Preliminary numerical study of offshore sediment transport by the tsunami

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Numerous studies of tsunami deposits have been conducted on the plains and lakes along the Pacific coast of Japan, and the tsunami histories during the past several thousand years have been reconstructed in various places (e.g., Sawai et al., 2008, 2009). Although these studies were mainly conducted on land, most of the tsunami deposits at the geological era are reported in the marine deposits (Fujino et al., 2006). However, there are few researches on offshore tsunami deposits so that little has been understood on characteristics, identification criteria and sedimentation process of offshore tsunami deposits. It is thus important to study recent offshore tsunami deposits as modern analogue.
Regarding to the 2011 Tohoku-oki tsunami, Tamura et al. (2015) and Yoshikawa et al. (2015) reported offshore tsunami deposits shallower than 30 m in depth in the Sendai Bay. According to them, offshore tsunami deposits were transported from the beach by backwash and the thickness became thinner toward the offshore. On the other hand, deposition of turbidites triggered by the earthquake and tsunami are reported on the sea floor deeper than 100 m in depth (Arai et al., 2013; Ikehara et al., 2014; Usami et al., 2016).In this way, erosion and deposition by the 2011 Tohoku-oki tsunami have been reported in a wide area ranging from the shallow to deep sea along the Japan Trench. However, conventional studies quantitatively evaluating the sediment transport process have focused on only in the shallow sea (Yamashita et al., 2016), not whole the shallow to deep sea.
Herein, we examine offshore sedimentation and erosion based on the numerical modeling for sediment transport by the tsunami in the Sendai Bay. The calculation was carried out with TUNAMI-STM model (Yamashita et al., 2016) which combines a sediment transport model with a numerical model by the finite-difference method of nonlinear long-wave theory. In this time, the behavior of sediment of 4 sizes (very fine, fine, medium, and coarse sands) was simulated in consideration of tsunami deposit and bottom sediment reported in Sendai bay.
As a result of calculation of very fine sand condition, bottom sediments in the wide area were suspended by the first run-up wave. However, the suspended sediments continued to have been moved landward and seaward both by run-up waves and backwashes. Consequently, sediments were not moved significantly from the original areas. In case of fine and medium sand conditions, coastal sediments were transported toward the shallow sea by backwash. Namely, sediments can be transported seaward by backwash up to 30 m under the fine sand condition. In case of coarse sand condition, sediment were not moved at the depth where coarse sand is actually distributed in the Sendai Bay.

Keywords: tsunami deposit, Tohoku-oki tsunami, numerical simulation, sediment transport

Grain size feature of 3.11 Tsunami origin sediment in Sanriku coast around Miyagi to Iwate pref.

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The recent 2011 Tohoku earthquake affected Tohoku area and coastal area of Pacific coast were strongly damaged by Tsunami. The seabed at local area of Sanriku coast have environment change (ex. erosion of seabed and become deposited new sediment etc.) by Tsunami. A lot of bay of Sanriku coast became deposited new sediment composed by coarse-grained material (called Type1, ex. Otsuchi, Toni, Okirai and Hirota bay etc.) and a few bay became deposited fine-grained material (called Type2, ex. Onagawa bay etc.). In this presentation we will show about characteristics of grain feature by each type bay.
We took the columnar core at Otsuchi bay, Hirota bay and Onagawa bay. Otuchi bay and Hirota bay belong to Type1, and Onagawa bay belong to Type2.
[Columnar core lithofacies]
Type1 (composed by coarse-grained sediment): Both bay core were able to sectionalize into mainly two units, Unit1 (sand layer) and Unit2 (mud layer) from the top. We estimate Unit1 were 3.11Tsunami deposit and Unit2 were normal sediment in this bay use Yokoyama et al. (2014) as the base. And several samples have Unit3 (sand layer) below the Unit2. Unit3 have possibility of event sediment by feature of litofacies.
Type2 (composed by fine-grained sediment): Onagawa bay core were able to sectionalize into two units. Unit1 composed silt~fine sand with coarse sand on the bottom and Unit2 composed silt characterized by bioturbation. We estimate Unit1 were 3.11Tsunami deposit and Unit2 were normal sediment in this bay.

