Paleotsunami workshop in Taiwan
2013 年台灣古海嘯國際研討會

2013 年台灣古海嘯國際研討會"訂於 102 年 7 月 3 日(星期三）於科技大樓 1F 簡報室召開，本次研討會邀請到新加坡、澳洲、日本的海嘯與古海嘯專家演講，藉由這些專家學者的海嘯研究經驗，來討論如何將這些研究成果與經驗應用在臺灣。歡迎會員蒞臨指教。

國立東華大學 顏君毅敬邀

一、時　　間：2013 年 7 月 3 日（星期三），9：10～15：00

二、地　　點：**科技大樓 1F 簡報室**，台北市和平東路二段 106 號

三、 會議議程：

Speaker	Time	Topic
NSC	09：10~09：20	Opening session
Yen, Jiun-Yee	09：20~09：30	Paleotsunami: 'Prospects' and challenges in Taiwan
Goff, James	09：30~10：00	Palaeotsunamis in the Landscape
Goto, Kazuhisa	10：00~10：30	The paleotsunami histories along the Ryukyu Islands inferred from coastal boulders
Shishikura,Masanobu	10：30~11：00	Evaluation of magnitude of past tsunami by geological records
Matsuta, Nobuhisa	11：00~11：30	The feature of the Tsunami height according to type of the coastal landforms - in the case of the 2011 Tohoku Earthquake
Ikehara, Ken	11：30~12：00	Assessing and evaluating rapid coastal change due to catastrophic events: Key messages for non-academic stakeholders
Break	12：00~13：00	
Cheng, Shih-Nan	13：00~13：30	Reconstructing 1867 Keelung earthquake and tsunami
Switzer, Adam	13：30~14：00	Assessing the tsunami hazard to Taiwanese coastal infrastructure
Hirakawa, Kazuomi	14：00~14：30	Identification of gigantic tsunami from the Kuril and Japan trench based on tsunami sediments
Ota, Yoko	14：30~15：00	Closing session: Current and future paleotsunami studies in Taiwan

主辦單位：國立東華大學自然資源與環境學系、國立台灣大學地質學系

Palaeotsunamis in the landscape

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When trying to identify past tsunamis, researchers often struggle to find (or provide) sufficient convincing evidence from the sediments they leave behind. However, it is important to remember that tsunamis are part of a larger suite of interlinked geomorphological processes that offer additional evidence of a tsunami origin.

The study of palaeotsunamis therefore extends well beyond that of just the potential deposits themselves and recognises that in seismically active regions, giant earthquakes act as regionally significant drivers of both immediate and delayed environmental responses. On a region-wide basis, linked post-seismic changes can be placed in a “Seismic Staircase” model in which factors such as tsunamis, landslides, increased fluvial sediment transport, coastal beach ridge formation and settlement abandonment combine to create a sequence of human and geomorphological responses to a large earthquake. As a part of the sediment transfer model, large pulses of fine material created by co-seismic landsliding are moved to the coast by rivers and then by longshore drift to leave a clear signature in the landscape in the form of a new, prograding sand beach ridge. These can often form up to several decades after the earthquake driving event. The effects of a single large earthquake are often responsible for the ‘Seismic Driving’ of environmental after-effects well beyond a single catchment and can, for example, cause near-contemporaneous beach ridge formation over 100’s km of coastline.

It is important to remember that tsunamis are caused by something, a driver, and this is normally (but not always) an earthquake. Other key drivers include landslides (either sub-aerial or submarine) and volcanic-related events, although there are several other types. Each type of driver leaves signals in the landscape and can, through careful study, be used to augment the geological record of a high energy marine inundation event to the point that a robust tsunami interpretation can be made.

