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Geological Study of Unusual Tsunami Deposits in the Kuril Subduction Zone for Mitigation of Tsunami Disasters

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1. Introduction

On 26 December 2004 a magnitude M 9.3 earthquake deformed the ocean floor 160 km off the coast of Sumatra, generating the Indian Ocean tsunami and thus causing large sediment transfers due to tsunami run-up in coastal lowlands around the Indian Ocean (e.g., Goff et al., 2006; Moore et al., 2006; Hori et al., 2007; Hawkes et al., 2007; Choowong et al., 2007, 2010). Sediment transfers of this scale are rare events historically. Only when an unusual tsunami strikes coastal lowlands does a large-scale sediment transfer occur, leaving a sedimentary record, that is, tsunami deposits, in the geological strata on shore (Dawson & Stewart, 2007). In this chapter, we seek to understand the run-up process of past unusual tsunamis by examining a series of tsunami deposits on the Pacific coast of eastern Hokkaido, northern Japan, and we estimate the average recurrence interval of such tsunamis from the geological record.

Large earthquakes with M > ~8 in the Kuril subduction zone have historically generated tsunamis that caused damage in eastern Hokkaido between Nemuro and the Tokachi coast (Satake et al., 2005; Fig. 1). Most recently, the 1952 Tokachi-oki, the 1960 Chilean, the 1973 Nemuro-oki, and the 2003 Tokachi-oki tsunamis caused considerable damage and great loss of life in this district. Therefore, it is very important to estimate the likely timing and size of the next large, earthquake-generated tsunami. Information about historical earthquakes in the Kuril subduction zone is limited, however, and no documents from before the 19th century that might refer to tsunami events are available. The earliest written records from eastern Hokkaido are the "Nikkanki" series of documents from Kokutai-ji Temple, which was built by the Edo government at Akkeshi in 1805 (Soeda et al., 2004; Fig. 1).

In the hope of finding traces of past giant tsunamis to use to evaluate the frequency and extent of past tsunami inundation in east Hokkaido, late Holocene coastal sediments such as peat beds and lagoon sediments have been studied since 1998 by our research group and other researchers (e.g., Hirakawa et al., 2000; Nishimura et al., 2000; Sawai, 2002; Nanayama et al., 2003; Soeda et al., 2004). Nanayama et al. (2003, 2007) and Sawai et al. (2009) have reported the general stratigraphy of unusual tsunami deposits due to "500-year earthquake"

along survey lines in Kiritappu marsh and adjoined lagoons, and have helped establish the regional stratigraphy of unusual tsunami deposits from the Tokachi coast to Kiritappu marsh (Fig. 1). The stratigraphy of unusual tsunami deposits in the Nemuro coastal area, however, has yet to be fully explained (Nanayama et al., 2008, 2009).

Since 2000, we have carried out a geological study of unusual tsunami deposits in the Nemuro lowland (Fig. 1). In this chapter, (1) we describe the typical sedimentary occurrence of tsunami deposits; (2) we discuss the dating of the deposits by tephrochronology and by accelerator mass spectrometry (AMS) ^{14}C and optically stimulated luminescence (OSL) methods; and then (3), on the basis of these data, we estimate the average recurrence interval of unusual tsunamis in the Nemuro lowland. We also describe the use of our results for mitigation of tsunami disasters.
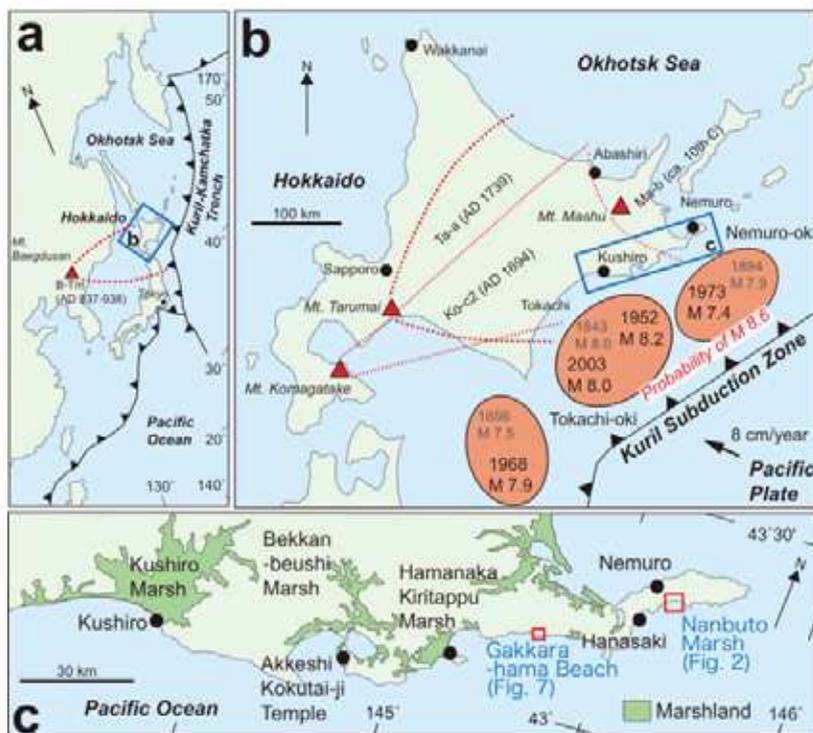

Fig. 1. Tectonic map of the ocean off Hokkaido showing earthquake sources along the Kuril subduction zone (a); index map of the Kushiro-Nemuro coastal area, eastern Hokkaido (b); and a detailed map of the area between Nemuro and Kushiro showing the location of Nanbuto marsh and Gakkara-hama beach (c). The locations of Mt. Baegdusan (a) and Mts. Komagatake, Tarumai, and Mashu (b), sources of tephra layers, are also shown.

