Tsunami generation due to large-scale submarine landslides induced by an earthquake

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Strong earthquake vibrations can liquefy sediments in the sea-floor slopes to induce large-scale (more than 1000 km^2 in area) submarine landslides, which generate tsunami waves. A submarine landslide (40x15 km^2), which took place in the slope at the Japanese trench off Sanriku, caused an abnormally high tsunami wave, which struck the central Sanriku coast, Japan on March 11, 2011[1]. The 2018 Palu earthquake, caused by the strike-slip movement of Palu-Kola fault, induce numerous number of submarine landslides in Palu bay to generate tsunamis struck the coasts of Palu city, Indonesia[2]. For the case of the 1923 Great Kanto earthquake in Japan, the changes in water depth more than 100 meters were reported after the earthquake in the entire region of Sagami bay and the mouth of Tokyo bay. This is the evidence of large-scale (100x50 km^2) landslide, running through the Sagami trough down to the Bando basin, which locates at the trench triple point. The landslide may cause the tsunami, which struck the coastline of Sagami bay, in particular Atami city. I will discuss the counter measurement to prevent the disaster by the landslide tsunamis.

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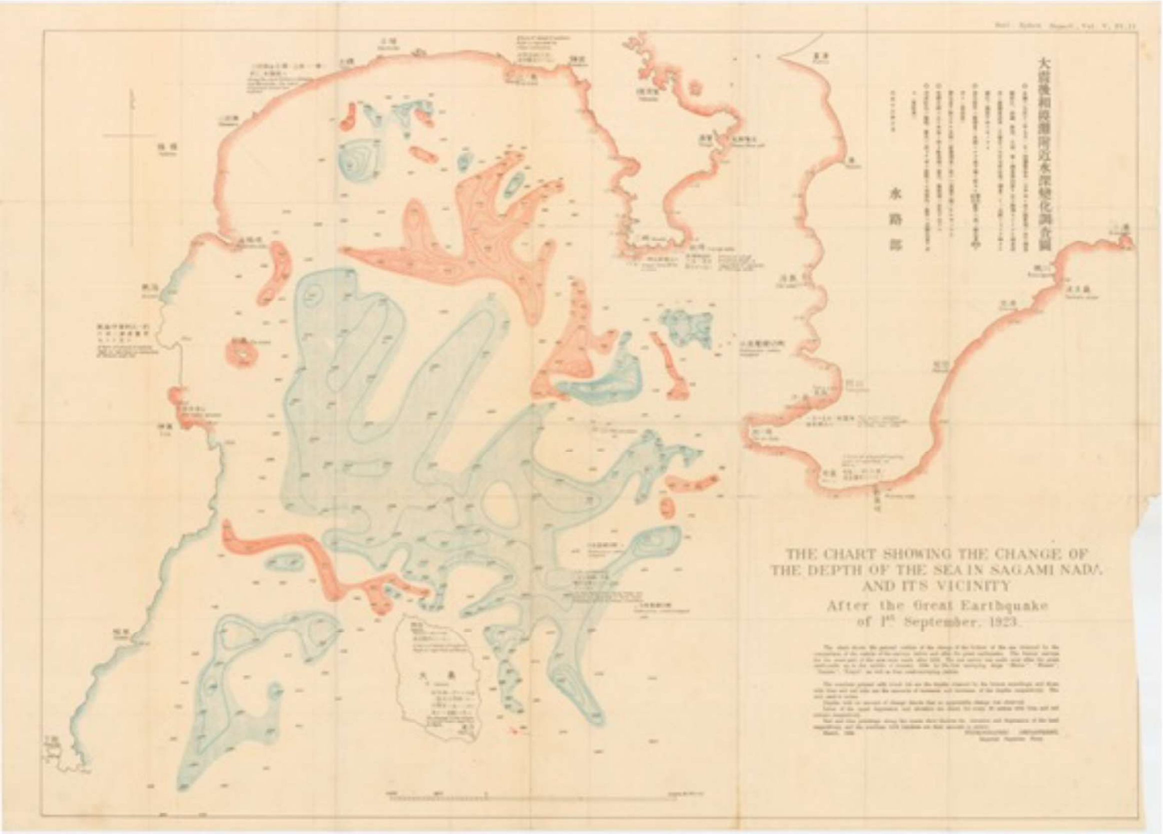

図 1. 大正関東地震前後の相模湾の水深変化，深くなった領域：青，浅くなった領域：赤（水路部 1924）

Geohazards on the Azores archipelago

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The Azores archipelago, located in the north Atlantic, is characterized by a complex geodynamic setting dominated by the triple junction where the North American, Eurasian and African lithospheric plates meet. This region is encompassed within a roughly triangular platform, delimited by the 2000 m isobath, characterize by a thicker oceanic crust associated with increased magmatism. Such evidence suggests that the area is controlled by the interplay between the distensive setting of the triple junction and a deep mantle plume.

