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Field Survey of the 1993 Hokkaido Nansei-Oki Earthquake Tsunami

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Abstract—Runup data in Hokkaido and in three prefectures in the Tohoku District are described with a few witnessed arrival times and with comments of tide records. The highest runup of 31.7 m was found at the bottom of a narrow valley on the west coast of Okushiri Island. In order to explain high runups of 20 m at Hamatsumae in the sheltered area, roles of edge waves, refraction of the Okushiri Spur and tsunami generation by causes other than the major fault motion should be understood. An early arrival of the tsunami on the west coast of Hokkaido suggests another tsunami generation mechanism in addition to the major fault motion.

Key words: Tsunami, runup, arrival time, edge wave, Japan Sea.

1. Introduction

At 22:17, July 12th (local time), 1993, an earthquake of $M_w = 7.8$ generated a giant tsunami. The tsunami reached the maximum runup height of 31.7 m. This was the highest runup of the century in Japan while human casualties were the largest of the last 50 years.

Shortly after the event, the authors formed two teams, composed mostly of members from Tohoku and Akita Universities; one team for numerical simulation and the other for field survey. The simulation team of 4 members began the work by purchasing detailed maps and charts. They then digitized the maps, obtained the fault parameters from TBB (Tsunami Bulletin Board) on e-mail communication, carried out the simulation and made a computer-graphics video animation.

The survey team of 19 members arrived in Hokkaido on July 15th and proceeded to Okushiri Island on July 18th as soon as the ferry transportation resumed. The team continued the survey until July 23rd, maintaining close contact with the numerical simulation team. Every morning and night the two teams exchanged their results, and determined the locations and density of measurement points.

Thereafter runup heights were measured along the Japan Sea coast of three prefectures in the Tohoku District.

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2. Areas and Types of Field Survey

The survey covers the entire coast of Okushiri Island, 60 km long; the western coast of Hokkaido, 310 km long from Furubira to Matsumae; and the coasts of Aomori, Akita and Yamagata Prefectures, 910 km long in the Tohoku District. Figure 1 shows the area of the survey and the position of the epicenter.

Major objectives of the survey were:

(1) Measurement of height and position of runups. Maps and GPS (Global Positioning System) were used to determine the positions. Locations of runup measurements were marked with stakes at sites by the survey team. All the measurements are in the Japan Sea where the tidal range is of the order of 20 cm. The runup is expressed in meters above mean sea-water level.

(2) Characterization of the tsunami such as arrival time, initial movement of water surface (i.e., whether the tsunami began with ebb or flood), incident direction, tsunami profile, the time at which the highest and/or maximum wave appeared, tsunami wave period, and so on.

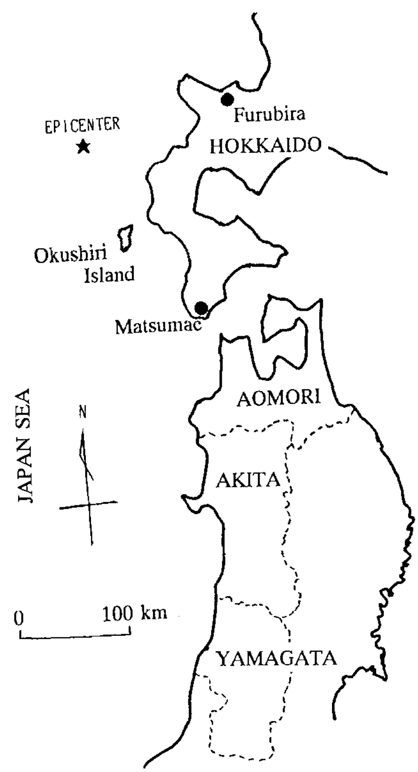

Figure 1
Area of survey and the epicenter.

(3) Inspection of damage to coastal structures.

The present paper reports the results of items (1) and (2).