2. Tectonic setting of the Pacific coast of eastern Hokkaido

Eastern Hokkaido is situated on a continental plate, the Okhotsk plate, under which the Pacific plate is being subducted at the rate of 8 cm/year, and many earthquakes with M > ~8

have occurred in the Kuril subduction area (Satake et al., 2005, 2008; Fig. 1). The most recent, the 2003 Tokachi-oki earthquake (M 8.0), produced a tsunami with a height of less than 3–4 m (Tanioka et al., 2004). This region has been steadily subsiding at a rate of 1 cm/year since the 19th century (Atwater et al., 2004), but previously it may have been uplifted, either about 0.5–1 m (Atwater et al., 2004) or 1–2 m (Sawai et al., 2004), by repeated great earthquakes (probably M 8.6) as a result of multi-segment interplate ruptures linking the Tokachi-oki and Nemuro-oki segments (Fig. 1; Satake et al., 2005, 2008), with an average recurrence interval of 400–500 years (Nanayama et al., 2003, 2007). The last great earthquake tsunami occurred in this area in the 17th century and left widespread tsunami deposits (Nanayama et al., 2003). Because of the complex history of seismic uplift and interseismic subsidence, sea-level changes during the late Holocene are not well understood in this study area.

3. Geomorphic setting of Nanbuto marsh and Gakkara-hama beach

The Nemuro coastal lowland is on the Nemuro Peninsula, the easternmost part of eastern Hokkaido (Fig. 1). The southern Kuril area, including the Nemuro Peninsula, is an active seismic area. The population of Nemuro City, which is the second largest city along this coast, is about 30000. In 1973, the Nemuro-oki earthquake tsunami (M 7.9) struck Hanasaki Port; its measured tsunami height was 2–3 m, and it caused heavy damage. Earlier earthquake tsunamis, the 1960 Chilean (M 9.5), the 1952 Tokachi-oki (M 8.2), and the 1894 Nemuro-oki (M 7.4) tsunamis, also struck Hanasaki Port (Satake et al., 2005). In addition, a Tokachi-oki earthquake tsunami (M 8.0) occurring in 1843 is described in the "Nikkanki," the earliest written records from this area (Soeda et al., 2004). We investigated tsunami deposits at two sites along this coast: Nanbuto marsh and Gakkara-hama beach.

Nanbuto is a small marsh along the coast near the Nemuro urban district (Fig. 2). The marsh is on a flat coastal plain ranging from 1 to 4 m in elevation with an area of about 8 km². Its maximum extent is about 2 km from north to south and about 4 km from east to west. The plain is surrounded on the north, west, and east by marine terraces, 60–80 m in elevation, of Pleistocene age, formed during marine oxygen isotopic stage (MIS) 9 (ca. 300 ka; Okumura, 1996) (Fig. 2). No large streams are present that might bring sandy sediments to the Nemuro lowland.

Nanbuto marsh is one of a group of marshes developed on low-lying coastal plains and valley floors of eastern Hokkaido that were inundated by seawater during the Jomon transgression since 10000 years BP, as shown by the presence of an abandoned sea cliff on the north side of the marsh that is estimated to date to 6000–5500 years BP (Nanayama et al., 2003; Sawai et al., 2009)(Fig. 2). Aerial photographs show that Nanbuto marsh is a typical strand plain, which probably formed as the sea retreated gradually from the plain, leaving up to three beach ridges along its southern edge (Fig. 2). These ridges may have formed during forced regressions associated with seismic uplift or subsidence (Atwater et al., 2004). Thus, these marshes developed and peat deposition began only after the sea retreated from the area, after 5500–6000 years BP.

At Hanasaki Port (Fig. 1), the spring-tide range is 1.2 m, and the neap-tide range is 0.9 m. The corresponding ranges are 1.3 and 1.0 m at Kushiro (Fig. 1), where the extreme tidal range, between the highest and lowest astronomical tides, is 1.7 m. We thus estimated the corresponding ranges at Nanbuto to be 1.2–1.3 m and 0.9–1.0 m (Fig. 3). During the last 200

years, typhoons and heavy storms have rarely struck this coast; thus, no large seawater flooding events or sand movements associated with huge storms or typhoons have occurred. We estimated the landward limit of the annual storm run-up from the distribution of flotsam washed up on the present beach (Fig. 2). Hanasaki Port suffered damage from the 1973 Nemuro-oki earthquake tsunami, which had a wave height of 2–3 m. Figures 2 and 3 show the area inundated by the 1973 tsunami and the flooding elevation.