[Grain size analysis]
We making correlation chart using median diameter and sorting value of core samples and using for infer the origin of Tsunami deposit.
Type1 : U1 and U2 distribute clearly different area. U1 distribute during the U2 and beach sand, it means the possibility of U1 have originated as both. U3 distribute same area of Unit1. So, Unit3 make by similar event of Unit1.
Type2 : Bottom of Unit1 samples and U2 distribute clearly different area. However, Type2 samples not clearly classification than Type1 samples.

Keywords: Tsunami deposit, Sanriku coast

Seasonal change of diatom assemblages and surface sediments in Hirota bay, Iwate, Japan.

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The recent 2011 Tohoku tsunami strongly affected the coastal area at the Pacific coast of Tohoku district. Especially of the damage caused by the tsunami activating around Hirota bay, Iwate prit.
Tsunami origin sediment over a wide range are distributed around the Hirota bay. We will show about characteristic such as lithofacies description, a grain size composition and diatom assembles of the surface layer deposit sampled from Hirota bay.
We checked 18 samples from survey lines L8, L9, and L3. L8 (7.5~9.9m deep) and L9 (11.1~13.4m deep) are a survey line drawn in the E-W direction. L3 (6.6~49m deep) is a survey line drawn in the N-S direction of Hirota bay.
From the results of the particle size analysis, in June 2015 survey, it was found that the content of sand from the central part to entrance of Hirota bay, was low and the mud content was high. But, in October 2015, sandy sediments are distributed widely in comparison with June.
From the results of the diatom analysis, of June 2015 samples, freshwater species are dominant, but seawater species dominantly at two points in L8.
From the results of the diatom analysis, in June 2015 survey, freshwater species dominated in the L8, but seawater species was dominant at two points. This is thought to be affected by Kesengawa river and coastal current. In the L9, freshwater species are dominant overall (seawater species: freshwater species= 3:7), and it is considered that there is no influence of coastal flow. In the L3, the freshwater species decreases towards offshore, and seawater species increases. However, in October 2015 survey, freshwater species dominated in the point that the seawater species dominated in June of the L8.
From results of two analyses, characteristics of surface sediment in Hirota bay have been clarified. In the autumn head of Hirota bay sediments, the sandy material increases compared to spring, the diatom group tends to dominate freshwater species, and the influence from the Kesen river is presumed.

Bioturbation structures in tsunami deposits

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Tsunami deposits provide important information on the magnitudes and recurrence intervals of the causative tsunami events. However, such deposits might be modified or obliterated by subsequent physical disturbances and/or biomixing of the sediment (bioturbation). For a clear understanding of the post-depositional alteration of tsunami deposits, it is necessary to monitor changes in sedimentary structures of the deposits several years after a tsunami event. Thus, we conducted field survey in the 2011-tsunami affected sea bottoms in 2016, to investigate preservation potential of the event layer. We obtained sediment core samples from ria coasts, northeastern Japan: i.e., from Onagawa Bay (Miyagi Prefecture, Seike et al., 2016, 2017), Samenoura Bay (Miyagi Prefecture), Kamaishi Bay (Iwate Prefecture), Otsuchi Bay (Iwate Prefecture), and Funakoshi Bay (Iwate Prefecture). From the all-sampling sites, tsunami deposits (sandy layer with parallel laminations) were recognized. In contrast, upper part of the layers was heavily bioturbated and lacks any physical sedimentary structures; the original sedimentary structures (parallel laminations) produced by the 2011-tsunami were obliterated by bioturbation. On the other hand, tsunamigenic coarse-grained deposit can be distinguished from ordinary background deposits (mud) based mainly on textural differences among the sediments in the semi-enclosed bays. Thus, recognition of the effects of post-depositional alteration of ancient tsunami deposits is important for the identification of paleotsunami events in the geological record.