About 130 runups were measured in Okushiri Island, about 70 in Hokkaido, and approximately 80 (60 measured by the authors' team and 20 measured by local authorities) in Aomori, Akita and Yamagata Prefectures in the Tohoku District.

Daily communication between the two teams was reflected in: (1) a dense measurement along the east coast of Okushiri Island, (2) a detailed survey at Aonae and Hamatsumae on the south coast of Okushiri Island, (3) efforts to access the coastal cliff near Horonai on the west coast of Okushiri Island, and (4) attempts to determine the arrival time along the southwestern coast of Hokkaido.

3. *The Tsunami in Okushiri Island*

It was night when the tsunami hit the island. Neither photos nor videos were taken and no witnesses could give a clear image of the tsunami. Figure 2 shows the runup distribution along the island.

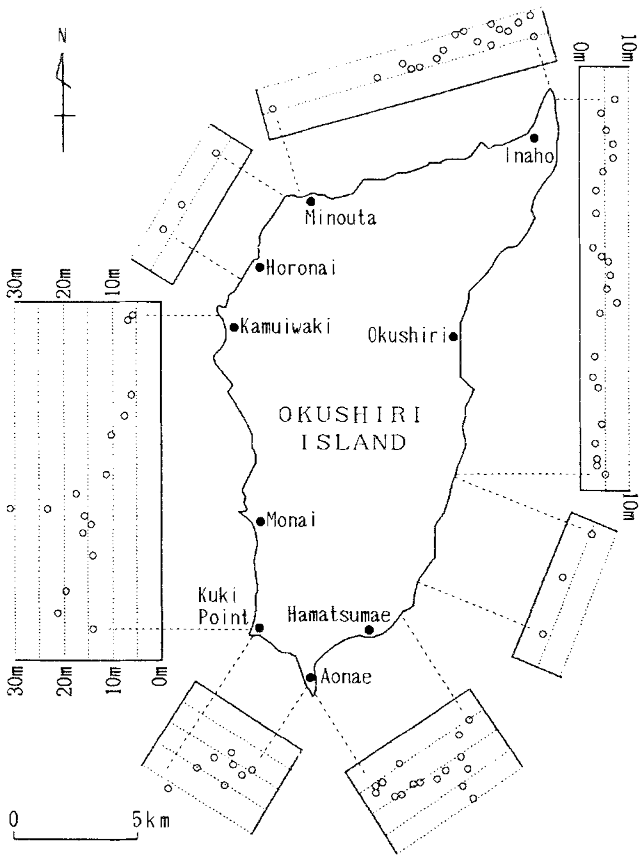

Figure 2
Runup distribution in Okushiri Island.

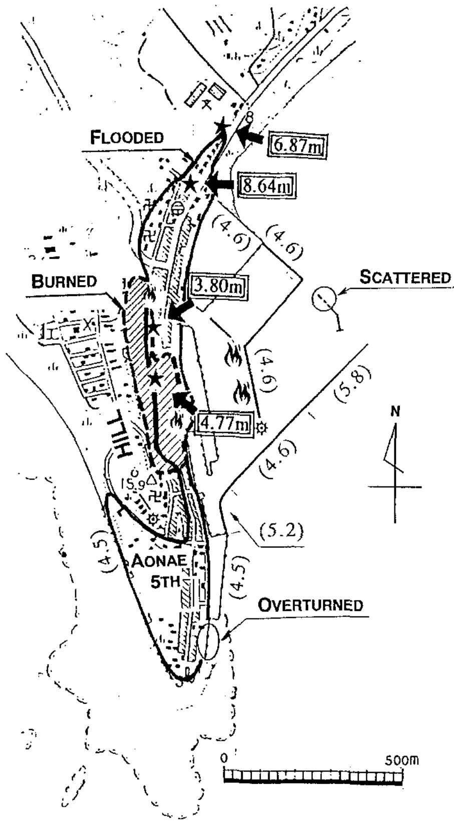

Figure 3
Tsunamis and damages in the town of Aonae. The fifth section of Aonae is on a sand spit in the south of a hill, and the first to fourth sections are along the eastern foot of the hill. Numerals in double rectangles are runup heights measured at the locations indicated by stars. Numerals in parentheses are the crown heights of structures. The area surrounded by the solid line was flooded by the tsunami. The hatched area was burned by fires.