The archipelago comprises nine volcanic islands aligned along a general WNW-ESE direction. The two most western islands emerge on the North American plate, in a more stable tectonic setting. The other seven islands are located along the boundary between Eurasian and African plates, in an area with intense seismic and volcanic activity.

Seismicity is typically associated to the main regional tectonic structures and is mostly of medium and low magnitude. Historical records, however, show that in nearly six centuries the islands have been stroke by 31 destructive earthquakes and seismic crisis that caused approximately 6500 fatalities and major social and economic losses.

During that period, at least 27 volcanic eruptions were documented at the archipelago, mainly along the same WNW-ESE direction as the seismicity. Presently there are 17 subaerial active volcanic systems and the geologic record shows a wide variety of eruptive styles and magnitudes. Historical eruptions range from effusive and mildly explosive events, such as hawaiian and strombolian eruptions, to more explosive surtseyan and subplinian events.

Along historical time, eruptions have caused several hundred victims and extensive damages. Last two eruptions on the archipelago, Capelinhos in 1957/58 and Serreta in 1998/2000, are examples with very different impacts. Capelinhos was a surtseyan eruption that caused massive damages and losses in Faial Island, whereas the submarine Serreta eruption had no impact in Terceira Island.

Another geohazard that frequently strikes the Azores are landslides. These are frequent phenomenon, triggered by different factors. At the archipelago, due to its subtropical oceanic climate, the most common trigger is intense rainfall. These phenomena are also highly potentiated by the young volcanic geomorphology and the friable nature of pyroclastic rocks. Large magnitude landslides had already occurred in the past, such as an earthquake-triggered landslide in 1522 that killed about 5000 people and destroyed an entire village in S. Miguel Island. Small and medium magnitude events are, however, much more frequent and recent years had shown that those smaller events are also responsible for tens of deaths and increasing losses.

Gas emissions are also a permanent geohazard in the islands and several villages are settled on high soil carbon dioxide degassing areas, with potential impact on the public health.

To cope with geohazards in the Azores, IVAR (Azores University) and the Regional Government constituted CIVISA, an operational association to run the seismovolcanic monitoring system of Azores and provide scientific advisory to civil protection authorities. This system integrates several networks, namely: seismic, geodetic, infrasound, geochemical, air quality, hydrometric, meteorological, landslide kinematic and geotechnical.

Improving the scientific and sociological understanding of geohazards in Sri Lanka

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After the Indian Ocean tsunami in 2004, the possibility of catastrophic disasters has realized, although Sri Lanka is not close to a plate margin. This catastrophic event highlighted that Sri Lanka as a country may not be able to cope with these major natural disasters, in addition to localized and frequent disasters such as landslides and floods, without an appropriate Disaster Management Plan. In the aftermath of the 2004 tsunami, the government of Sri Lanka developed a comprehensive Disaster Management Plan in consultation with international experts. This study examines Disaster Management Plan in Sri Lanka and examines the effectiveness of the existing management structure in revisiting the areas and communities affected by selected case studies in a coastal strip hit by the tsunami in 2004, recent catastrophic landslides and other disaters. Questionnaire surveys and field observations were used to collect data on the preparedness, availability of evacuation plans and pre-disaster alert systems. The results show the need to further improve the management of geohazards.

Urgent research on the impact of tsunami on the coastal geology: experiences and challenges of international research

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The purpose of the post-tsunami survey is to record the influences of the tsunami on society and the natural environment, in addition to the behavior of the tsunami such as wave height and inundation distance. The impact on the natural environment includes coastal erosion and sediment movement caused by the tsunami, and associated ecosystem changes. Among them, tsunami deposits composed of the various sizes of materials, which remain on the surface after the tsunami receded can become traces of the tsunami that will remain until later generations. Tsunami deposits provide a basis for knowing the recurrence feature of earthquakes accompanied by tsunamis and are also useful for long-term evaluation of giant earthquakes that cause low-frequency catastrophes. However, the identification of paleo-tsunami deposits is not easy. The reason is that not only the behavior of the tsunami on land is complicated, but also the distribution and sedimentary characteristics of the tsunami deposit depend on the topography, geology, vegetation of the coastal area, and season at the time of the tsunami. Besides, it is affected by weathering from the formation of the tsunami deposit until it remains in the soil. During the years when tsunami traces remain on the surface, they are exposed to rain and wind and are disturbed by flora and fauna. Also, after they are buried in new soil, chemical properties of groundwater and soil can cause the disappearance of microfossils which are valuable evidence that they are marine sand. For a reconstruction of the long-term history of the tsunami and earthquakes based on a small part of the tsunami deposit, we have to understand these processes and also know the conditions under which no trace of a tsunami remains. Therefore, it is important to collect information about modern tsunami deposits around the world, which are formed under various environments and are subject to weathering. I've been involved in 14 tsunami field surveys over the past 25 years. In some cases, we examined multiple locations with different environments for the same event, and sometimes we visited the same location repeatedly to observe the preservation and disappearance of the deposit. In the presentation, I introduce case studies, including the insights from surveys of the

Krakatau eruption tsunami in Indonesia in December 2018. Here, tsunamis of the same height form completely different sediments on the coral reef shore and the sandy beach near the river. The preservation potential of the tsunami deposit is confirmed to be very high in the forest. And following the modern tsunami deposits in the forest, traces of the 1883 tsunami that caused the worst volcanic tsunami disaster in the world have been found.