Our other study site, Gakkara-hama beach, is situated on the western margin of Nemuro City, 30 km west of Nanbuto marsh (Fig. 1), at the edge of a marine terrace formed during MIS 9 (Okumura, 1996). There is private ranch and no colony. Behind the rocky Gakkara-hama beach, there is a small marsh, 2 to 6 m in elevation. The marsh deposits are exposed in the sea cliff that extends along the shoreline.
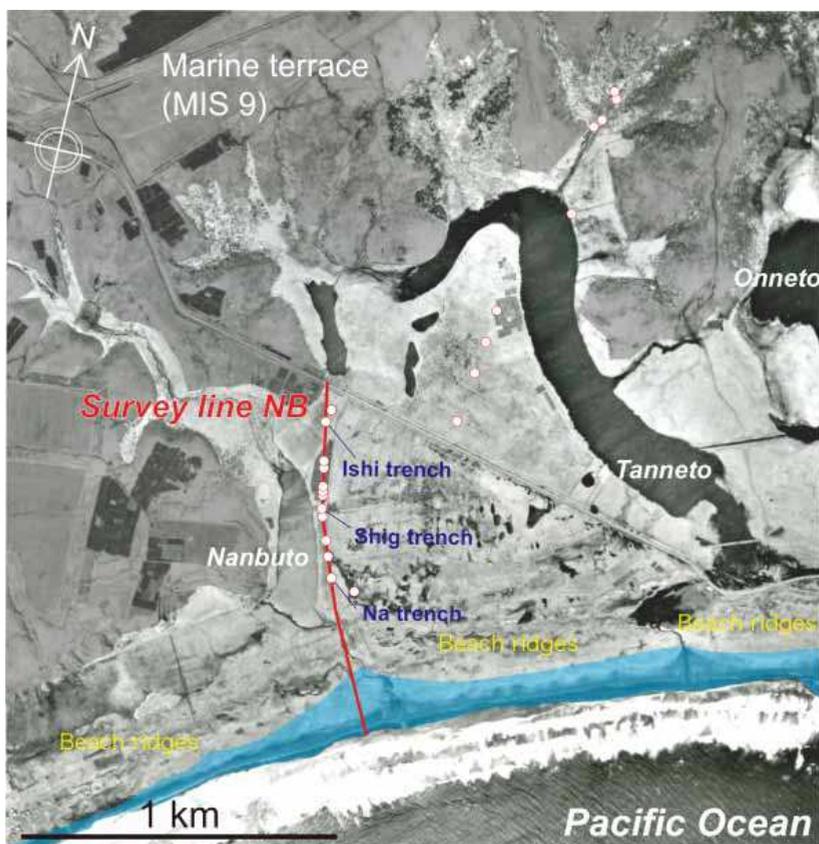

Fig. 2. Aerial photograph showing the topography around Nanbuto marsh, and the locations of three of the trenches excavated along survey line NB. Circles show sites where 17th century tsunami deposits (layer NS1) were observed. The blue shading shows the area inundated by the 1973 Nemuro-oki tsunami. Dark gray shading shows MIS 9 marine terrace surfaces, and light gray shading shows the area inundated by the 17th century tsunami (estimated from the distribution of NS1).
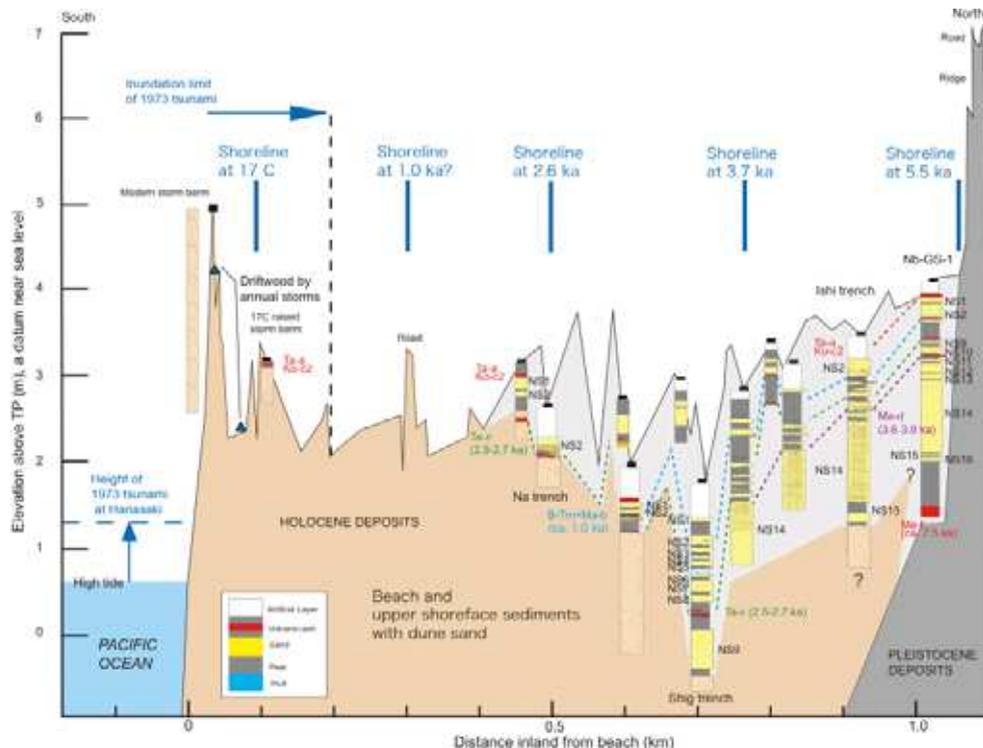
Fig. 3. Geomorphologic profile along line NB. Seven tephra layers were used to correlate the sedimentary stratigraphy among trenches in Nanbuto marsh (colored dashed lines).