At the southern tip of the island, the tsunami hit the town of Aonae. This town, composed of five sections, is located at the foot of a hill 20 m high as shown in Figure 3. The first to fourth sections are located on a beach along the eastern foot of the hill. Their waterfront is used as a fishing harbor, protected by breakwaters. The fifth section of Aonae is on a southern sand spit 3 m high. This fifth section was hit by the tsunami from the west, 4 to 5 minutes after the earthquake. The entire fifth section was swept away by the first tsunami, although the section was protected by sea walls 4.5 m high.

This first tsunami did not damage the first to fourth sections of the town, because the tsunami was not high enough to overflow the hill. Approximately ten minutes after the first tsunami, the second tsunami struck these sections from the east.

At the northern tip of the island, the tsunami hit the village of Inaho from the north.

Along most of the eastern coast of Okushiri Island, runups are not high because the coast is sheltered by the island itself against the tsunami source. A spatial fluctuation of runup distribution along it, however, may suggest the tsunamis behaved as edge waves.

Special attention should be directed to the fact that runups 20 m high were measured at Hamatsumae on the southeastern coast of the island even though it is located in the sheltered area.

The highest runup of 31.7 m was measured on the western coast directly facing the tsunami source. It was found at the bottom of a small valley north of Monai. The tsunami arrived at Monai 4 minutes after the earthquake.

The total length of the coastline on which runups are higher than 10 m is about 13 km on the west and south coasts of Okushiri Island.

4. *The Tsunami on the Southwestern Coast of Hokkaido*

Figure 4 displays the runup distribution. Runup heights are less than 10 m, except in a few locations.

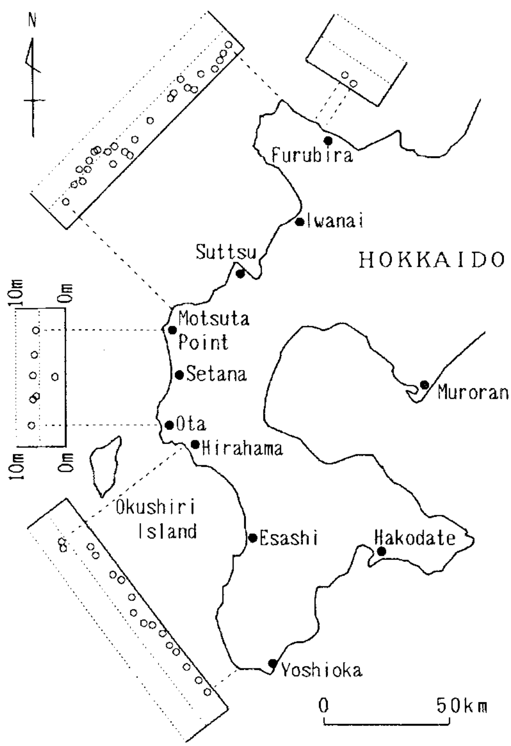

Figure 4
Runup distribution in Hokkaido Island.

Spanning the coast from Motsuta Point to Furubira, runups decrease northward from 5 m. The tsunami recorded at Iwanai began with a rise of the water surface.

Along the coast from Motsuta Point to Ota which protrudes westward and is parallel to the major axis of the estimated fault, runups are higher than 5 m. According to witnesses, the first tsunami arrived 4 to 5 minutes after the main shock. It began with a fall of the water surface, and the first or second wave was the highest.