Significance of fundamental datasets for tsunami numerical modeling

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Tsunami numerical modeling has been playing a key role to evaluate tsunami hazards, such as wave height along the coastlines, inundation area and run-up height. The tsunami modeling is able to simulate sediment erosion and deposition, by means of coupled modeling of tsunami hydrodynamics and sediment transport. Such tsunami modeling can be used to assess the damages to the coastal environments and communities and to prioritize areas for emergency response and post-tsunami field survey.

Data on bathymetry, topography and sedimentary environments is the foundation to generate useful simulations. Since the tsunami can totally alter coastal environment, the data must be acquired prior to a tsunami event. Behavior of tsunamis is quite sensitive to the coastal bathymetry and topography, which often results in significant local variation in the wave heights. This is most evident in rocky indented shorelines, such as the southern Sanriku Coast. Preferable spatial resolution of the modeling may be less than ten meters, in order to reproduce tsunami run-up in narrow valleys. In case of a flat coastal plain with sandy beaches, such as the Sendai Plain, micro-topographies like beach ridges, swamps and artificial features sometimes give considerable effects to the processes of sediment transport and resulting morphological changes. To account for the effects from the micro-topography, sedimentary environments must be included in the model, in addition to high-resolution topography data. The sedimentary environments includes information on initial distribution, thickness and property of sediments and type and density of vegetation. Most important sediments property is the grain size.

The tsunami modeling requires such kind of data as indispensable inputs. Thus, high-resolution, accurate topography data with relevant information is required to generate meaningful simulations for assessing the tsunami impact. The Light Detection and Ranging (LIDAR) technique provides onshore topographic data with a horizontal resolution of ~1 m and a vertical accuracy of ~0.1 m, which are being common for recent tsunami numerical modeling. It enables tsunami modelers to reproduce detailed spatial variation of tsunami height and inundation area, as well as distribution pattern of tsunami deposits. Availability of high-resolution bathymetric data, on the other hand, is limited typically in the neighborhood of major bays or harbors. If not available, the tsunami modeling inevitably employs accessible coarse bathymetric data with interpolation technique, which may introduce uncertainties in the simulations. Lack of information on the sedimentary environments is the additional source of uncertainties.

This calls for development of the fundamental dataset for the tsunami modeling, which combine coastal bathymetry and topography and sedimentary environments. The dataset will enhance our ability to assess tsunami impacts. Note that natural and anthropogenic processes, such as coastal sand drift and construction works, may alter the topography and sedimentary environments. Maintenance of the dataset with newly-acquired data is needed for the emergency use at the time of tsunami event.

Importance of post-tsunami geological survey for the future progress of paleotsunami research

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Paleotsunami history and size based on the geological studies provide us useful information for the hazard assessment of low frequency but large tsunamis. Moreover, it is important to know extreme tsunamis through the Earth's history which contributes to understand the nature of causative events such as asteroid impacts. Based on these motivations, many researchers have studied paleotsunami deposits worldwide. However, researchers always confronted the difficulties on the identification of paleotsunami deposits and the interpretation of their sedimentary process, because these are similar to those deposited by other water-related events such as storm surge and flood. To overcome these issues, understanding the sedimentary features and process of recently formed tsunami deposits are very important. Therefore, post-tsunami geological survey, which is conducted soon after the tsunami event, is a key to develop future paleotsunami research. Also, geologists can contribute recovery process and future tsunami risk assessment through the post-tsunami geological survey. In order to perform efficient survey within the limited time and ability during emergency situation, it is important to prepare a kind of manual about the survey procedures. In this presentation, current situation and problems of both paleotsunami and post-tsunami geological surveys are reviewed. Then, importance to prepare the manual for post-tsunami geological survey and its possible contents will be discussed.

Seismicity and Potential Seismic Hazard of Thailand: The need of high quality research work along the mountain slopes in Thailand.