4. Methods

4.1 Field survey and sampling

Line NB is 1000 m long and traverses the western part of Nanbuto marsh along the eastern side of Lake Nanbuto (Fig. 2); it is approximately perpendicular to the present shoreline. We measured elevation and distance from the present shoreline with a tape measure, a leveling instrument, and a Handy GPS system (Leica System 1200 GNSS). Most of the marsh is part of a private ranch; therefore, it is partially cultivated and also used by domestic animals.

We looked for regional tephra layers and sand beds of possible tsunami origin within the peat beds and other marsh deposits and traced every sand bed that we found, taking samples with a scoop or a peat sampler at 10-m intervals along the survey line (Fig. 2). In addition, we used heavy equipment to dig seven trenches, up to 2.7 m wide, 14.4 m long and 2.7 m deep, and described the trench walls. Finally, we obtained a wide, oriented sample, 300 cm long by 30 cm thick, with a Geo-slicer soil sampler (Atwater et al., 2001) at Nb-GS-1 (Fig. 3).

4.2 Sedimentary description

We made three-dimensional oriented peels of the trench walls and described major sedimentary structures in the field. We also used a large plastic box (21 cm × 30 cm) to take

oriented samples of sand beds for radiographic observation from each trench wall and from the Geo-slicer sample.

In our laboratory at the Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST), we took radiographs of typical sand beds in this area to infer their depositional processes. We also described the sedimentary structures of each sand bed, including bed form, grain size, and current directions, and we recorded the color of each bed with a digital soil color reader (Minolta SPAD-503). Finally, we examined each sand sample under a binocular microscope for marine components such as rounded beach sand grains and marine microfossils. We then integrated all this information and used it to identify tsunami deposits in the Nemuro lowland.
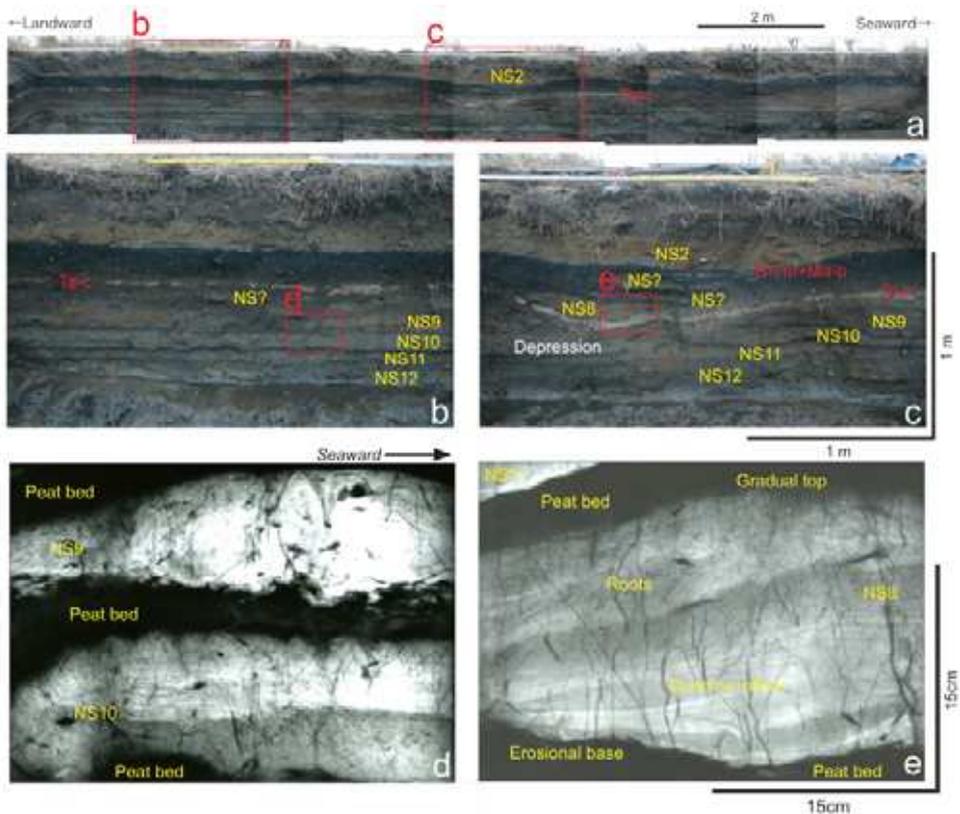

Fig. 4. Wall photographs of Ishi trench, the most inland trench (a); close-ups of portions of the wall (b, c); and radiographs of typical tsunami deposits (d, e) in this trench.

4.3 Tephra study

We described the thickness, color, and grain size of tephra layers and collected samples in the field. In our laboratory, the tephra samples were mounted on slides with resin and double-polished and their petrographic features, including glass shard morphology and phenocryst assemblage, were examined under a stereoscope (polarizing microscope).