Along the coast from Hirahama down to Esashi, runups are less than 5 m. The tsunami recorded at the Esashi tide gauge station began with a fall of the water surface. At Yoshioka on the southern end of the Oshima Peninsula, the tsunami on tide records began with a rise of the water surface. The maximum tsunami height measured above the estimated astronomical tide was 0.82 m, induced by the seventh wave which lasted a period of 8 minutes.

5. The Tsunami along the Tohoku District

5.1. Aomori Prefecture

Figure 5 shows the runup distribution along the coast of Aomori, measured by the local authorities.

The tsunami did not affect the Pacific coast.

In the middle of the Tsugaru Strait, a maximum runup of 1 m was obtained at Oma, at the northern end of the Shimokita Peninsula.

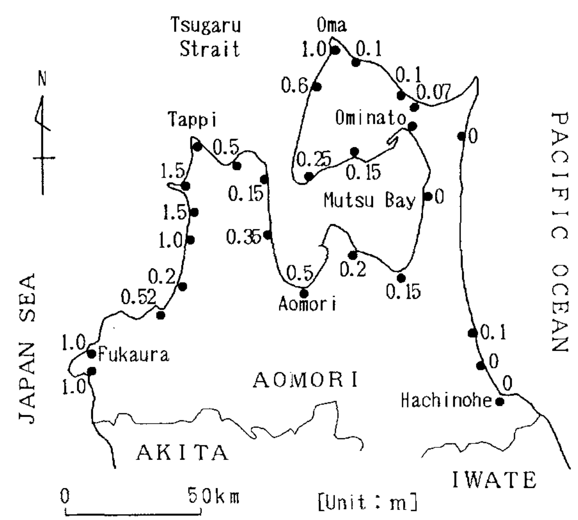

Figure 5

Runup distribution in Aomori Prefecture (measured by local authorities).

In Mutsu Bay, a maximum runup of 0.5 m was measured at Aomori, at the southern end of the bay. At Ominato on the northeastern side of the bay, the tsunami was recorded by the tide gauge but it proved difficult to determine the arrival time of the tsunami. The record here shows an oscillation with a period of 30 to 40 minutes, which is estimated to be close to the natural oscillation period in the bay. The maximum wave height was estimated as 0.57 m.

The tide record obtained at Tappi at the western entrance of the Tsugaru Straight reveals that the tsunami began with a rise of the water surface at 22:44, similar to the record at Yoshioka on the opposite side of the straight.

At Fukaura near the southern border of Aomori Prefecture, the tsunami recorded by the tide gauge began with a rise of the water surface at 22:43. The tsunami height of the first wave was the highest, 0.25 m. The first and fourth waves reached a wave height of 0.48 m. The wave period slightly exceeded 10 minutes.

5.2. Akita Prefecture

Figure 6 shows the runup distribution. Runup heights were on the order of 2 m. The highest runup of 3.47 m in Akita Prefecture was found at the left bank of the Mizusawa River in the village of Minehama, where a maximum runup of about

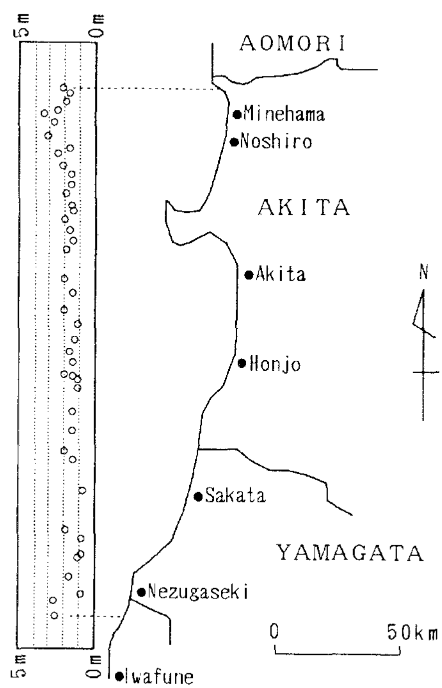

Figure 6
Runup distribution in Akita and Yamagata Prefectures.

