsunamis for regions or periods without sufficient instrumental and written records. What has been learned from the 2011 Great East Japan Earthquake is that if the findings from tsunami deposit research had been applied to the practices for disaster prevention activities, the damages might have been much reduced. During the last 10 years, researchers have been dedicating a lot of effort to ensure they do not overlook unexpected tsunami hazards again.

Keywords: geological record, tsunami deposit, Miyagi-oki earthquake, Jogan earthquake, supercycle model

Introduction

What is the key to predicting and preparing for future tsunami disasters? Given that the earth's structure, dynamics and principles for physics and chemistry are invariable throughout space and time, we can acquire useful implications for the future from past records, including historical documents, archaeological sites and relics, sedimentary deposits and fossils. Such records are sparsely scattered in space and time, and information tends to be more vague in the deeper past. Nevertheless, we have to prepare for future disasters. How far back will we need to look for records to help with this?

1: Problems Revealed by the Great East Japan Earthquake

What happened?

The Pacific coast of Tohoku, which is facing the Japan Trench, has repeatedly been damaged by past tsunamis. The oldest historical record dates back to the Heian Period (ca. 794 ~ 1192 C.E.), but the quality and quantity of the records before the Edo Period (1603 ~ 1868 C.E.) are quite limited. Before the 2011 Great East Japan Earthquake, the Sanriku coast was well known for its tsunamis. The 1896 Meiji Sanriku earthquake (Mw 8.1) triggered a huge tsunami that reached a height of 38.2 meters at Ryori Bay in Ofunato City, Iwate Prefecture. The earthquake and tsunami brought the worst tsunami disaster in Japan and claimed 21,753 lives. The 1933

Showa Sanriku earthquake (Mw. 8.5) also triggered a huge tsunami that recorded the maximum runup of 28.7 meters at Ryori Bay. The earthquake and tsunami caused 3,064 deaths and missing persons across the devastated areas. Since then, the Sanriku Coast has been considered to be prone to tsunamis and this promoted the construction of protection walls. The tsunami triggered by the 1960 Chilean earthquake (Mw 9.5) traveled across the Pacific for 23 hours and struck the Sanriku and other coasts in Japan. A maximum runup of 8.1 meters was recorded at Noda Village in Iwate Prefecture. The tsunami again caused considerable damages with 116 deaths and missing in Iwate and Miyagi prefectures. Total number of victims was 139 in the country.

During the period from 1897 to 2005, four major earthquakes occurred off the coast of Miyagi Prefecture (Miyagi-oki earthquakes). According to research on historical and instrumental records, the Miyagi-oki earthquakes have been considered as a characteristic earthquake in this region, with a magnitude ranging from 7.1 to 7.4 and an averaged recurrence interval of 38 years. In general, tsunamis from the Miyagi-oki earthquakes were minor. For example, the tsunami height due to the 1978 Miyagi-oki earthquake was around 1 meter within and to the south of the Sendai Bay. In 1793, a large-scale earthquake occurred off the coast of Miyagi and triggered a tsunami with heights ranging from 2 to 5 meters that struck the coasts of Iwate, Miyagi, and Fukushima. The rupture area of the 1793 earthquake has been considered to have extended from off the coast of Miyagi to near the Japan Trench, and the magnitude was estimated at M 8.0. Nevertheless, damages from the tsunami were not so extensive. Before 2011, a Miyagi-oki earthquake was considered to have been quite imminent, and the 10-year probability of occurrence was estimated at 70% based on the historical and instrumental records. On March 9th in 2011, an earthquake with Mw 7.3 occurred offshore of Miyagi Prefecture. The focal region and magnitude of the earthquake were within the scope of the supposition. People might have deemed that the threats from the Miyagi-oki earthquake had passed. Two days later, however, people were stricken with the unexpected disaster due to the Mw 9.0 off the Pacific coast of Tohoku earthquake. The official name of the earthquake determined by the Japan Meteorological Agency is long, so it is often abbreviated as ‘Tohoku earthquake’ or ‘Tohoku-oki earthquake’. In this article, we use the latter abbreviation.