Chemical analyses were performed with a JEOL JXA-8900R electron probe microanalyzer at the Geological Survey of Japan. Nine major elements (SiO_2, TiO_2, Al_2O_3, FeO, MnO, MgO, CaO, Na_2O, and K_2O) were analyzed with an accelerating voltage of 15 kV and a beam current of 12 nA. The narrow beam scanned within a 10-µm grid, with counting times of 20 and 10 s for peak and background, respectively.
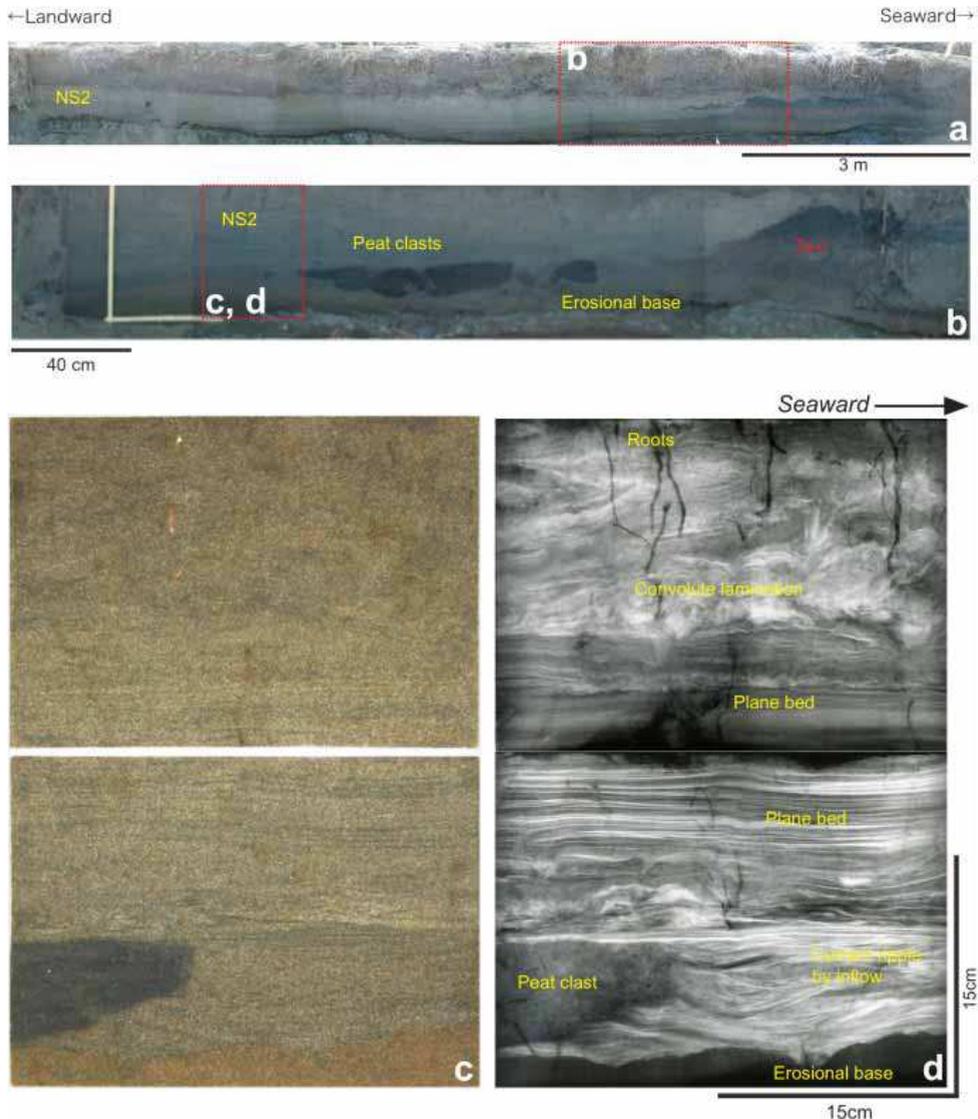

Fig. 5. Na trench, at the seaward location of the survey line, in Nanbuto marsh. Trench wall photographs (a, b); photograph of the oriented plastic-box sample of NS2; (c) radiograph of the same sample with sedimentary interpretation (d).

At least 30 volcanic glass shards from each tephra sample were analyzed to identify the origin of the volcanic ash (Furuta et al., 1986). We compared our results with the known chemical compositions of regional tephra layers as reported by Furukawa et al. (1997), Furukawa & Nanayama (2006), and Yamamoto et al. (2010).

4.4 Radiocarbon dating

Plant materials and one bone sample were selected for ^{14}C dating from each peat bed and basal beach sediment. In all, 20 samples were dated at the AMS facilities at Geo-Science Laboratory Co. in Nagoya, Japan and the Institute of Accelerator Analysis Ltd. in Kawasaki, Japan. The dates were converted to calendar years before present (cal. yBP) and calendar thousand years before present (cal. ka BP) with the calibration program IntCal04 (Reimer et al., 2004), where BP is relative to the year AD 1950. We refer only to the 2-sigma range of calendar years in this chapter.