Unfortunately for us, all of these processes operate on a landscape occupied by humans. This does, however, have an added benefit for the researcher trying to determine the origin of the sediments they are studying because there can also be archaeological and anthropological records of the event in question. Using New Zealand examples - a close tectonic parallel to that faced by Taiwan - this talk discusses the suite of seismically-driven changes that can help us identify past tsunamis. Ultimately, there are two key points that we as tsunami researchers are trying to clarify, a) can we find enough evidence to be able to identify a possible tsunami deposit and, b) can we then determine whether this was indeed laid down by a tsunami or some other form of high energy event.

The paleotsunami histories along the Ryukyu Islands inferred from coastal boulders

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The Ryukyu Islands, Japan extend approximately 1000 km northeast to southwest along the Ryukyu Trench between Taiwan and Kyushu, Japan. Most of the islands and islets of the Ryukyu Islands are rimmed by fringing reefs. At the southern end of the Ryukyu Islands (Sakishima Islands), the 1771 Meiwa Tsunami devastated and the tsunami run-up height is estimated up to 30 m and it caused approx. 12,000 deaths (Goto et al., 2010). On the other hand, there are no historical records of huge tsunamis in the Okinawa and Amami Islands, north from the Sakishima Islands. Moreover, occurrence of large tsunamis along the Ryukyu Islands during prehistoric age is uncertain and the the key to which is the long-term geological record.

Numerous boulders deposited at the reefs of each island are important geological evidence to understand the recurrence interval and magnitude of historical and prehistoric tsunami events along the Ryukyu Islands. In fact, boulders of tsunami origin were observed only at a specific island group at the southern end, suggesting the local occurrence of tsunamigenic earthquakes there (Goto et al., 2010). According to the 14C dating, some tsunami boulders at the Sakishima Islands were deposited by the 1771 Meiwa Tsunami, while the others were deposited prior to this event with 150-400 years interval (e.g., Araoka et al., 2013). This in turn suggests that such coralline boulder deposits are useful to investigate the tsunami recurrence interval at the subtropical area instead of the sandy tsunami deposits. I also introduce a new technique using paleomagnetic analysis to know the history of emplacement and displacement of tsunami boulders (Sato et al., 2013).

References

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Evaluation of magnitude of past tsunami by geological records

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The Great Off-Tohoku Earthquake (M 9.0) of 2011 turned out to be an unprecedented disaster due to the giant tsunami that invaded the Pacific coast, and it is often said that its magnitude was “unexpected.” However, geological data such as tsunami deposit obtained from the coast facing the Japan Trench suggested that the giant tsunami as large as the 2011 event had repeatedly occurred for several thousand years, including the Jogan Earthquake (greater than M 8.4) of 869. Subduction Zone Paleoearthquake Research Team in GSJ has conducted paleoseismological survey to evaluate the recurrence time, tsunami inundation area and source of the Jogan Earthquake and its predecessors since 2004. Eventually, the inundation area of the tsunami in 2011 was very similar to the estimated tsunami inundation area of the Sendai Plain at the time of the Jogan Earthquake (Sawai et al., 2012) (Fig. 1). What this implies is that if the magnitudes of past earthquakes and tsunamis are elucidated and if histories of occurrence are reconstructed, we will be able to make a rough assumption of the magnitude and imminence of future probable earthquakes and tsunamis.

After the 2011 earthquake, GSJ urgently surveyed to observe the distribution and sedimentological characters of tsunami deposit which was derived from the 2011 tsunami. This is for improving a reconstruction technique of past tsunami inundation. From the results of this survey, it is recognized that actual tsunami inundation is able to reach 1-2 km further inland than the landward limit of the distribution of tsunami deposit (Fig. 1). This means that reconstructed past tsunami inundation from geological record indicates 62.2-82.9 % of actual inundation area (Shishikura et al., 2012). For more reliable estimation of future tsunami inundation area for mitigating disaster, it is highly important that we not only focus on the distribution of past tsunami sand layer, but also evaluate the scale of tsunami inundation by methods such as chemical component analysis in combinating with tsunami simulations. This instruction should be immediately apply to other coastal areas facing subduction zone which have