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Seike, K., Kobayashi, G. and Kogure, K., 2017, Post-depositional alteration of shallow-marine tsunami-induced sand layers: A comparison of recent and ancient tsunami deposits, Onagawa Bay, northeastern Japan. *Island Arc*, doi:10.1111/iar.12174

Keywords: Bioturbation, Burrow, Ichnology

On the secular change of the bottom sediment after the 2011 Tohoku-oki tsunami in Onagawa Bay

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Tokai University conduct, as part of Tohoku Ecosystem-Associated Marine Sciences(TEAMS), various surveys (MNB, SSS, SBP, ROV, bottom sediment survey) at Sanriku region for continue to distribution and characteristics of tsunami deposits since 2012. This time we will report on the survey conducted at Onagawa Bay located in the southern part of the Sanriku Rias coast.
In this research, as a result of the bottom sediment survey of Onagawa Bay after the 2011 Tohoku-oki tsunami, it was found that the sediment was changed from sandy to muddy environment by the effect of the tsunami.
The bottom sediment distribution map was prepared from the data of the sediment survey conducted by Tohoku University (data from 2013).
As a result, it seemed that the proportion of mud content is low. The secular change of bottom material after the 2011 Tohoku-oki tsunami in Onagawa Bay, is thought that the proportion of mud decreases over time and it is changing to sandy material.

Keywords: Tsunami deposit, Onagawa Bay

Preservation and disappearance of the 2011 Tohoku-oki tsunami deposit along the Misawa coast, Aomori Prefecture, northern Japan

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We investigate the preservation and disappearance of tsunami deposits that formed by the 2011 Tohoku-oki Tsunami in Misawa Coast, Aomori Prefecture. In September 2016, we revisited 137 sites where the 2011 sandy tsunami deposits were described in April 2011 (Nakamura et al., 2012), and we found that the deposits are preserved at 65 sites (47%) of them. The deposits are well preserved especially in the not-damaged coastal forest, where the deposits are covered with new soil and their thicknesses are not changed significantly. Meanwhile, at the seaside forest where the trees were fallen or heavily damaged by the tsunami, the trees were removed and new plantation started, and there the 2011 tsunami deposits disappeared. Sites where the original deposit thickness are less than 1 cm, they are not detectable in 2016 not only within the residential area but also inside the forest. We can trace the deposits up to the tsunami inundation limit for 2 profiles from the 13 profiles. These information is useful to evaluate the tsunami inundation based on the deposit distribution for historical or prehistorical events. The Misawa Coast is, thus, a valuable place to continuously observe the 2011 tsunami deposits preserved in the soil, including their weathering or successive process in the natural environment. The preserved tsunami deposits are one of the 2011 earthquake disaster archives. We should explore ways of their preservation and utilization that contribute to research, disaster prevention and education for long years.

Nakamura, Y., Nishimura, Y., Putra, P.S., 2012, Local variation of inundation, sedimentary characteristics, and mineral assemblages of the 2011 Tohoku-oki tsunami on the Misawa coast, Aomori, Japan. Sedimentary Geology, 282, 216-227.

Keywords: tsunami deposit, the 2011 Tohoku tsunami, Miasma coast, preservation, disaster archives

Thickness, gravel content, and gravel size distribution of historical and paleo-tsunami deposits in Koyadori on the Sanriku Coast, northeast Japan

