

## Bleaching of K-feldspar grains contained in the tsunami deposits of the 2011 off the Pacific coast of Tohoku Tsunami

HAYASHIZAKI, Ryo<sup>1\*</sup> ; SHIRAI, Masaaki<sup>1</sup>

<sup>1</sup>Tokyo Metropolitan University

Optically stimulated luminescence (OSL) dating is feasible method to obtain depositional age from sediments and then, it is expected to be useful for tsunami deposits dating. However, it is not clear that the degree of sun bleaching during tsunami transport processes. Firstly, bleaching of K-feldspar grains during tsunami transport processes was investigated with post-IR IRSL (pIRIR) dating using the 2011 off the Pacific coast of Tohoku Tsunami deposits. Then, single-grain OSL dating was attempted to obtain accurate equivalent doses of tsunami deposits. Equivalent doses of K-feldspar grains obtained from various sampling locations and positions.

Comparing IRSL and pIRIR equivalent doses which showed different decreasing rates of OSL intensities with the sunlight exposure time, sandy tsunami deposits were hardly exposed sunlight during tsunami transport processes. However, nearly zero equivalent dose of single-grain OSL measurement was often acquired. Probably, these “ zero-dose ” K-feldspar grains had been exposed enough to sunlight before the tsunami. Upper position of one run-up tsunami deposits seemed to be rich in K-feldspar grains suggesting the accurate depositional age.

Keywords: tsunami deposits, Optically Stimulated Luminescence, post-IR IRSL, K-feldspar, sedimentary structure, Fukushima

## Sedimentological features of tsunami deposit caused by the 2011 Tohoku-oki earthquake tsunami

YOSHII, Takumi<sup>1\*</sup> ; HAMADA, Takaomi<sup>1</sup> ; SASAKI, Toshinori<sup>1</sup> ; MATSUYAMA, Masafumi<sup>1</sup> ; TANAKA, Shiro<sup>1</sup> ; ITO, Yuki<sup>1</sup> ; WATANABE, Masakazu<sup>2</sup> ; OKUZAWA, Koichi<sup>3</sup>

<sup>1</sup>Central Research Institute of Electric Power Industry, <sup>2</sup>Ceres, Inc., <sup>3</sup>Obayashi Corporation

In some areas, the inundation distances of the 2011 Tohoku-oki earthquake tsunami was comparable to that of the 869 Jogan tsunami estimated by geological investigations of tsunami deposits. This fact revealed the potential of research of tsunami deposits to speculate the scales of future tsunamis, resulting in strong social demand to detect ancient tsunamis, especially giant tsunamis, using geological studies. Investigation of present tsunami deposits is crucial to understanding sedimentological features of tsunami deposits because the present tsunami deposits can be identified with high reliability and the investigation of the surrounding circumstances is also feasible. In this study, we collected tsunami deposits caused by the 2011 Tohoku-oki earthquake tsunami from 19 areas with different topography. The obtained cores were observed by the unaided eye and by using CT images. In this presentation, we will discuss sedimentological features of these tsunami deposits and relationship with the surrounding circumstances.

Keywords: Tsunami deposit, The 2011 Tohoku-oki earthquake, Tsunami

## Characteristic of tsunami deposit left by 2011 Tohoku earthquake, case study of Toni bay

IJIMA, Satsuki<sup>1\*</sup> ; SAKAMOTO, Izumi<sup>1</sup> ; YOKOYAMA, Yuka<sup>1</sup> ; YAGI, Masatoshi<sup>1</sup> ; IMURA, Riichiro<sup>1</sup> ; NEMOTO, Kenji<sup>1</sup> ; FUJIMAKI, Mikio<sup>2</sup> ; FUJIWARA, Yoshihiro<sup>3</sup> ; KASAYA, Takafumi<sup>3</sup>

<sup>1</sup>Tokai University, <sup>2</sup>COR, <sup>3</sup>JAMSTEC

The recent 2011 Tohoku tsunami strongly affected the coastal area of the Pacific coast of Tohoku. The result of onshore features for tsunami impact is well researched, but offshore is only a few researches.

In this presentation, we will show about characteristic of tsunami deposit left by 2011 Tohoku earthquake, case study of Toni bay. We researched about tsunami deposit using acoustic equipments (Multi beam echo sounder ; MBES, Sub bottom profiler ; SBP) and Vibration core sampler (VCS).