15 m had been measured 10 years ago, at the time of the 1983 Nihonkai-Chubu earthquake tsunami.

At the tide station in Noshiro Harbor, the tsunami began with a rise of the water surface at 23:00. The tsunami reached a maximum height of 0.72 m at 1:12 and maintained the tsunami height of about 0.5 m until 7:00 on the 13th. The oscillation in the harbor continued until 7:00 on the 14th when the wave period was about 30 minutes. The wave period in the early stage could not be determined because of the very irregular time history.

The tide record at Akita Harbor demonstrates that the tsunami began with a rise of the water surface at 23:18, and reached the maximum tsunami height of 0.35 m at 0:35 on the 13th. The maximum wave height of 0.63 m was observed twice, at 0:35 and 11:00 on the 13th. The dominant wave period was about 20 minutes around 0:35 on the 13th.

5.3. Yamagata Prefecture

Figure 6 also shows the runup distribution in this prefecture. Runups are on the order of 2 m, and increase southward to 3 m.

The tide record at Sakata Harbor shows that the tsunami began at 23:23 with a rise of the water surface. The maximum tsunami height of 0.58 m was due to the 9th wave at 4:18 on the 13th, which registered a wave period of about 33 minutes.

At Iwafune in Niigata Prefecture, just south of the border, the tsunami began with a rise of the water surface. The maximum tsunami height of 0.70 m was due to the first wave. The maximum wave height of 1.36 m was also due to the first wave. The wave period exceeded 17 minutes.

6. Special Characteristics of the Tsunami

6.1. Early Arrival

A few minutes after the earthquake, the tsunami hit Okushiri Island and Hokkaido. Table 1 summarizes the results of the authors' team, the UJNR team (HOKKAIDO TSUNAMI SURVEY GROUP, 1993), and the arrival time obtained from tide records. Although there are doubts concerning the accuracy of witnessed arrival times owing to the nighttime arrival, it seems certain that the tsunami arrived very early at the west and south coasts of Okushiri Island and at the coasts of the towns of Taisei and Setana on Hokkaido.

The early arrival 4 to 5 minutes, on the west coast of Okushiri Island, is no wonder, because the coast is located close to the estimated tsunami source. The first tsunami was very large. For example, the fifth section of the town of Aonae was completely destroyed by the first tsunami as mentioned in Section 3.

Table 1

Arrival time and other remarks

Hokkaido	Arrival Time	Remarks
SHAKOTAN TOWN		
Shakotan Point	20 min.	The highest first wave began with an ebb
Kamui Point	5–6 min.	Ditto
Numamae Point	25–35 min.	Ditto
KAMOENAI VILLAGE		
Kawashiro Point	10 min.	
Sannai	10 min.	
Ryujin Point	5–10 min.	
IWANAI TOWN		
Iwanai	15 min.	
Iwanai Tide Gauge	22:37	Began with a flood
SHIMAMAKI VILLAGE		
Enoshima	5 min.	
SETANA TOWN		
Sukki	about 3 min.	The first wave was the highest
Shimauta	less than 5 min.	Ditto. Began with an ebb From the northwest
Setana	5 min.	
Futoro	less than 5 min.	The first wave from the northwest. Begin with an ebb. The second or third was the highest
TAISEI TOWN		
Ota	5 min.*	
Miyano	5 min.	The highest second wave at 22:27 or 22:28
Hirahama	5 min.	Began with an ebb from the west The second wave was the highest
Esashi Tide Gauge	22:28	Began with an ebb.
Okushiri Island	**Arrival Time**	**Remarks**
WEST COAST		
Hoyaishikawa P.S.	22:23*	
Monai	22:21	
SOUTH COAST		
Aonae 5th	4–5 min.	From the west
Aonae 1st–4th	22:37, 22:38*	From the east
Hamatsumae	22:22	

* Data with * from UJNR (1993).