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Characteristics of tsunami deposits (e.g., particle size, grain composition, thickness, and sedimentary structure) are the most fundamental information to describe tsunami deposits and reflecting conditions of tsunamis (tsunami height and flow velocity) and site settings (beach sediments and tsunami flow process). The information might allow us to reconstruct the paleo-tsunami’ s flow speed, inundation height, and wavelength. In this study, we extracted some parameter of tsunami deposits and estimated relative magnitudes of paleo-tsunamis based on comparison of historical tsunami deposits.
We used historical and paleo-tsunami deposits in Koyadori on the Sanriku Coast, northeast Japan, where Ishimura and Miyauchi (2015) identified eleven historical and paleo-tsunami deposits, including the 2011 tsunami deposits. They named them E1 - E11 deposits in descending order and correlated E1 to E3 deposits with the 2011 Tohoku-oki tsunami, 1896 Meiji Sanriku tsunami, and 1611 Keicho Sanriku tsunami, respectively. Additionally, these tsunami deposits are composed of granule to pebble beach gravels (rounded gravels).
We used three parameters of tsunami deposits: thickness, gravel content, and gravel size distribution. Thickness of each tsunami deposits is measured using the trench-wall sketches and core photographs. We also calculated average thicknesses of them. Gravel content was measured by sieving method, using the E1 - E11 tsunami deposits obtained from the trench and cores. Furthermore, we applied image analysis to measure long/short axis lengths, perimeters, areas, aspect ratio, and circularity, using sieved gravels of the E1 - E11 tsunami deposits .
As a result, there was no significant difference in each gravel size distribution. However, average of thickness and gravel content are different from each tsunami deposits, especially those of the E1 to E3 deposits are consistent with the magnitudes of historical tsunamis. These facts potentially mean that the differences of average thicknesses and gravel contents are indicators of the transport process from the beach to the study site.

Keywords: tsunami deposits, Sanriku Coast, 2011 Tohoku-oki tsunami, gravel size distribution

Paleotsunami history in Hachinohe, Aomori

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Since the Tohoku-oki earthquake followed by tsunami on March 11, 2011, many researches on paleotsunamis along the Pacific coast of Tohoku and Hokkaido have been conducted (e.g. Ishimura and Miyauchi, 2015). On the other hand, no researches have been conducted around Hachinohe, Aomori. There is a possibility that Aomori may be affected by tsunamis occurred both along the Japan and the Kuril trenches (Nakamura et al., 2012 ; Minoura et al., 2013). Thus, it is important to reveal the history of paleotsunamis in Hachinohe in order to reconstruct the history of paleotsunamis occurred along these two trenches. Moreover, the place faces to the flection point of these two trenches, where no historical earthquake and tsunami are known. Therefore, the objective of our study is to reconstruct tsunami records in Hachinohe through geological survey followed by laboratory analyses.
In this research, we found up to 11 sandy deposits in Hachinohe and identified them as event deposits based on sedimentary features. Subsequently we correlated each of these event deposits based on lithology. As a result, 4 event layers are distributed widely and continuously. Since upward fining is confirmed in all of these four event layers, they were deposited in a way of settling of suspended sediments. In addition, landward fining and thinning are confirmed in them. Therefore, the source for these deposits is likely to be from sediments near seashore.
Following above, in order to consider possibilities of these event deposits being tsunami deposits, we evaluate possibilities of these event layers having been deposited by storms based on previous studies (Watanabe et al., 2016). The results show that it is impossible even for the storm surge and waves generated by the largest possible typhoon to deposit sands to this study site. Thus, we identified these four event layers as tsunami deposits. Since discovered tsunami deposits may be correlated with tsunami deposits found at adjacent sites such as northern Iwate and the Shimokita Peninsula, further studies are required to determine the sources of tsunamis. Moreover, identification of origin of other 7 event layers is critically important to estimate the recurrence interval of tsunami.

Keywords: Paleotsunami Deposits

Geological and hydrological investigations of boulders deposited by the 2011 Tohoku-oki tsunami along the Sanriku coast, Japan

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There are many enigmatic boulders along the coast in the world. However, many of their origin and transport process are uncertain. It is suggested that high energy waves such as tsunami and storm wave can transport boulders. However, criteria to distinguish origin of boulders whether they were deposited by tsunami or storm wave has not been established. In fact, boulders with clear tsunami origin have been reported rarely. In this study, we report the survey results of boulders along Sanriku coast, Japan, which were deposited by the 2011 Tohoku-oki tsunami in order to establish criteria for distinguishing boulders deposited by tsunami or storm wave. We also estimate wave height and velocity from field data using simple model.