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Thailand is surrounded by major plate boundaries but have been encountered with relatively small amount of moderate earthquakes in the past. Still, only a moderate earthquake can cause a major damage to the communities. For example, a magnitude 6.2 earthquake that occurred in Chiang Rai province in the Northern Thailand on 5 May 2014 caused damages to more than 15,000 building with degrees from minor damages to total collapse and yielded a total damage of US$300 million. Overall, the northern Thailand and the western Thailand have relatively higher seismic hazard compared to other regions. In addition, as most the mountain ranges are located in the northern and western Thailand, these areas are susceptible to the effect from the earthquakes occurring in the region especially slope stability during the rainy season. There is a need for high quality research work along the mountain slope in Thailand to make local communities safe and ready for landslides and flashfloods. Southern Thailand also have potential hazards for landslides in the mountains, moderate earthquakes and tsunami.

This talk will cover for seismic hazard and active faults studies and the earthquake mitigations of Thailand along with seismicity and major historical seismic events in Thailand. Overviews of other natural geological hazards such as landslide and land subsidence will also be included. The talk will also cover a case study of the hazard in the mountain for the case of Tham Luang Cave Rescue Operation in 2018 when the Thai boys soccer team and their coach were trapped in Tham Luang Nang Non cave in Chiang Rai Province, Thailand to show how important geoscientists from various fields can assist the society during the natural crisis.

Recent landslides by natural geologic hazards in Hokkaido

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This report describes characteristics of landslides that were caused by natural geologic hazards during the last decade in Hokkaido. A geologic hazard is a geologic condition or phenomenon, natural or brought about by human activity, that represents a threat to human life, welfare and property (Neuendrof *et al.*, 2005). The natural geologic hazards are such conditions or phenomena which can lead to losses through landslides, floods, earthquakes, coastal and beach erosion, faulting and so on. Hokkaido had 53 cases of landslides by natural geologic hazards from 2008 to 2019 (figure 1). The hazards such as rain, snow-melt, earthquake and flood caused a lot of landslides.

Firstly, landslides occurred frequently in a snowmelt season. The landslides in a snowmelt season are as much as in a rainy season. Both rapid snowmelt and rain often caused landslides.

Secondly, heavy rain by typhoon caused many landslides on paleo-periglacial slopes. Especially in 2016, four typhoons had hit or come close to Hokkaido from the Pacific Ocean for the first time. The typhoons caused heavy rain, and caused a lot of landslides on paleo-periglacial slopes. The periglacial slope had evolved under cold-climate conditions primarily by mass-wasting processes of solifluction in last ice age. Surface water eroded ill-sorted angular debris on the periglacial slope in the behind of the road.

Thirdly, the 2018 Hokkaido Eastern Iburi earthquake lead more than 6,000 landslides however landslides by earthquake were only two cases during the last decade. Numbers and collapsed area of the landslides were the most abundant in a history. A Ta-d tephra fall layer was a slip surface to cause the landslide. The Ta-d is a pumice fall layer, which had been erupted by Tarumae volcano about 9,000 years ago. It is considered that excess pore water pressure given by crushing the weathered pumices lead so many landslides.

A landslide is known to occur repeatedly at a same place by natural geologic hazard. Histories of the geologic hazards are the key to avoid and mitigate disasters.

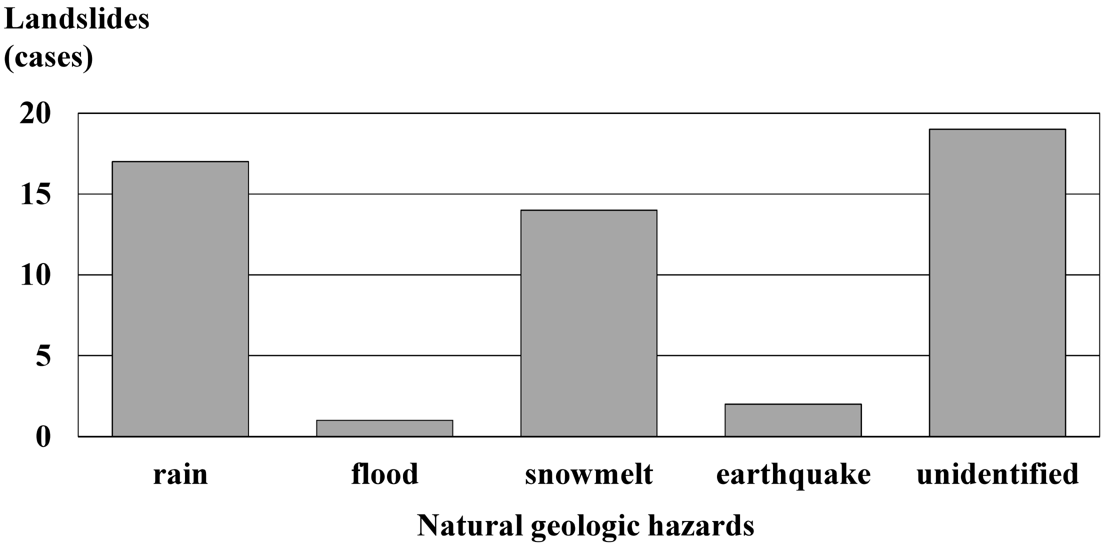

figure 1. 59 cases of Landslides by natural geologic hazards in Hokkaido from 2008 to 2019.