The first of all, as the characteristic of submarine topography was sectionalized to 4 areas from topography profile of the valley axis direction.

Second, SBP data was seen signature reflecting surface (40-100cm down from seabed), and it was able to track at the wide area. Thickness of this reflecting surface and seabed were estimate 25-110cm in this bay. This thickness corresponded with the characteristic of the submarine topography.

Moreover, columnar sample of 13T\_V\_2 (water depth 14 m) could be divided into U1 (sand), U2 (mud), and the U3 (gravel bed). Sand to silt sediments layer with grading (fine sand to gravel) structure observed at the U1. We assume this U1 is 2011 tsunami deposit. The boundary of between U1 and 2 has continuity reflecting surface by SBP data and confirm distribution of this reflecting surface and thickness.

Finally, we were able to estimate tsunami deposit distributed with thickness approximately 25-110cm, and high thickness was distributed to the valley axis.

Keywords: Tsunami deposit, Sanriku Coast

## Characteristic of tsunami deposit left by 2011 Tohoku earthquake, case study of Hirota bay

YOKOYAMA, Yuka<sup>1\*</sup> ; SAKAMOTO, Izumi<sup>1</sup> ; YAGI, Masatoshi<sup>1</sup> ; IMURA, Riichiro<sup>1</sup> ; IIJIMA, Satsuki<sup>1</sup> ; KANEI, Tatsuki<sup>1</sup> ; NEMOTO, Kenji<sup>1</sup> ; KITO, Takeshi<sup>2</sup> ; FUJIMAKI, Mikio<sup>3</sup> ; FUJIWARA, Yoshihiro<sup>4</sup> ; KASAYA, Takafumi<sup>4</sup>

<sup>1</sup>Tokai University, <sup>2</sup>FODECO, <sup>3</sup>COR, <sup>4</sup>JAMSTEC

The recent 2011Tohoku tsunami strongly affected the coastal area of the Pacific coast of Tohoku. The study of onshore features for tsunami impact is well researched, but offshore is only a few researches. In this presentation, we will show about characteristic of tsunami deposit left by 2011Tohoku earthquake at Hirota bay using by Sub bottom profiler (SBP) and Vibration core sampler (VCS).

We took the total 17sites columnar core (2012:5sites, 2013:12sites) at water depth 8-25 m. The columnar cores were able to sectionalize to 2 units from lithofacies. Unit-1 consists of sand layer and Unit-2 consists of muddy sediment.

Unit-1 was sand to silt sediments layer with grading (fine to very coarse consists gravel and shell fragments) and lamination, and has forms the erosion surface with the lower layer. We assume that denudation is boundary of previous or after tsunami sediment and upper layer (Unit-1) is 2011tsunami deposit. And, Unit-1 was able to sectionalize to some subunits (Unit1a-1e) by grain size analysis and soft X-ray photo.

Unit-2 was massive sediments with fine sand to silt layer characterized by bioturbation. We assume this unit is normal sediment in this bay. And, some columnar cores have Unit-3(underlying layer of Unit-2) that has similar characteristics of Unit-1.

We estimate the 2011tsunami deposit distribution with thickness approximately 20-50 cm, and high thickness area was valley axis and estuarine region, and those area have sedimentation axis each other (NNW-SSE and NW-SE), and join together at offshore area (around 20m). So, tsunami deposits become thicker by overlap with a few tsunami deposits at offshore area.

Keywords: Tsunami deposit, Sanriku coast

## Characteristic of tsunami origin submarine topography -Case study of Toni Bay and Okirai Bay

YAGI, Masatoshi<sup>1\*</sup> ; SAKAMOTO, Izumi<sup>1</sup> ; YOKOYAMA, Yuka<sup>1</sup> ; MIZUNO, Ren<sup>1</sup> ; IIJIMA, Satsuki<sup>1</sup> ; NEMOTO, Kenji<sup>1</sup> ; FUJIMAKI, Mikio<sup>2</sup> ; FUJIWARA, Yoshihiro<sup>3</sup> ; KASAYA, Takafumi<sup>3</sup>

<sup>1</sup>School of Marine Science and Technology, Tokai University, <sup>2</sup>COR, <sup>3</sup>JAMSTEC