The reality of the damage

The size of a Mw 9.0 earthquake is 180 times greater than that of a Mw 7.5 earthquake, if we compare by using the seismic moment. The tsunami triggered by the Tohoku-oki earthquake reached 40.1 meters at Ryori Bay, which exceeded the record set at the time of the 1896 Meiji Sanriku earthquake. The generation mechanism of the gigantic tsunami has been explained by a huge slip in the shallow portion of the plate boundary superimposed on a large fault slip in the deeper portion. The Sanriku Coast again suffered from devastating damages due to the Tohoku-oki tsunami, although many countermeasures had been taken during the last decades to prevent tsunami disasters. The size of the Tohoku-oki tsunami was unexpectedly large throughout the Pacific coast of East Japan. The gigantic tsunami brought both direct and indirect damages to the extensive areas with all possible processes, which resulted in a complex disaster.

2: Paradigms Destroyed by the Earthquake

Conventional wisdom and necessary responses

Before 2011, attempts to predict future major earthquakes had been based on ‘reliable’ information, such as historical documents since the Edo period and modern instrumental data from seismology and geodetics. Few researchers have pointed out that the strain rate of the Tohoku region estimated by geodetic observations (a time span of 100 years) is one order greater than that by geologic observations (several thousands of years). This discrepancy was explained by a strain release due to a giant earthquake; unfortunately, the pre-disaster earthquake predictions did not take this into account. The occurrence of the Mw 9.0 earthquake demonstrated the validity of the view of the discrepancy in the strain rate. After the disaster, the supercycle model was introduced to explain the occurrence of a giant earthquake. According to the model, a major earthquake does not release all of the strain caused by the motion of subducting oceanic plates. Residual strains are accumulating during a period of repetition of several major earthquakes which may have a recurrence interval of 10’s to 100’s of years. After this time frame, a large amount of strain accumulated between the plate interfaces is finally released by a giant earthquake. Records with a much longer time span are needed to understand the possibility of the giant earthquake. Although such records were available at that time, they were almost overlooked.

3: A New Approach

The Great East Japan Earthquake has been considered to be a recurrence of a once-in-a-millennium disaster, because of the similarity to the 869 CE Jogan earthquake and tsunami that struck the ancient Tohoku region. A historical document named *Nihon Sandai Jitsuroku* (the Veritable Records of Three Reigns of Japan) tells of damages due to the Jogan earthquake and tsunami at the Tagajo castle in the Sendai Plain. Despite its older age, the descriptions are clear; however, it does not allow us to read further details about the earthquake and tsunami, such as the wave height, inundation area and earthquake magnitude. Thus, the size and spatial extent of the earthquake and tsunami deduced from the historical document and other relevant legends and folklore have long been a subject of debate among researchers. Surprisingly, much of our current understanding on the earthquake and tsunami are based on the findings from tsunami deposits, which are the geological traces of past tsunami inundations. Geological studies of the Jogan tsunami deposit were initiated in the late 1980s in the Sendai Plain. Until 2010, researchers have discovered the Jogan tsunami deposit from the coastal plains of Sendai Bay and Joban Coast with an estimated inundation distance of more than 4 kilometers from the paleo-shoreline. An intraplate earthquake greater than Mw 8.4 was assumed for the tsunami source, based on the comparison of spatial extent of the tsunami deposit and inundation area estimated from the numerical simulations. In the Sendai Plain, 4-5 layers of tsunami deposits, including from the Jogan event, have been found within the coastal sedimentary sequences during the last 3000 years. It means the recurrence interval of the tsunamigenic earthquake can be 500 to 800 years. If such findings from the tsunami deposits were considered for the attempts of earthquake predictions, damages from the Great East Japan Earthquake might have been reduced. Immediately after the earthquake, the lessons learned from the disaster have been implemented to the government’s objective for disaster management. During the last 10 years, investigations of tsunami deposits have been promoted in many coastal areas of the country. Findings from tsunami deposits are going to be considered in countermeasures for future earthquakes and tsunamis.