On the other hand, the early arrival at Taisei and Setana towns on Hokkaido would be one of the riddles of the present tsunami. They are located far from the estimated faults, but the tsunami arrived about 5 minutes after the earthquake. This arrival time is of the same order as that to the west coast of Okushiri Island. In addition, there were many witnesses who confirmed that the first tsunami was small. These facts suggest that there might be another tsunami generation mechanism in addition to the major fault movement.

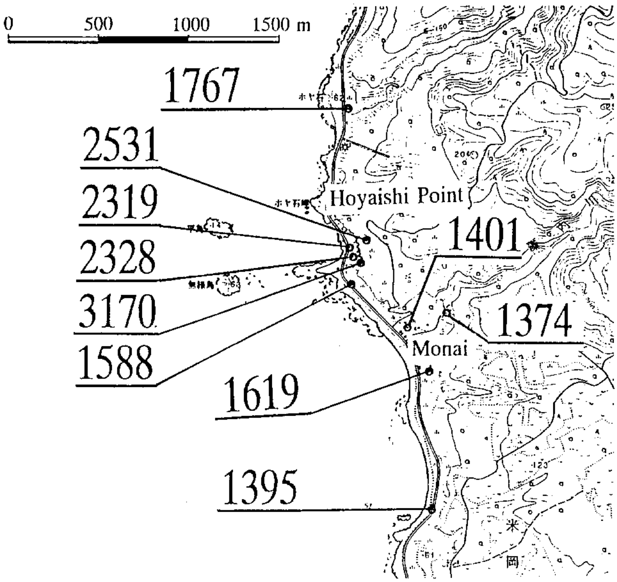

Figure 7
Runup in cm at and near the site of the highest runup of 31.7 m.

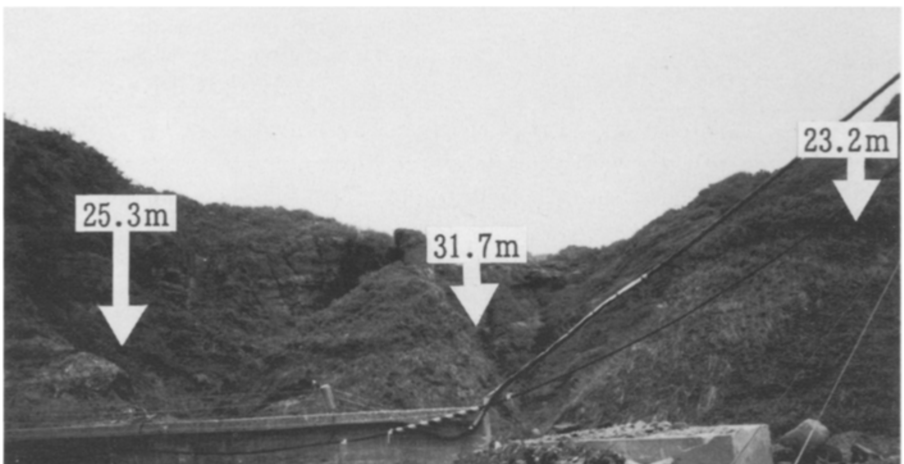

Photo 1
A small valley where the highest runup was measured.

6.2. The Highest Runup of 31.7 m

This very high runup was measured at a small pocket beach, north of Monai and south of Hoyaishi Point, on the west coast of Okushiri Island which directly faces the major fault. Figure 7 shows the map and the measured runups in cm.

The north and south ends of the pocket beach, which is 250 m long, are bounded by rocky shallows which continue to small islands and exposed rocks offshore. From the shoreline toward land, there are a narrow pebble beach, a coastal road of two lanes, and high coastal cliffs. A small sharp valley which has two branches is open at the pocket beach. Its entrance width is about 50 m. The northern branch is wider and shorter than the southern branch. The runup height was about 23 m on the south cliff at the entrance of the valley, 25.3 m at the bottom of the northern branch, and 31.7 m at the bottom of the southern branch (see Photo 1).