The recent 2011 Tohoku tsunami strongly affected the coastal area of the Pacific coast of Tohoku. Toni Bay located south of Kamaishi city and open toward east. Also Okirai bay open toward east. Tokai University started survey there to confirm effect of Tsunami in 2012

Survey of first year, we make extensively submarine topography. As a result, anomaly topography was observed at Toni Bay (depth of 20-25m) and Okirai (depth of 15-20m). Transparent layer with poor internal reflection was observed as the surface layer within the anomaly topography by Sub Bottom Profiler (SBP). Characteristic of columnar core have grading structure (fine to coarse) of sand sediment and erosion structure between sand sediment and clay sediment. It was guessed that erosion structure was made by turbidity current by tsunami activity. For the above reason, estimated anomaly topography is Tsunami origin topography. So we survey around anomaly topography area more closely in 2013. Describe below the character of Toni Bay and Okirai Bay.

[Toni Bay]

In this research area, submarine topography can be divided into three: 1)gentle slope (0.9 degrees) at depth of 15-22m, 2)planation surface at depth of 22-24m, 3)gentle slope at depth of 24m or more. On the 1)-3), these are a lot of protuberance has distributed. Around the protuberance, current marks like a fan or delta shape extend to toward offshore. And groove mark also observed. And we assume this tsunami origin submarine topography have control by protuberance in this way.

[Okirai Bay]

In this research area, topography can be divided into three: 1)gentle slope (1 degrees) at depth of 8.5-17.5m, 2)planation surface at depth of 17.5-19m, 3)gentle slope at depth of 19.5m or more. On the 1), these are a lot of protuberance has distributed. Some tool mark that is cause of protuberance distribute similar to Toni bay, but most of current mark show scour mark.

Tsunami origin submarine topography has almost same character (ex. Water depth) at both bays. But formation factor is different from Toni and OKirai bay.

Keywords: Tsunami orijin submarine topography, Toni Bay, Okirai Bay, Current mark

## Relationship between the inundation limit and the maximum extent of the sandy tsunami deposit in Sendai Bay coasts

ABE, Tomoya<sup>1\*</sup> ; GOTO, Kazuhisa<sup>2</sup> ; SUGAWARA, Daisuke<sup>2</sup>

<sup>1</sup>Department of Geography, Nagoya University, <sup>2</sup>IRIDEs, Tohoku University

Maximum landward extent of the sandy tsunami deposits can be regarded as the minimum inundation limit. Before the 2011 Tohoku-oki tsunami, recent post-tsunami field surveys along low-lying coastlines showed that sandy tsunami deposits commonly extend to approximately over 90% of the actual inundation limit (MacInnes et al., 2009). On the other hand, after the 2011 Tohoku-oki tsunami, some researches of the 2011 tsunami pointed out that the significant gap (0.6-2.0 km) between the inundation limit and the maximum landward extent of the sandy tsunami deposit where the inundation distance was more than 2.5-3.0 km (Goto et al., 2011; Abe et al., 2012; Shishikura et al., 2012). However, it is uncertain why the gap appeared. This study focuses on the relationship between the maximum extent of sandy tsunami deposits and inundation limit of the 2011 Tohoku-oki tsunami.

Inundation limits of the Tohoku-oki tsunami were assessed over 15 shore-normal transects in the Sendai Bay coast. Inundation distances of the 15 transects were found to range from 0.60 to 5.07 km. The maximum limit of the sand layer extended to 2.3-3.0 km (55-74% of the inundation distance) along 6 transects in the wide coastal plain in the northern-middle part of the Sendai Plain. Absence of the sandy tsunami deposits over 3.0 km inland may explained by the limitation of the sand supply from sand beach and sand dune.