Heavy Rain and Landslide Disaster of July 2018 in Western Japan

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Heavy rains, mainly in western Japan in July 2018, caused widespread and catastrophic disasters. The seasonal rain front was stagnated for three days and squall lines were formed, resulting in record rainfall in various places. Areas of heavy rainfall ranged from Kyushu, Chugoku, Shikoku, and Kinki to the Chubu region. In Gifu, Kochi, and Tokushima prefectures, continuous rainfall exceeded 1,000 mm. Along with this, there were more than 2,500 landslide disasters, and many river inundations occurred. The number of dead and missing persons related to this disaster was 245.

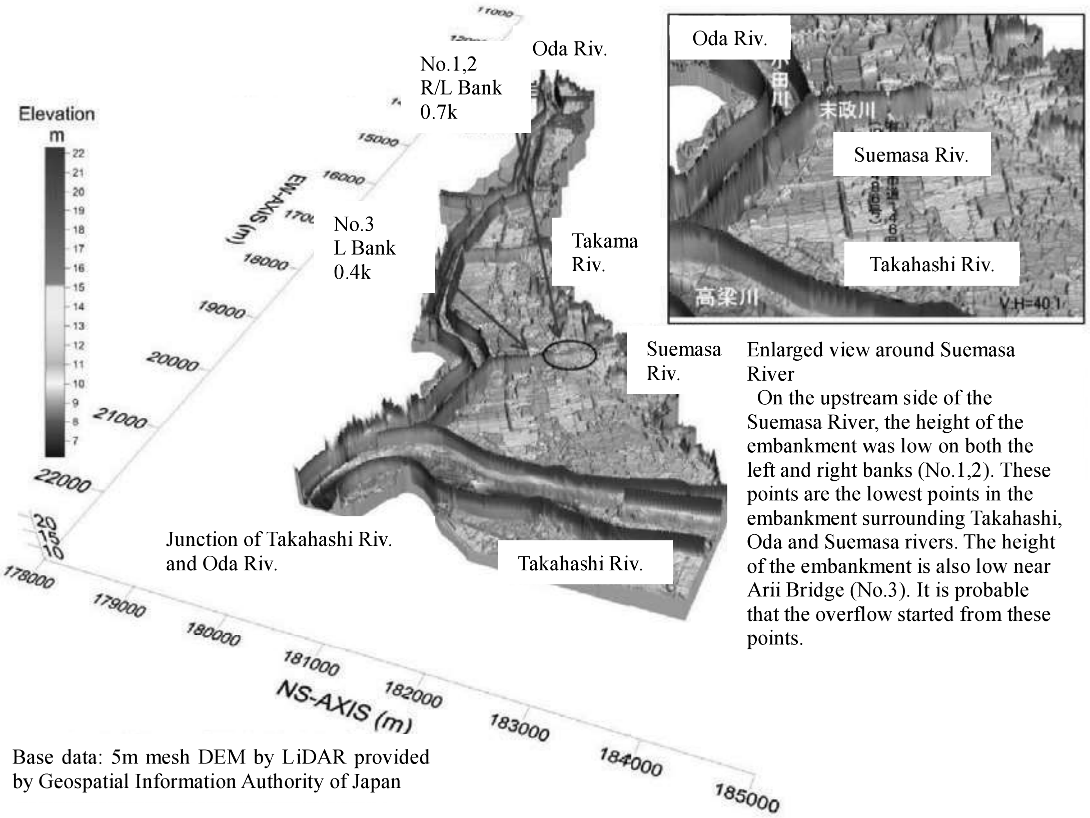
After these disaster, the Japan Society of Engineering Geology (JSEG) immediately formed a disaster research team consisting of 76 people, conducted surveys in many fields such as detailed records of disaster, cause of disaster, recovery after disaster, and evacuation behavior, and compiled 29 reports. Here are some of the results.

In Hiroshima Prefecture, debris flow disasters occurred mainly in Higashi-Hiroshima City and Kure City. The disaster situation was understood over a wide area using satellite imaging, and the damage characteristics were analyzed. And, it was clarified that the characteristics of the debris flow and the damage situation were different depends on geology and topography. In addition, a comparative study was conducted with the debris flow disaster that occurred in the same area in 1945, and it was shown that the debris flow that occurred in the same valley had a different location of the collapse site as the source.