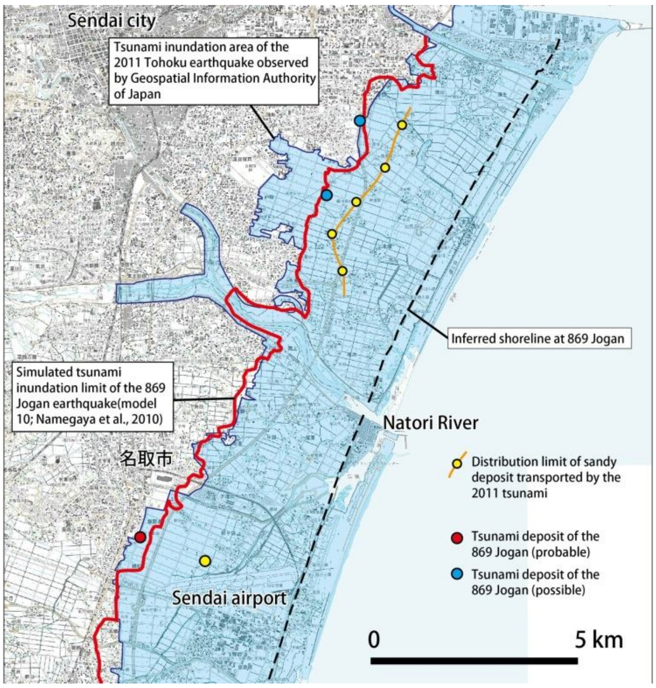

Fig.1 Comparison of tsunami inundation area between the 2011 Tohoku and the 869 Jogan, and inland limits of tsunami deposits.

potential of giant tsunami in near future such as the Nankai Trough. GSJ therefore is conducting field survey along the Pacific coast of Japan.

On the other hand, regardless of paleoseismology, recently the government announced the estimation of disaster for future giant earthquake and tsunami in the largest case simulated from mega-thrust ruptured as much as possible. However the evidence of such largest event has not yet been found in any records not only historically but also geologically. Therefore a role of paleoseismological study was oppositely changed. Before the 2011 event, paleoseismologists suggested the possibility of future giant earthquake from field survey data by inductive approach. But after the 2011 event, paleoseismologists must evaluate by deductive approach whether such the largest event suggested by the government exist or not from the evidence of field survey data.

Fig. 2 Photos of tsunami boulders scattered on wave-cut-bench near the Cape Shionomisaki, which have recorded past giant tsunami produced from mega-thrust along the Nankai Trough.

One of the solutions to evaluate the largest event was identified in the Shionomisaki Cape, where we found tsunami boulders which were moved at only the timing of giant earthquake generated from the Nankai Trough such as the 1707 Hoei earthquake (M 8.6) (Fig. 2). The boulders are distributed over the range of ca. 200 m from shoreline, but nothing was found on the Holocene terrace of 2-4 m in altitude just behind them. Because the terrace was probably emerged during 6000 years ago, the largest tsunami in the past 6000 years must be not able to transport the boulders over the terrace. Then it can evaluate the actual magnitude of the largest tsunami by calculation of critical velocity.

For more precisely reconstruction of past earthquake and tsunami, we should develop paleoseismological methods and widely find geological evidence of past phenomena (tsunami, crustal movement and strong ground motion), which are not only tsunami deposit but also emerged shoreline topography, biological marker of sea level change, sand dike of liquefaction, mass movement and submarine turbidite. Although each record may be incomplete, it would be able to reveal actual past phenomena by combining them.