Keywords: 2011 Tohoku-oki tsunami, Sendai Bay coast, Inundation limit, Maximum extent of sandy tsunami deposit

## Historical tsunami deposits in Numanohama on the Sanriku coast, Japan

GOTO, Tomoko<sup>1\*</sup>; SATAKE, Kenji<sup>2</sup>; SUGAI, Toshihiko<sup>1</sup>; ISHIBE, Takeo<sup>2</sup>; HARADA, Tomoya<sup>3</sup>; MUROTANI, Satoko<sup>2</sup>

<sup>1</sup>GSFS, the University of Tokyo, <sup>2</sup>ERI, the University of Tokyo, <sup>3</sup>CIDIR/ERI, the University of Tokyo

We conducted tsunami deposit survey in a small valley along the Sanriku coast, Japan, just north of Taro (Miyako city, Iwate prefecture), where the 2011 tsunami heights from the Tohoku earthquake ranged from 17 to 34 m. We identified six tsunami deposits during the recent 500 yrs from the 3-m long Geo-slicer sample. The uppermost one is located on or just below the ground surface and probably from the 2011 Tohoku earthquake. The <sup>210</sup>Pb and <sup>137</sup>Cs dating analyses indicated that the 2<sup>nd</sup> to 4<sup>th</sup> uppermost tsunami deposits can be correlated with historical tsunamis: the 1960 Chilean tsunami, the 1933 and 1896 Sanriku tsunamis. According to Japanese historical documents, other candidate tsunamis since the 15<sup>th</sup> century are from the 1793 Miyagi-oki earthquake, the 1763 and 1677 Aomori-oki earthquakes, the 1677 Boso-oki earthquake, and the 1611 Sanriku earthquake. Other trans-Pacific tsunamis includes the 1700 Cascadia tsunamis severe damage along the Sanriku coast and these tsunami deposits may be also preserved.

After the 2011 Tohoku earthquake, many surveys for tsunami deposits have been conducted in Sendai plain (Goto *et al.*, 2011, Marine Geology; Shishikura *et al.*, 2012, Annual Report on Active Fault and Paleoseismicity Researches). There are few reports of tsunami deposit studies along the Sanriku coast. Furthermore, depositional ages of many identified tsunami traces along the Sanriku coast were estimated to be several thousand years before present. The reasons for absence of recent tsunami deposits include that the Sanriku coast is a ria coast characterized by sawtooth-shaped coastline. Because of the steep-sloped valleys, alluvial deposits are very limited and tsunami traces are difficult to be preserved. Around the survey site, however, a marsh is separated from open sea by a beach ridge of ~ 4m high. In this marsh, well-decomposed peat has been developed. The sand deposits were brought by large tsunamis over the beach ridge and preserved in the marsh peat. Our study is the rare case that the geological evidence of recent historical tsunamis was continuously identified.

To identify tsunami deposits, we sketched the sedimentary structure, measured the distribution of grain sizes, and analyzed the microfossils. Depositional ages of tsunami deposits were estimated on the basis of radiocarbon (AMS) dating and <sup>210</sup>Pb, <sup>137</sup>Cs analysis. The <sup>210</sup>Pb dating is useful to determine the depositional rate during the recent 100 years because of its short decay time (the half life time is 22.3 year). The <sup>137</sup>Cs dating is useful to judge whether the depositional ages are before or after the start of atmospheric nuclear experiments in AD 1954.

Peat and sand layers are alternated with their thickness of several centimeters to several tens centimeters. Each sand layer consists of beach pebble and sand or rock pieces from host rock in this area. The sand layers have structure characteristic to tsunami deposit: erosional contact, alternation of normal- and inverse-grading, lamination and thin mud layer sandwiched between two sand layers. The sand layer can be traced continuously along the landward transect. Abundant marine microfossils in the sand layers indicate that the sea water flow into the marsh with the tsunami sand.

The <sup>14</sup>C result shows that peat at around 3 m depth deposited after the 15<sup>th</sup> century. The <sup>210</sup>Pb decay curve indicates that the deposition ages of the upper four tsunami deposit layers are during recent 100 yrs. The 2<sup>nd</sup> uppermost tsunami deposit can be correlated with the 1960 Chilean tsunami because <sup>137</sup>Cs was detected down to this layer.

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Keywords: Tsunami deposit, Sanriku coast

## A Study of Paleo-Tsunami along the Coastal Area of Akita Prefecture, the eastern margin of Japan Sea

KAMATAKI, Takanobu<sup>1\*</sup> ; HOSOYA, Takashi<sup>2</sup> ; KUROSAWA, Hideki<sup>3</sup>

<sup>1</sup>Akita University, <sup>2</sup>Chuo Kaihatsu Corporation, <sup>3</sup>OYO Corporation

Tsunami is the most destructive natural disaster on the coastal area. North-eastern Japan along the Japan Sea has been suffered by tsunamis, such as the 1833, 1983, and 1993 tsunamis. Recently, tsunami deposits have been reported from various areas and environments in Japan. However, paleo-seismological study based on the tsunami deposits has not been reported from along the coastal area of Akita Prefecture. We report a study of paleo-tsunami along the coastal area of Akita Prefecture. These results will be presented in this session.