4.5 OSL dating

Dose estimation in the OSL dating method has improved greatly over the last 10 years, with the result that OSL has been increasingly used to date late Quaternary sediments. However, the age range to which OSL dating of quartz, feldspar and other minerals can be applied, which depends on both the saturation dose and the dose rate, is limited (Tsukamoto & Iwata, 2005). Nevertheless, it is a very useful method because it can be used to obtain age data directly from tsunami deposits.

We collected 14 samples from 12 sand beds interpreted as tsunami deposits (NS1–NS12) for OSL dating by the radiation laboratory of Nara University of Education. These samples, which contained both quartz and feldspar grains with other mineral grains, were dated by the infrared stimulated luminescence method (Nanayama et al., 2009).

5. Results and discussion

5.1 General stratigraphy

In the Nanbuto marsh, the most seaward trench (Na) was dug about 490 m from the shoreline, and the most inland trench (Ishi) was approximately 970 m from the shoreline. The survey found the formation of about 2.2-m-thick peat layer in its deepest zone within the subject area. We identified 7 regional tephra layers and 16 tsunami deposits (NS1–NS16) (Figs. 4 and 5).

On the basis of macroscopic examinations and the known stratigraphy of volcanic ashes in the region (Furukawa & Nanayama, 2006; Yamamoto et al., 2010; Fig. 1), we identified, in descending order, ashes Ta-a (erupted from Mt. Tarumai in 1739), Ko-c2 (Mt. Komagatake, 1694), Ma-b (Mt. Mashu, 10th century), B-Tm (Mt. Baitousan, about AD 937–938), Ta-c (Mt. Tarumai, 2.5–2.7 ka), Ma-d (Mt. Mashu, 3.6–3.9 ka), and Ma-f (Mt. Mashu, ca. 7.5 ka).

In addition, we obtained AMS ^{14}C dates on plant materials from peat beds (Table 1). Of 18 samples dated by OSL from NS1 to NS12 (Fig. 5), we considered six to yield reasonable dates for the tsunami deposits. The other luminescence dates were apparently too old, by comparison with the tephrochronology and AMS ^{14}C data, as discussed below (Table 1).

On the basis of the tephra age of the deepest peat horizon immediately overlying beach sediment at each trench site, we estimated past shoreline positions at the 17th century, 1.0

ka?, 2.6 ka, 3.7 ka, and 5.5 ka (Fig. 3), which we used to estimate the run-up distance between the observation site of each tsunami deposit and the corresponding shoreline. The estimated run-up distances exceeded several hundred meters, which was an important consideration in our association of these deposits with unusual tsunamis.

We also described 12 tsunami deposits, NS1–NS12 (Nanayama et al., 2009; Fig. 7), in the sea cliff scarp at Gakkara-hama beach. The stratigraphic sequence of the tephra layers and tsunami deposits were the same as at Nanbuto, indicating that these unusual tsunami deposits are distributed regionally in the Nemuro lowland.

5.2 Sedimentary structures in unusual tsunami sand beds

When the 1973 Nemuro and 2003 Tokachi-oki tsunamis struck the Nemuro lowland, no large sediment transfer occurred, nor was there much coastal erosion. These tsunamis were too small to leave tsunami deposits in this environment. Giant tsunamis on the scale of the 2004 Indian Ocean tsunami very likely struck the coast in the past, generating large-scale sediment transfers that formed the tsunami deposits that we observed in the marsh environment of the Nemuro lowland.

The major component of each of the 16 tsunami deposits (NS1 to NS 16) is very well sorted fine sand. These sands were mainly scoured from beach and dune sand after the tsunami hit the coast. In marsh environments, tsunami deposits are usually interbedded with peat (Dawson & Stewart, 2007). No shell fragments or carbonate microfossils were observed, presumably because they were dissolved by submersion. At Shig trench, some sand beds were covered by mud layers (Fig. 3). We interpreted this as mud deposited in a trough between two sand ridges, possibly during seawater flooding. The thickness of the tsunami sand layers is important information because it indicates the magnitude of local topographic depressions in the marsh environment. For example, NS2 ranges in thickness from a few centimeters to tens of centimeters; where it reaches maximum thickness of 95 cm, it clearly displays parallel lamination and resembles beach sediment (Fig. 5). NS2 also shows clear landward thinning.

Although we did not observe any clear graded bedding, the sand beds included internal sedimentary structures such as plane beds, dunes, and current ripples, suggesting bedload transport (Figs. 5 and 6). Moreover, within each bed, dune forms and current ripples indicate two flow directions, thus recording both the tsunami inflow and its outflow (Nanayama & Shigeno, 2006).

The gradual upper boundary and the erosional base of each sand bed are characteristic features of tsunami sedimentation. We inferred that the tsunami run-up eroded the underlying stratum, and that the gradual upper boundary reflects the regrowth of marsh vegetation in the years following the tsunami sand deposition. The erosional lower bounds and associated peat blocks or clasts that characterize the tsunami sand layers in this area constitute important evidence of past tsunami deposits in a marsh environment (Bondevik et al., 2003; Gelfenbaum and Jaffe, 2003). Without the application of large stress, it is difficult to detach peat clasts from a peat bed, because of the fibrous nature of peat. According to our radiograph observations, the deposits contained accretion structures generated by flowing water such as plane beds and current ripples. We also observed convolute lamination, reflecting rapid sedimentation and water drainage (Fig. 5), both of which occur during tsunami run-up.