During survey, we measured long axis, short axis, height and density of boulders as well as their sedimentological features. The boulders we could identify as tsunami origin were limited to the following cases: (1) boulders that are deposited at the places where aerial photographs or satellite images are available, (2) remains of marine organisms are attached on the boulders, and (3) boulders that have features indicative of their marine origin such as round shape. On the other hand, boulders that were not transported by the tsunami are partially buried by sand or gravel and/or are located fixed position just in front of the cliff without space for movement.

We further estimated minimum flow depth of tsunami using revised Nott (2003) model and the results showed that calculated values are generally fit to the field observation data, although further validation is required and assumption of Froude number should be reconsidered.

Organic elemental analysis and stable isotope analysis of tsunami deposit

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Assessment of tsunami deposits is necessary to reduce the hazard in coastal area in the future. Multiple proxies using sand units, grain size and/or microfossils such as diatoms have been applied to identify tsunami deposits. However, the way of distinguish tsunami deposits has not been established yet. Recently, various geochemical compositions have been proposed in order to distinguish them more precisely. In this study, C/N and isotopic (d13C) analyses were used to determine source of organic matter in 2011 Tohoku-oki tsunami deposits collected from 17 coastal areas which range from north to south in 500 km. We collected particulate organic matter (POM) in seawater, beach sand and tsunami deposits and treated them with HCl. The data of POM and sand beach are evaluated to be an end-member of marine origin, while these values of tsunami deposits vary greatly.

Keywords: tsunami deposit, Tohoku-oki tsunami, organic matter

Evidence on the Koseda coast of Yakushima Island of a tsunami associated with the 7.3 ka Kikai caldera eruption

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Many researchers have noted that Yakushima Island, southwestern Japan, may have been struck by a huge tsunami before the arrival of the Koya pyroclastic flow (K-Ky) during the 7.3 ka Kikai caldera eruption, but there is currently no clear evidence of this. We undertook sedimentological analyses and radiocarbon dating of gravel and tephra deposits along a shore-normal profile across the Koseda coast of northeastern Yakushima Island, and compiled a local Holocene sea-level curve, seeking firm evidence of a tsunami deposit there. Of three gravel units we identified, one (Unit TG) was a poorly sorted, 30-cm-thick gravel bed deposited on a wave-cut bench and overlain by the K-Ky tephra. We dated wood fragments in Unit TG at 7416–7167 cal yr BP. Unit TG is of similar composition to the modern beach and river gravels on the Koseda coast, but contains fibrous pumice derived after the initial plinian eruption at Kikai caldera and before the deposition of the Koya pyroclastic flow, and unlike the beach and river gravels appears to have been transported under a lamina flow regime from the NNW. On the basis of our analyses, we infer that Unit TG was deposited at 7.3 ka when a tsunami associated with the Kikai caldera eruption moved beach and river gravel inland in a stony debris flow, just before the arrival of the Koya pyroclastic flow at the Koseda coast.

Keywords: Tsunami evidence, 7.3 ka Kikai caldera eruption, Koya pyroclastic flow, Koseda coast, Yakushima Island

Detection of tsunami deposits in the east of Taiwan using Ground Penetrating Radar

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Tsunami deposits are the indicator to show when and how the areas were inundated by paleo-tsunamis. Recently, investigation of the tsunami deposit has been made progress in east coast area of Taiwan (Ota, 2013; Lallemand et al., 2015). Distribution of the tsunami deposit informs the timing, runup, and inundation area of paleo-tsunamis. We employed the Ground Penetrating Radar (GPR) to detect the scatters in the tsunami deposits and revealed the distribution of the tsunami deposits.

The GPR survey was carried out at Chenggong (north of Taitung, east coast of the Taiwan) from August 18 to 21, 2016.