The authors consider that the maximum runup height of 31.7 m is a very local value and is not a representative value of the present tsunami. The representative runup of the present tsunami would be 23 m to 24 m, marked on the coastal cliff.

The authors also consider that if one tries to simulate this very high runup, he would need a map of very fine resolution, and must design a simulation with a spatial grid finer than 5 m.

6.3. Tsunami at Aonae

Aonae, which is located at the southern end of Okushiri Island, was most severely damaged by the tsunami and the tsunami-induced fires (see Fig. 3).

The island of Okushiri consists of hilly areas and narrow beaches. Extending to the southern end of the island, a hill 20 m high continues and it ends with a sudden decrease in height. On the west coast of the hill, there are very narrow beaches with no residents. From the southern end of the hill, a sand spit 3 m high, 500 m long and 250 m wide extends. The fifth section of the town of Aonae was located on this sand spit, protected by surrounding sea walls 4.5 m high. Along the eastern foot of the hill, there is a sandy beach about 150 m wide, on which the first to fourth sections of the town of Aonae were located. The land in front of the town area was recently reclaimed to construct Aonae Fishing Harbor. The crown height of breakwaters and sea walls at the harbor is 4.6 m.

The tsunami hit the fifth section first from the west 4 to 5 minutes after the earthquake. The tsunami height is estimated to be 7 m to 10 m. The sea walls 4.5 m high were inundated and left almost intact, but the entire 5th section was swept away by this first tsunami.

This first tsunami, however, did not influence and damage the first to fourth sections of the town because they were protected by the hill. About ten to fifteen minutes after the first tsunami, the second tsunami struck these sections from the east. The second tsunami overflowed a sandy hill on the northern part of the area, engulfed sea walls and breakwaters of the harbor, invaded the first to fourth sections of the town of Aonae, destroyed about half of these sections, and ignited a fire. Another fire started about two hours after the second tsunami. The two fires burnt the first to fourth sections except for a few houses in the fourth section. No fire engine could reach the fire, because the road was covered by debris transported by the tsunami.

It is certain that the second huge tsunami originated from the east. The time interval between the first and second waves is ten to fifteen minutes. There are three possibilities which explain the development of the second tsunami. The first possibility is that the tsunami generated by the north fault, rounded the northern tip of Okushiri Island and propagated along the eastern shore. There is evidence that the tsunami which hit the east coast of the island emanated from north. The