Keywords: tsunami deposit, paleo-tsunami, eastern margin of Japan Sea, Akita Prefecture



## Paleoenvironmental changes and tectonic movements reconstructed from diatoms in Tokushima, during the last 4000 years

CHIBA, Takashi<sup>1\*</sup> ; FUJINO, Shigehiro<sup>1</sup> ; KOBORI, Emmy<sup>2</sup>

<sup>1</sup>Faculty of Life and Environmental Sciences University of Tsukuba, <sup>2</sup>College of Geoscience, School of Life and Environmental Sciences, University of Tsukuba

The average recurrence interval of the interplate earthquakes along the Nankai Trough is estimated from many historical records and archaeological data (Sangawa 2008). However, the studies of tectonic movement related to Nankai earthquakes is still limited (Maemoku 1989, Shishikura et al. 2008).

Yuki city, Tokushima prefecture, which located in north part of the Nankai Trough, has been subsided and many tsunamis attacked along the coast of the Shikoku islands accompanied by the previous Nankai earthquakes. Therefore, some historical documents and memorial monuments written about the past Nankai earthquakes and tsunamis remain in this city.

In order to obtain the geological evidences of tectonic movements and tsunami deposits, we conducted a 7m long core drilling at a small marsh behind a barrier spit in Tainohama of Minami city nearly Yuki city. The core includes more than 12 sand layers in organic-rich muddy sedimentary succession up to 5 m depth in this core. And we analyzed fossil diatoms from the core.

The diatom assemblages included in the peat and peaty mud deposits were predominated by fresh and brackish water species, especially *Pseudostaurosira brevistriata*, *Pseudostaurosira subsalina*, *Staurosirella pinnata*, *Tabellaria fenestrata*. *Pinnularia* spp. and *Eunotia* spp. are also dominated. In contrast to the above mentioned sand layers, brackish water and marine species, especially *Diploneis smithii*, *Mastogloia recta* were increased. The diatom assemblages from the organic rich muddy sediments and radiocarbon ages indicates that freshwater marsh or saltmarsh formed in this region during at least the past 4000 years. On the other hand, the diatoms from the sandy layers indicates that salinity of environments when the layers were formed was higher than freshwater or salt marsh. The diatom assemblage suggest that the sand layers were transported from seaside by past tsunamis. On the other hand, changes of diatom assemblages in the muddy sediments show increase or a decrease of freshwater species, suggesting a paleo coastal environment changes due to past earthquakes along the Nankai Trough.

Keywords: Nankai trough, Tsunami deposit, Tectonic movement, Pleo coastal environment, Diatom

## Study of tsunami deposits along west coastal area of Kagoshima Prefecture, Japan

OSHIMA, Akihiro<sup>1\*</sup> ; HARAGUCHI, Tsuyoshi<sup>2</sup> ; TAJIRI, Yuuta<sup>3</sup>

<sup>1</sup>West Japan Engineering Consultants, Inc., <sup>2</sup>Osaka City University, <sup>3</sup>Kyushu Electric Power Co., Inc.

In the west coast of the Kyushu district, there is no plate boundary in the front, and there is few record of an earthquake and tsunami. There are little investigations and researches of tsunami deposits in this area compared with East Coast facing the Pacific Ocean. However, reexamination of the disaster prevention planning in a coastal area is advanced by the occurrence of the 2011 off the Pacific coast of Tohoku Earthquake, and it is necessary to expand the data about the past tsunami history.

We have investigated the literature about records of the disasters of tsunami, and observed drilling core. We read aerial photos and topographical maps, and classified topography such as beach ridge, sand dune, backswamp. Based on the geographical classifications, we confirmed geographical features and existence of reclaimed land, and determined the survey sites. Drilling cores were taken in ten sites along the west coastal areas of Kagoshima Prefecture. In order to clarify lateral continuity of sediments, several cores were taken at each site. In consideration of sea level change, we collected sediments after about 6,000-7,000 years ago.