We surveyed in the middle terrace (asl. 20m) near the Chenggong town. The survey lines were set in the sea side (SS) and mountain side (MS) of the middle terrace. The survey lines in the sea side survey area forms rectangle, short lines are parallel to the shore and long lines are perpendicular to the shore. We surveyed all lines at the radar frequency of 500MHz and 250MHz to compare the subsurface structure by the different frequencies. As a result, we could detect the boundary between the top sediment layer and the basement at the depth of approximately 1m. We could detect the scatters of the radar which were possibly originated to the tsunami deposits in the mountain side of the SS. The scatters were found in the east and west survey lines. We could detect many scatters at the frequency of 250MHz than 500MHz in this area. From the hand-auger survey, we found the coral boulders with the diameter of 10~40cm near the middle point of the survey lines of the mountain side of the SS.

The results suggest that the scatters, which we detected at low frequency range, are distributed densely or buried large boulders. In case of the high frequency GPR survey, we could detect the scatters with a several centimeter size. These imply that size of the pebble or boulders in the tsunami sediments could be estimated using the difference the imaging of the GPR profiles of different radar frequencies.

Keywords: Tsunami Deposits, Taiwan, Ground Penetrating Radar

Effects of terrestrial topography on sedimentary processes and distribution of tsunami deposits: two cases of flume experiments

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Recent detailed surveys of onshore tsunami deposits including the 2004 Indian Ocean tsunami and the 2011 Tohoku-oki tsunami have revealed that terrestrial topography causes a variety of their features and distributions. Therefore, to identify and interpret tsunami deposits correctly, a better understanding of the effects of not only tsunami magnitude but also topographic setting is required. In this presentation, we report two cases of flume experiments that were designed to simulate a water body (e.g. coastal lake) on a coastal lowland and a cliff. In both cases, the results suggested relationship between the distribution of tsunami deposits and the hydraulic condition of the tsunami flow associated with the terrestrial topography. In the experimental series with a water body, the run-up tsunami flow transformed from supercritical flow to subcritical flow with a hydraulic jump, which caused characteristic distribution of deposits. Similar flow transformation was also observed in the experimental series with a cliff: it blocked and pooled the run-up tsunami flow, and induced the flow transformation. The flow transformation forced the suspended sediment in the subsequent flow to stall and deposit, and as a consequence, caused a local maximum of deposits near the cliff. These two cases of the experimental series imply significant effects of terrestrial topography on the spatial distribution of tsunami deposits and their features.

Keywords: Tsunami deposit, Flume experiment

Characteristic of storm surge deposits deposited on the sandbar in Horokayanto, Taiki, Hokkaido, Japan

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There are some coastal lagoons that were separated from sea by sandbar in eastern coast of Hokkaido, Japan, and Horokayanto is one of these lagoons. The mean height of the sandbar is c.a. 5.7 m and soil and vegetation cover on the surface of the landward side. We recognized tongue-shaped sandy deposits and rip-up clasts of the soil covered the soil and vegetation in June 2016. The sandy deposits are composed by similar components to seashore sand and showed the tendency of the landward-fining and landward thinning, so this sandy deposits was formed by a storm surge. Moreover, relatively many marine diatoms such as *Thalassiosira* cf. *nanolineata*, *Thalassionema* sp., and few freshwater diatoms such as *Pinnularia borealis* derived from the soil were contained in the sandy deposits and also diatom valves increased from seaward to landward on the sandbar. These tendencies suggest the storm surge eroded and transported a part of the sandbar and soil, coarser particle including the rip-up clast deposited in the seaward side on the sandbar and the finer particle deposited in the landward side by the decreasing flowing speed. According to the previous wave data of NOWPHAS information in Tokachi harbor, it is highly possible that the sandy deposits formed by the storm surge due to the explosive cyclogenesis which developed at Pacific Ocean during 17th-19th of January 2016.

Keywords: Horokayanto, Storm surge deposit, Diatom assemblage