In Mabi-Town, Okayama Prefecture, a wide-area inundation disaster occurred downstream of the Oda River in the Takahashi River system. In the area where the inundation damage occurred, the changing of land use in about one century was clarified, and the state of transmission of past disasters records were investigated. And, by analyzing DEM data by LiDAR, topographical features such as differences in the height of the river embankment where overflowed or destroyed, and flooded areas were clarified (Fig. 1). In addition, we interviewed many residents about the inundation start time and showed how the inundation progressed on time line.

Many slides occurred in Uwajima City, Ehime Prefecture. The Study Team conducted intensive surveys on these areas and identified topographical and geological features at many points. It was also suggested that the frequent occurrence of slide was related to mineral veins (laumontite) formed in the sandstone layer. It is known that the volume change of laumontite occurs due to dry and wet conditions, and it is reported that laumontite is often formed in the Shimanto group, which constitutes the geology of this area.

At JSEG, the results of these surveys were compiled as a report, and one year after the disaster, a debriefing session were held in Okayama University for citizens and researchers. We hope that these results will help all people to consider countermeasures for the upcoming disaster.



Enlarged view around Suemasa River

On the upstream side of the Suemasa River, the height of the embankment was low on both the left and right banks (No.1,2). These points are the lowest points in the embankment surrounding Takahashi, Oda and Suemasa rivers. The height of the embankment is also low near Arii Bridge (No.3). It is probable that the overflow started from these points.

Base data: 5m mesh DEM by LiDAR provided by Geospatial Information Authority of Japan

Fig.1 Bird view around the junction of Takahashi River and Oda River

Earthquake induced landslides by the Mw 6.6 2018 Hokkaido Eastern Iburi Earthquake

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On Sep 6th of 2018, the 2018 Hokkaido Eastern Iburi Earthquake with Mw 6.6 was occurred by about 1.2 m slip of reverse fault at 37 km depth, as inland type earthquake in south central Hokkaido of Japan. This site is located in the northeastern edge of the Arc-Arc collision zone that formed by westward motion of Kuril fore-arc sliver toward NW-Japan arc driven by oblique subduction of Pacific Plate. Based on aerial photo analysis, 0.5 m resolution DEM analysis by aerial laser survey and field survey after earthquake, the two types of the earthquake induced landslides has been identified around the epicenter. The shallow type landslides occurred at over 6000 slopes and they distribute in hilly area of 20 x 20 km in 3-22 km north from the epicenter. The shallow landslides are classified into earth slide and flow of 2-3.5 m thick tephra and soil layers on slope, that covers on the basement rock consisting of Miocene to Pliocene marine sedimentary rocks. The distribution of the shallow landslides is clearly corresponding to thick area of the tephra fall deposits of Ta-d (ca. 9 ka; Mt. Tarumae) or Ta-d with En-a (ca. 20 ka; Mt. Eniwa). Using the 0.5 m resolution DEM, we newly identified over 250 deep-seated landslides within 5-15 km from the epicenter. At 5 km north from the epicenter, the largest rockslide occurred with 350 m slide of a dip-slope ridge topography of 350 m wide and 800 m long and the slide block formed landslide dam. This high-resolution DEM enables to subdivide the rockslides into ridge-, slope- and shallow-type depending on shape and depth of crown crack and main scarp below a few meters wide. The rock slides are concentrated within 3-10 km from the epicenter and their basement predominantly consists of marine sediments of shale, mud and sandstone of Karumai Formation (Late Miocene). Based on the topographic analysis using DEM data combined with geological survey and map analysis, most of the rockslides are presume to be occurred in ridge or slope with dip-slope structure. Thus, high resolution DEM is a strong tool for rapid identification of earthquake-induced landslides in tens km-scale area. In addition, high-resolution

DEM data is also useful as a reference surface for slope monitoring using multi-period models by UAV-photogrammetry at tens to hundreds meter scale.