Fig. 6. Collection of samples for OSL dating at Shig trench (left). Photograph of the trench wall showing the OSL sampling horizons and dating results (right). AMS ^{14}C dating results, tephra layers and dates, and sand beds NS1 to NS9 are indicated to the right of the photograph.
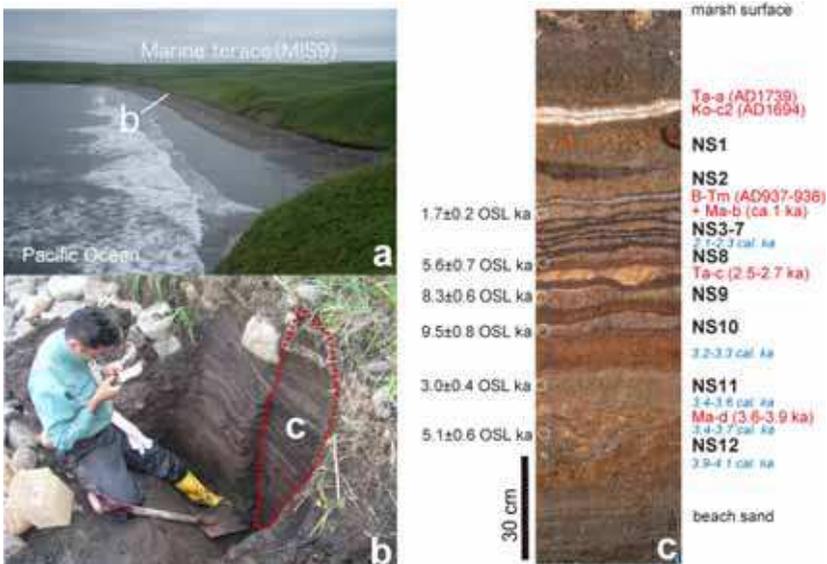

Fig. 7. View of Gakkara-hama beach looking southwest (a), and photograph of the sampled outcrop (b). Photograph of a large peel sample (c) showing the locations of tsunami sand beds NS1–NS12, tephra layers and dates, OSL sampling horizons and dating results, and AMS ^{14}C dating results.

5.3 Estimation of the recurrence interval of unusual tsunamis

We identified 16 tsunami sands (NS1 to NS16) within peat beds in the Nemuro lowland, and ascertained the chronology of their deposition using tephrochronology, AMS ^{14}C dating, and OSL dating. The date of each peat bed can be measured by AMS ^{14}C dating to within a 2-sigma range of several hundred years. Because the base of each sand layer is usually erosional, it is not possible to estimate the exact age of each tsunami deposit from the AMS ^{14}C ages of the peat horizons. We thus inferred the average recurrence interval of unusual tsunamis to within about 100 years by using the regional tephra ages along with the AMS ^{14}C ages from certain important peat horizons as follows (Table 1).

1. Ko-c2 (AD 1694) overlies tsunami deposits NS1 and NS2, which overlie both B-Tm (AD 937–938; Fukusawa et al., 1998) and Ma-b (10th century). We correlated NS1 with the 17th century tsunami and NS2 with a 13th century tsunami. They are estimated to be separated by 379 years, obtained by dividing the interval between the two time markers by two.
2. Underlying B-Tm and Ma-b, and overlying Ta-c (2.5–2.7 ka), are six tsunami deposits (NS3 to NS8). Their estimated recurrence interval is thus 250–283 years.
3. Underlying Ta-c and overlying Ma-d (3.6–3.9 ka), there are three tsunami deposits (NS9 to NS11), and the estimated recurrence interval is 200–367 years.
4. Underlying Ma-d and overlying the lowest peat horizon (4.8–5.0 ka) are five tsunami deposits (NS11 to NS16), for an estimated recurrence interval of 220–320 years.

Therefore, the estimated average recurrence interval of unusual tsunami events in the Nemuro coastal area is 200–379 years (Table 1). However, the recurrence interval was not estimated by using dates obtained directly from the tsunami sands, so this value should be understood as a maximum. The number of tsunami deposits in the Nemuro area between the regional tephra layers Ko-c2, B-Tm, and Ta-c is greater than the number in the Tokachi-Kiritappu area, suggesting a possible tsunami source off Habomai, Shikotan, Kunashiri, and Etorofu Islands (southern Kuril Islands), in addition to tsunami-generating multisegment interplate earthquakes along the Tokachi-oki and Nemuro-oki ruptures (Fig. 1).

We also attempted to date the tsunami deposits directly by using the OSL dating technique (Fig. 6; Table 1). We hope that it will be possible to obtain the formation ages of individual tsunami deposits more exactly by future advances in OSL dating technology. However, our luminescence results yielded numerous, erroneously old ages compared with ages ascertained by tephrochronology and AMS ^{14}C dating. These erroneous ages may be attributable mainly to (1) insufficient zeroing or (2) the mixing of deposits of different ages by scouring during the tsunami run-up, or both. We plan to investigate the sources of the tsunami sand deposits by using the OSL technique, and to conduct basic research on erosional and depositional processes during tsunami run-up in detail in a new study area.