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The feature of the Tsunami height according to type of the coastal landforms - in the case of the 2011 Tohoku Earthquake

Mastsuta Nobuhisa

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Spatial variation in hazards of earthquakes or tsunamis is a key element to control disaster risks in each site. For tsunami-disaster management, we have to geographically understand tsunami run-up heights in each lowland, valley or bay, which would be needed to develop resilient societies in the future. We have conducted GIS-based analysis of run-up heights of the tsunami associated with the 2011 off the Pacific coast of Tohoku earthquake, using air-photo-based tsunami-damage map released by The Association of Japanese Geographers and 2- or 5-m-mesh digital elevation model (DEM) obtained by Geospatial Information Authority of Japan, to plot detailed distribution of tsunami run-up heights. Our first version of detailed run-up-height maps and date pacakege, which covers the vast damaged areas hit by the 2011 tsunami, has clearly revealed spatial variation in tsunami run-up heights. In this presentation, we discuss several examples that illustrate spatial tsunami-behavior differences, which would result from topographic geometry, elevation, scale of lowland, or valley/bay direction in each site.

These run-up heights have the distinct variation in same longitude. The variation seems to be in responses by coastal landform pattern. I classify the run-up tsunami height according to coastal landforms; 1. V-shaped bay bordering the outer sea, 2.U-shaped bay bordering the outer sea, 3.concavo-convex-shaped coast bordering the outer sea, 4.V-shaped bay bordering the inner bay, 5.U-shaped bay bordering the inner bay, 6.concavo-convex-shaped coast bordering the inner bay, 7.smooth beach. In the historical Tsunami case, run-up heights of Meiji (1896) and Syowa Sanriku (1933) tsunami has the tendency for the bay bordering the outer sea to be higher than the inner bay, however Chili (1960) tsunami has the tendency for the bay bordering the inner bay to be higher than the outer sea. The difference is depend on the wave length, a location on a inner bay is damaged by the wide wave length tsunami and a location on a open sea has a bigger damage by the short wave length tsunami.

In the 2011 tsunami case, the distribution chart of each group is shown that run-up heights at points on the outer sea are higher than at points on the inner bay in northern area (north of Kamaishi) and southern area (south of Shinchi), however that feature is not clear in the middle area from Ofunato to Sendai. This result means that the south and north area has short wave surface deformation and the middle area has wide wave deformation on 2011 Tohoku earthquake. It looks to contradict the shallow dynamic overshooting model in which the pulse tsunami wave is produced by huge slip on the shallow plane.

Coastal landforms have a potential to teach us tsunami feature of paleo tsunami and poor observation equipment area.

Sediment erosion, resuspension, transportation and redeposition by tsunami: Evidences from the 2011 Tohoku-oki tsunami

Ken Ikehara, Kazuko Usami (Geological Survey of Japan, AIST)
Tomohisa Irino (Hokkaido University)
Robert Jenkins (Kanazawa University)

Juichiro Ashi and Akiko Omura (Atmosphere and Ocean Research Institute, Univeristy of Tokyo)

Large friction velocity of huge tsunami might erode, resuspend and transport sea floor sediments. Occurrence of bathyal benthic micro-organism remains in on-shore tsunami deposits clearly showed the potential of submarine sediment transport by the tsunami waves. However, there are only a few reports on the influence of tsunami waves to submarine surface sediments and sea floor environments. To understand the influence, we conducted several survey cruises in off Sanriku area. On the inner-mid Sendai shelf, sedimentary structures and sediment grain size were changed at several locations. Extremely coarse-grained thick sand beds sometimes recognized at the shoreface-offshore transition zone. This probably suggested the transport of beach-shoreface sand toward offshore by the tsunami. Clean and well-sorted medium-fine sand is another example of possible tsunami-related sandy event deposit. Homogeneous or parallel laminated mud with upward fining graded structure is a typical example of possible tsunami-related muddy event deposit. These sedimentary structures suggest that the deposit formed from suspended water masses. Such a suspended water mass in the shelf area might be formed by resuspension of shelf mud by the tsunami waves. Radioactive Cs profiles in the event deposits suggested that the suspended water mass was maintained at least several days after the earthquake/tsunami event. Generation of turbidity currents from such a suspended water mass was inferred from the occurrence of a turbidite on the outer Sendai shelf. Furthermore, long-distance transport of resuspended materials was expected from the benthic foraminiferal analyses of an event turbidite at the forearc basin of off Sanriku. These facts indicate that the tsunami has enough potential to erode and resuspend the shelf sediments, and to form the highly suspended water masses, and further to generate the turbidity currents and to conduct the long-distance transport from shallow water to deep water.