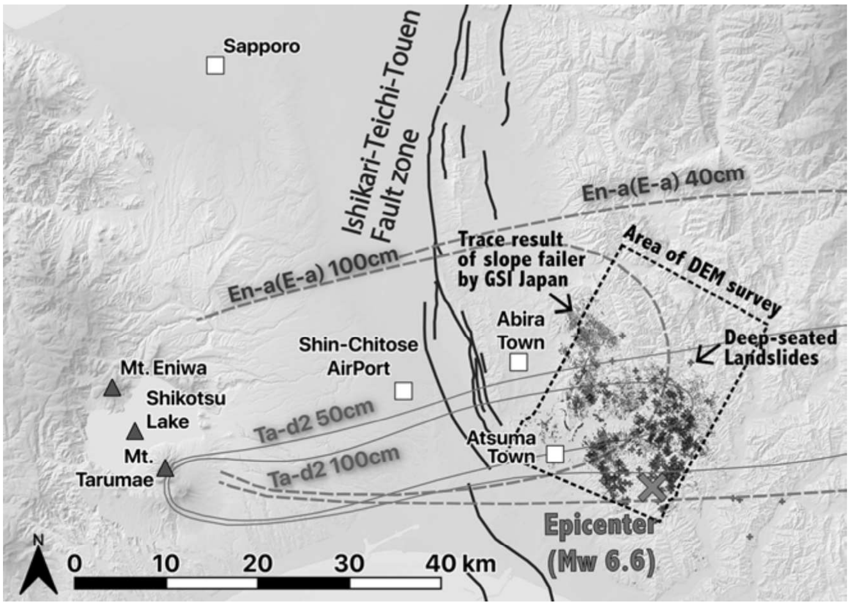

Fig.1 Location of epicenter of the 2018 Hokkaido Iburi Tobu Earthquake, with distributions of earthquake-induced landslides (GSJ Japan and our reuslts) and tephra isopach of Ta-d2 (Mt. Tarumae) and En-a (Mt. Eniwa).

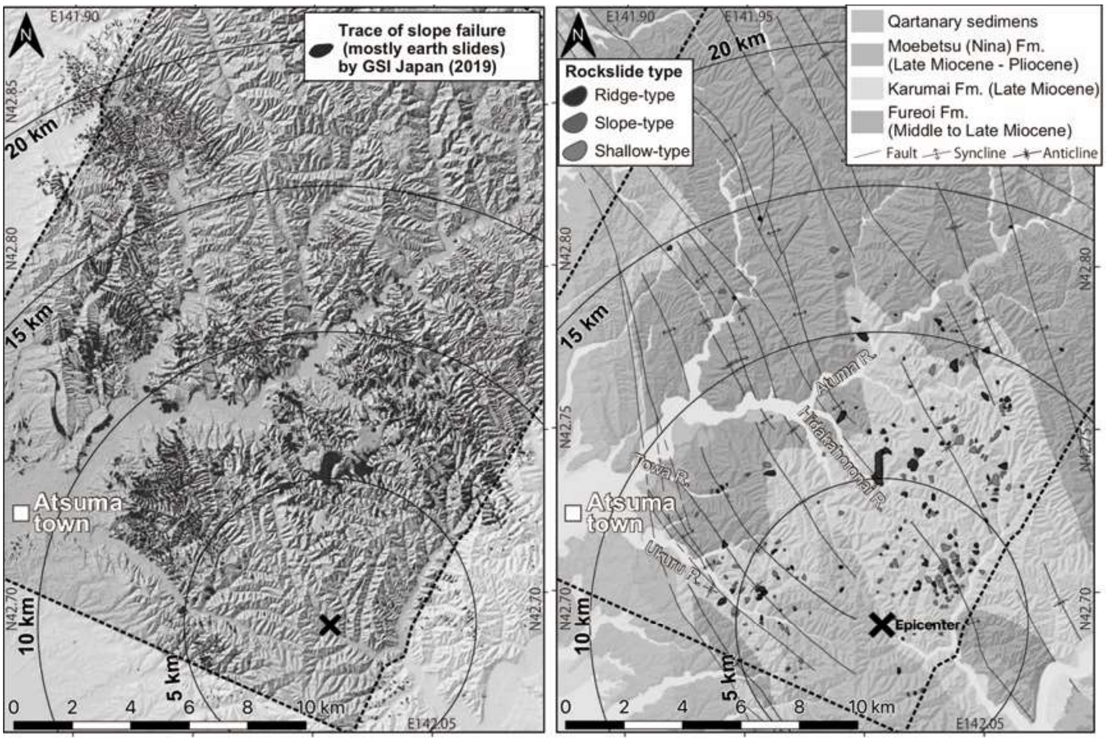

Fig. 2 Identification result of the shallow landslides (left; trace result of GSI Japan, 2018) and the deep-seated landslides by high-resolution DEM analysis (right; this study).

Tsunami modeling by marine landslides and reduction of disasters

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The marine landslides due to large earthquakes caused much larger tsunamis than that expected from the magnitudes of the earthquakes. One example is the large tsunami along Aleutian Inlands due to the 1946 Aleutian earthquake (Ms7.2). The maximum tsunami height was about 40 m. The marine landslide is believed to be the main cause for this large tsunami near the source area. The other example is the 1929 Great Banks tsunami due to the earthquake of Ms7.2. The earthquake itself was caused by the marine landslide which cut the ocean bottom cables. Therefore, the large tsunami was completely generated by the marine landslide. We try to model the tsunami by our numerical simulation of marine landslide and tsunami to find volume of the landslide.