5.4 Open trench demonstration and donation of large peel samples

Unusual tsunami deposits can be traced as high as 18 m above the current sea level and as far as 1–4 km inland from the Pacific shoreline of eastern Hokkaido, and such unusual tsunamis have recurred at intervals of several hundred years, with the most recent event in the 17th century (Stake et al., 2008). The results of this study has thus improved the unusual tsunami hazard map, produce in accordance with government guidelines, municipalities of eastern Hokkaido, including Nemuro City.

Because Nemuro is an active seismic area, it is important for citizens to be informed with regard to tsunami hazards. Therefore, on 15 October 2005, we conducted an open trench

demonstration for the people of Nemuro at Ishi trench. The Geological Survey of Japan, Hokkaido University, Nemuro City Museum of History and Nature, and the Historical Museum of Hokkaido cosponsored this outreach event. About 200 residents of Nemuro City and eastern Hokkaido participated, giving us a good opportunity to explain the importance of our research results directly to local citizens.

After our investigation, we donated some large peel samples to the Nemuro City Museum of History and Nature and to the Historical Museum of Hokkaido, Hokkaido University, to use as educational materials in regard to tsunami disaster mitigation (Fig. 8).

Stratigraphy	OSL dating (ka)	AMS^{14}C dating (2-sigma cal. ka)	Recurrence interval
Ta-a (AD1739) / Ko-c2 (AD1694)			
NS1 (17C)	2.9 ± 0.2		379 years
NS2 (13C)	0.8 ± 0.3		
B-Tm (AD937-938) +Ma-b (ca. 1ka)			
NS3	1.7 ± 0.2, 1.5 ± 0.1		
NS4	1.4 ± 0.2		
NS5	5.1 ± 0.8		250-283 years
NS6	10.3 ± 1.9		
NS7	5.3 ± 0.6		
		2.1-2.3 (wood)	
NS8	5.6 ± 0.7, 9.3 ± 1.0		
Ta-c (2.5-2.7 ka)			
		2.5-2.8 (wood)	
NS9	2.7 ± 0.4, 8.3 ± 0.6		200-367 years
NS10	9.5 ± 0.8		
		3.2-3.3 (wood)	
NS11	3.0 ± 0.4		
		3.4-3.6 (wood)	
Ma-d (3.6-3.9 ka)			
		3.4-3.7 (wood)	
NS12	5.1 ± 0.6		
		3.9-4.1 (wood)	
NS13			
		4.5-4.8 (wood)	220-320 years
NS14			
		4.8-4.9 (wood)	
NS15			
		4.9-5.0 (wood)	
NS16			
		4.8-5.0 (wood)	
Beach sand		5.5-5.7 (bone)	

Table 1. Tephrochronology and OSL and AMS ^{14}C dating results and estimated recurrence intervals of unusual tsunamis (NS1–NS16) during the last 5000 years. OSL dates in black type are considered reasonable ages by comparison with AMS ^{14}C dating and tephrochronology results, and those in purple type are considered to be erroneous (too old).

Fig. 8. Open trench demonstration held for Nemuro residents on 15 October 2005 at Ishi trench (left). A large peel sample that was donated for tsunami education (right).

6. Conclusion

1. We conducted a geological study of unusual tsunami deposits in the Nemuro lowland, along the Pacific coast of eastern Hokkaido, to obtain information useful for planning for tsunami disaster mitigation.
2. On the basis of sedimentary descriptions, tephrochronology, and AMS ^{14}C and OSL dating results, we identified 16 tsunami deposits in Nanbuto marsh and estimated the unusual tsunami recurrence interval to be generally 220–379 years during the last 5000 years.
3. We described internal sedimentary structures such as plane beds, dunes, and current ripples that indicate bedload transport. Within each bed, dune forms and current ripples show both the inflow and outflow directions of the tsunami inundation.
4. The geological information obtained by this study is valuable for mitigation of tsunami disasters. We show two examples. An open trench demonstration afforded a good opportunity to present our results to local residents. In addition, we donated large peel samples to local museums for effective tsunami education.

7. Acknowledgements

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The Tsunami Threat - Research and Technology

Edited by Nils-Axel Mörner

Submarine earthquakes, submarine slides and impacts may set large water volumes in motion characterized by very long wavelengths and a very high speed of lateral displacement, when reaching shallower water the wave breaks in over land - often with disastrous effects. This natural phenomenon is known as a tsunami event. By December 26, 2004, an event in the Indian Ocean, this word suddenly became known to the public. The effects were indeed disastrous and 227,898 people were killed. Tsunami events are a natural part of the Earth's geophysical system. There have been numerous events in the past and they will continue to be a threat to humanity; even more so today, when the coastal zone is occupied by so much more human activity and many more people. Therefore, tsunamis pose a very serious threat to humanity. The only way for us to face this threat is by increased knowledge so that we can meet future events by efficient warning systems and aid organizations. This book offers extensive and new information on tsunamis; their origin, history, effects, monitoring, hazards assessment and proposed handling with respect to precaution. Only through knowledge do we know how to behave in a wise manner. This book should be a well of tsunami knowledge for a long time, we hope.

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