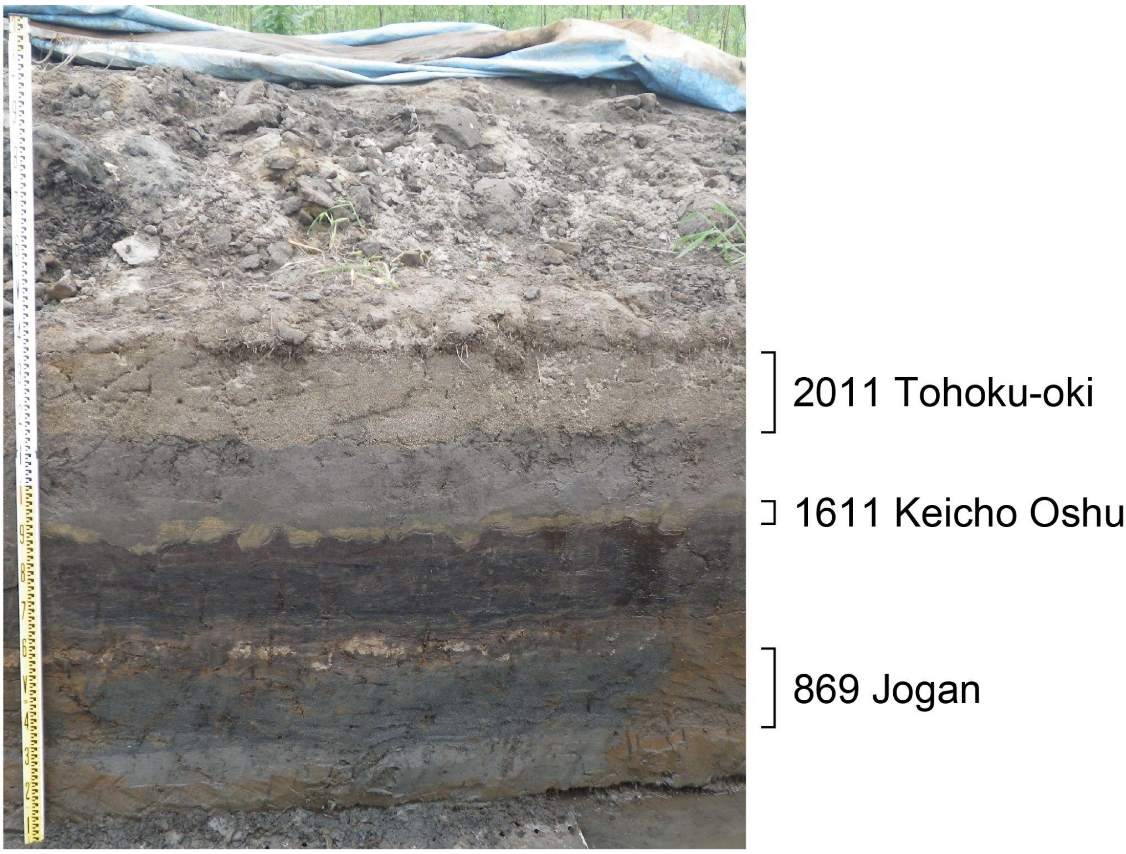

Figure 3-1. Tsunami deposits found from an archeological site in Iwanuma City, Miyagi Prefecture. Three layers of sandy tsunami deposits, which correspond to the 2011 Tohoku-oki, 1611 Keicho Oshu and 869 Jogan tsunamis have been identified at this site.

4: Achievements and the Future

A new approach to disaster science

Whether or not tsunami deposits can be formed and preserved as a sedimentary record depends on environmental factors, such as local topography and geology, in addition to the tsunami size. Field investigation taken after the Great East Japan Earthquake revealed that tsunami-induced sediment erosion may erase earlier tsunami records. This means that sedimentary records are not necessarily continuous; there may be missing intervals within the records. To compensate for that and to better determine the timing and spatial extent of the tsunamis, researchers are attempting to discover more tsunami deposits and correlate them on a regional scale. The International Research Institute of Disaster Science (IRIDeS) developed an open database that combines historical and geological records of past tsunamis in Japan based on old documents, articles, research reports and papers (Tsunami Trace Database). This will help to screen potential areas, in which information on tsunami deposits is not yet sufficient and new findings from the area are indispensable for reconstruction of paleotsunami history.