The marine landslides due to the volcanic eruptions also caused large tsunamis. Landslide during the 1741 eruption of Oshima-Oshima volcano in Hokkaido, Japan, occurred in the Japan sea generated a large tsunami. The tsunami caused severe damage along the coast of Hokkaido. We numerically simulated the landslide and tsunami generated by the 1741 Oshima-Oshima eruption using an improved two-layer model to explain the depositional area of the landslide, the tsunami heights written in historical records, and the distributions of tsunami deposits. Areas of erosion and deposition by the 1741 landslide were estimated from the bathymetric data on the northern slope of Oshima-Oshima volcano. From the bathymetry difference before and after the landslide, the volume of collapsed material was estimated at 2.2 km^3. Based on those data, the landslide and tsunami were numerically simulated by solving equations of an improved two-layer model that incorporates Manning's formula in the bottom friction terms of the lower layer. An apparent friction angle of 2.5 and a Manning's roughness coefficient of 0.15 were selected to explain the area of deposition estimated from the bathymetry analysis and distributions of tsunami deposits. The thickness distribution of the computed landslide mass fits relatively well with the depositional area. Computed tsunami heights match those from historical records along the coast. Computed tsunami inundation areas cover most of the distributions of tsunami deposits identified along the coasts.

No tsunami forecast method for those tsunamis generated by marine landslides exists.

It is needed to be developed for the tsunami disaster mitigation. Because a dense cabled observation network, called the seafloor observation network for earthquakes and tsunami along the Japan Trench (S-net), was installed in Japan recently, those ocean bottom pressure data should be used to forecast tsunami heights along the coast for landslide tsunamis. We developed a tsunami numerical simulation method by assimilating those ocean bottom pressure data as a tsunami forecast method (Tanioka and Gusman, 2018). The method was tested for tsunami generated by earthquakes, but it should be used for landslide tsunamis, too.

Reference

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Submarine slides and tsunamis: a review

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In this paper, I review the general characteristics of submarine slides, and their trigger mechanisms in short- and long-terms and marine geohazards due to the submarine slides. Submarine slides have been reported in various sedimentary environments.

From their geometry, submarine slides are generally zoned into three domains from their geometry; headwall, translational and toe domains. Even in the very initial deformation stages, these domains can be distinguished; i.e. the headwall domain includes fissures, the translational domain includes asymmetric deformation structures due to shear deformation, and the toe domain is dominated by pressure ridges.

Most of the slip surfaces correspond to clayey layers, but sand layers could also be such surfaces under undrained conditions as reported in the Nankai Trough. Geological record of past 20 ka suggest that large submarine slides have not occurred from 5 ka to present, but it is uncertain because of the lack of data.

The trigger mechanism would more likely be related to the consequence of earthquakes, such as an abrupt increase in ground acceleration and increased pore fluid pressure. The precondition includes many factors, such as gradual increase in pore pressure by decomposition of methane hydrate due to climate change, increase in pore pressure by high sedimentation rate, ground deformation due to subduction/collision of seamounts, and/or slope steepening due to volcanic activities.

Case study of submarine landslides, liquefactions, injections by past earthquakes: Guidance of field trip for Miura Peninsula on 24th May

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Recent study on geohazardous phenomena in the past and present subduction zones were summarized to suggest the submarine and on-land geology offers best comparison for understanding the geohazard history, process and mechanism. They involve volcanic activities and associate sedimentation of an island arc, large subduction type earthquakes and related tectonic movement. They used to be associated with large submarine sliding and tsunamis. In these years the critical comparison of both field geology on land and by submersibles in and around the Japanese trench areas are the strongest method (Kawamura et al., 2008; Ogawa, 2011; Ogawa and Yanagisawa, 2011). For the best comparison, we chose the type areas around the Izu arc collision zone in central Japan, particularly along the Sagami trough subduction zone, where geologically and historically known activities have been well analyzed since the middle Miocene to the modern ages, when the Boso triple junction came to the present areas (Mori and Ogawa, 2020). Several tracts of accretionary prisms from early to middle Miocene to Pliocene represent the total history of sedimentation and deformation of Izu arc-derived volcaniclastics (Ogawa and Taniguchi, 1988; Ogawa et al., 2008; Muraoka and Ogawa, 2011; Mori and Ogawa, 2019).

On land geology is well exposed on the continuous coastal benches in the Miura-Boso peninsulas, which have been repeatedly uplifted by subduction type large earthquakes (M ~ 8) with recurrent years of 400 to 2000 (Shishikura, 2014). The syn-sedimentatary deformation under semi-lithified conditions are analyzed by means of application of the soil and rock mechanical viewpoints (Ogawa, 2019). We will observe the representative outcrops on the southern tip of the Miura Peninsula, 60 km SW of Tokyo during the post-meeting field trip. The outcrops show liquefaction, mud diapir, vein structure, some are during large earthquakes, which also triggered large landsides and possibly tsunamis. Some debris flow and turbiditic deposits and chaotic injection bodies may be the products of such geohazardous phenomena. We will have good discussion on the causes and results between these phenomena, by learning the present submarine geology of the Sagami trough plate boundary as well.

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