We acquired X-rays CT images to visualize internal structure of sediment three-dimensionally without destroying core. After having photographed X-rays CT image, we divided the core into half in lengthwise direction and observed the surface. Sediments are dated using radiocarbon dating and tephrochronology.

Some event deposits are identified in the drilling core taken from Gumizaki site, Nakayama site and Hashima site. Ages of these event deposits are around 7,000 cal BP and 9,500 cal BP (Gumizaki site), 3,500-2,500 cal BP (Nakayama site). However, these event deposits are not defined in other sites. These event deposits were possibly made by local event.

We found the layer including volcanic glass derived from the Kikai-Akahoya tephra in drilling core which were taken from Gumizaki site. The layer was possibly carried by the event accompanied with explosion of Kikai caldera.

In this presentation, we discuss the depositional environmental changes and the origin of event deposits by analysis of micro-fossil and detail observation of cores.

Keywords: tsunami deposits, event deposits, Kagoshima Prefecture

## Tsunami deposits in eastern coast area of Ishigaki Island, Japan.

KITAMURA, Akihisa<sup>1\*</sup>; ANDO, Masataka<sup>1</sup>; TU, Yoko<sup>4</sup>; OHASHI, Yoko<sup>1</sup>; NAKAMURA, Mamoru<sup>2</sup>; MIYAIRI, Yosuke<sup>3</sup>; YOKOYAMA, Yusuke<sup>3</sup>; SHIGA, Shota<sup>2</sup>; IKUTA, Ryoya<sup>1</sup>

<sup>1</sup>Shizuoka University, <sup>2</sup>Ryukyu University, <sup>3</sup>The University of Tokyo, <sup>4</sup>Institute of Earth Sciences, Academia Sinica

We found two tsunami deposits in eastern coast area of Ishigaki Island, Japan. The tsunami deposits contain many pebble-sized bioclasts such as coral fragments and mollusks, and clay rip-up clasts comprising material from the underlying soil. These deposits have erosive basement and fine upward. These layers thin abruptly at the landward margins, and fine inland. The altitude of the landward end of the lower and upper tsunami deposits attain up to 6 and 8 m, respectively. We referred to as deposits T-II and T-I in order of ascending stratigraphic position. Radiocarbon ages of excellent preserved and articulated marine bivalves mean that T-I and T-II were caused by the AD 1771 Meiwa tsunami and by tsunami at 740-500 cal. yrs BP (AD 1210-1450), respectively. It is noteworthy that abundant fragments of coral and molluscs remains are found from the debris flow deposit below T-II. Radiocarbon ages suggest these fragments were transported up to 8 m elevation by tsunami between 2490-2240 and 930-620 cal. yrs BP.

Keywords: tsunami deposits, Ishigaki Island

## The use of benthic foraminifera within tsunami sediments

MAMO, Briony<sup>1\*</sup> ; TOYOFUKU, Takashi<sup>1</sup>

<sup>1</sup>Japan Agency for Marine and Earth Science and Technology

Tsunami hazard assessment begins with a compilation of past events that have affected a specific location. Given the inherent limitations of historical archives, the geological record has the potential to provide an independent dataset useful for establishing a richer, chronologically deeper time series of past events. Recent geological studies of tsunami are helping to improve our understanding of the nature and character of tsunami sediments. Wherever possible, researchers should be increasingly working to improve the research 'tool kit' available to identify past and analyse modern tsunami events. Marine, benthic foraminifera (single celled heterotrophic protists) have often been reported as present within tsunami-deposited sediments but in reality, little information about environmental conditions, and by analogy, the tsunami that deposited them, has been reported even though foraminifera have an enormous capacity to provide meaningful palaeo-environmental data. In light of more recent tsunami events, the use of foraminifera has increased yet their full potential in this capacity is still often not frequently utilised. We discuss the potential use of foraminifera within tsunami research using results from specific case studies from Japan, south Asia, North America, Europe, the UK and New Zealand. We present an updated review in the gaps in our understanding on this topic area and reassert models for 'better' practice where possible, to assist researchers who examine foraminiferal assemblages within tsunami geology.

Keywords: Tsunami, Foraminifera, Benthic, Tsunami deposit