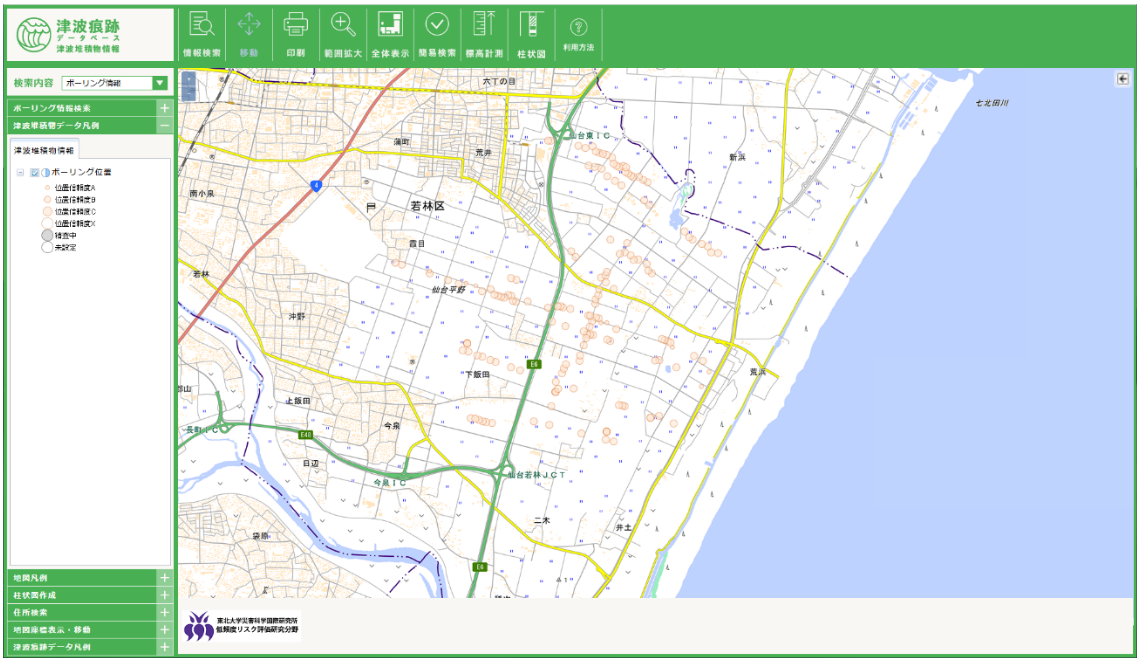

Figure 3-2. A screenshot of the Tsunami Trace Database.

Occurrences of giant earthquakes are impending in regions facing the Kuril Trench and Nankai Trough. To utilize findings from tsunami deposits to predict future earthquake disasters, improvements must be needed for the clarity and accuracy of tsunami deposit surveys. To this end, the IRIDeS is promoting research projects that employ non-destructive data acquisition technology, such as ground-penetrating radar and X-ray fluorescence scanning. High-precision radiocarbon (14C) dating for better correlation of paleotsunami events and tsunami sediment transport simulations for screening candidate survey area and tsunami source modeling are of additional great interest of the research.

We sometimes have a poorer understanding of the details for historic tsunamis, even if they are recent ones. Identification of the predecessor of the 2011 Tohoku-oki and descendant of the 869 Jogan earthquakes is crucial for the long-term assessment of risks from giant earthquakes. In the Tohoku region, two historical earthquakes, the 1611 Keicho Oshu and 1454 Kyotoku events, have been known as candidates for giant earthquakes between 869 and 2011 CE. Regarding the Keicho Oshu earthquake, which is considered to have occurred along either the Kuril or Japan Trench, paucity of historical records makes their interpretations difficult, and this has left the identification of the main rupture area of the earthquake as the subject of debate. The majority of deposits of the Keicho Oshu tsunami have disappeared due to modern anthropogenic activities, and they do not provide conclusive evidence. Historical records of the 1454 Kyotoku earthquake and tsunami are much rarer. Despite tsunami deposits with their corresponding ages have been found from some localities around the Sendai Bay, the magnitude of and damages from the earthquake and tsunami are quite uncertain. The main problem for discrimination of the two historical earthquakes comes from the uncertainty in 14C dating due to the fluctuation of the calibration curve for calendar ages. To establish a better understanding of the history of giant earthquakes, IRIDeS promotes collaboration between the humanities and sciences that combine information from a broad spectrum of fields.

Conclusion - from the author

After the Great East Japan Earthquake, the importance of geological records such as tsunami deposits have drastically increased. In order not to repeat the unexpected damages from future earthquakes and tsunamis, further efforts are needed to reconstruct much more comprehensive paleotsunami history and to utilize them for predictions and countermeasures for future disasters.

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