Reconstructing 1867 Keelung earthquake and tsunami

Cheng, Shih-Nan

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On December 18, 1867, a disastrous earthquake occurred in northern Taiwan, and triggered tsunami, killing hundreds of people. Because of the age, the lack of relevant information, for this limited understanding of the 1867 Keelung earthquake and tsunami. In this paper, first, the collection and collation of historical documents, evaluate the credibility of information, discussed ancient names corresponding to the position, the GIS was used to establish the distribution of disaster, to reconstruct the 1867 Keelung earthquake and tsunami. The relevant geological and geophysics information are referenced to evaluate the possible source parameters. The attenuation law is used to simulate the distribution of intensity. Compare intensity distribution and disaster distribution to discuss the reasonableness of the source parameters. The results showed that the 1867 Keelung earthquake and offshore extension of Shanchiao fault are closely related, the fault length is about 40 km, epicenter: 25.34N, 121.91E, DEP=10 km, the magnitude Mw = 7.0, strike, dip, and rake of possible fault plane are 60, 62, -90. The height of tsunami is about 6 meters In Huang-Kang and Shuei-wei region. Jinshan and Pa-tao-chi flooded area elevation are about 15 meters.

Assessing the tsunami hazard to Taiwanese coastal infrastructure

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Much of the coast of Taiwan is exposed to a significant tsunami hazard. This paper summarizes the likely sources of tsunami that can affect Taiwan, evaluating their potential to generate tsunami, the likely waves produced, and their impact on the principal urban centres around the Taiwanese coastline. In order to provide estimates of the tsunami risk, i.e., the probability that various localities will experience tsunami, and the likely losses in terms of the cost of damage, lives lost and injuries caused the various sources must be considered. The major tsunami risk to Taiwan comes from possible earthquake-generated tsunami from nearby subduction zones. The possibility of landslide and volcano generated tsunamis must also been given close consideration. There is a clear, significant and ongoing risk from tsunami in Taiwan and it is possibly considerably higher than many people may realise. Taiwan has experience of tsunami in the historical past, but few lives have been lost and damage to property and infrastructure has been modest.

Identification of Gigantic Tsunami from the Kuril and Japan Trench based on Tsunami Sediments

Kazuomi HIRAKAWA

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The 2011 Tohoku Earthquake Tsunami struck 2000 km along the Pacific coast of Japan, and reached the Pacific coast of Hokkaido, northernmost island of Japan. Referring to such propagation of Tsunami associated with Mw 9 earthquake, gigantic Tsunami history since last ca. 6000 years along the coast from Hokkaido to Tohoku could be reconstructed on the basis of Tsunami sediments layers at several hundred localities. Geomorphology such as coastal terraces or slopes is absolutely significant to identify and to evaluate a tsunami sediments layer as gigantic tsunami origin. Four individual sources of gigantic tsunami could exist: Tohoku (Sanriku)-Joban like 3.11 Tsunami, Tohoku North (off the Shimokita), Hokkaido Pacific Coast, and off the Northern territory. Recurrence intervals of tsunami from each source are ca. 1000 years respectively, that is the supercycle.

Recent field survey revealed the gigantic Tsunami recurrence also along the eastern margin of Japan Sea, off the Okushiri Island SW Hokkaido (1993 Earthquake Tsunami). I will introduce also the tsunami sediments from the Nankai-Trough, stressing the importance of landforms as well as intertsunami -soil formation for the identification of gigantic tsunami.