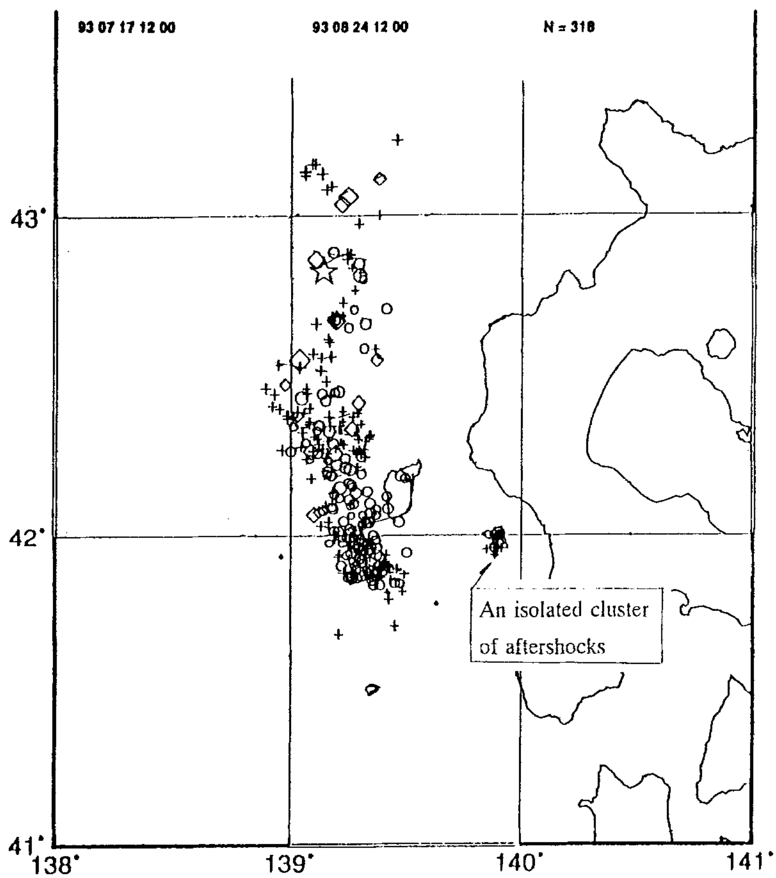

Figure 8
Aftershock distribution (Research Group, 1993) with the epicenter shown by star.

breakwaters under construction and parts of seawalls in Okushiri Harbor were overturned southward. The second possibility is that the tsunami was generated by the south fault, refracted by the Okushiri Spur, a very wide shallow in the sea as an extension of the Aonae Point, and hit the Aonae from the east after propagating on a long path due to refraction. The third possibility is that the tsunami might be generated not by the major fault motion, but by another crustal motion which is indicated in Figure 8 (RESEARCH GROUP, 1993), by an isolated cluster of aftershocks between Okushiri Island and Hokkaido.

6.4. *High Runup at Hamatsumae*

There are few locations where runup height exceeds 20 m. They are only found on Okushiri Island (see Fig. 2). Along the west coast from Monai down to the Kuki Point to the south, runup heights are from 20 m to 24 m. Moving eastward from the Kuki Point to the Aonae Point, runup heights gradually decrease to 10 m. This tsunami height was still high enough to sweep away the 5th section of Aonae, even though the 5th section was protected by seawalls 4.5 m high, which were built by taking into consideration the maximum heights of the 1983 Nihonkai-Chubu earthquake tsunami.

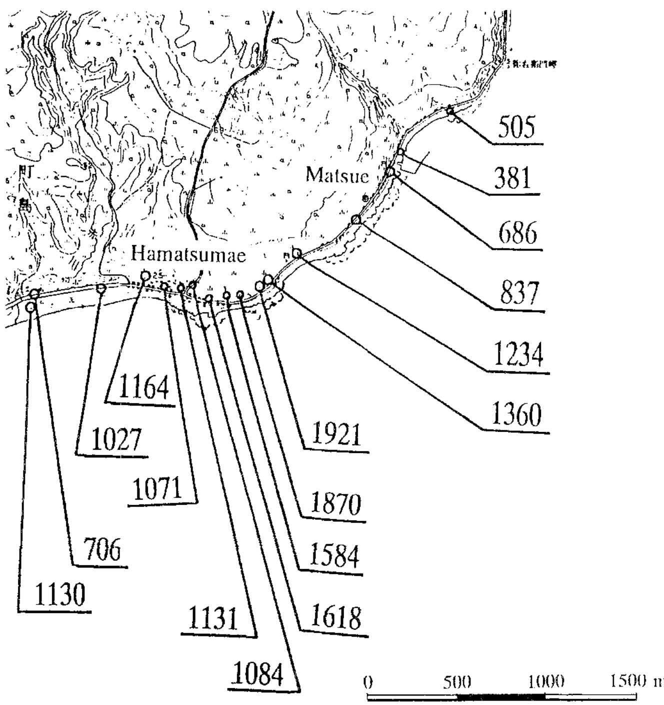

Figure 9
Runups in cm at and near Hamatsumae.

Further east of the Town of Aonae, high runups were found at Hamatsumae, in the area sheltered by the Aonae Point. When the field survey team found this high runup height, the authors decided to densely measure the runup height distribution in the neighborhood of Hamatsumae. The result is that, approaching Hamatsumae from both sides, runups become higher, as shown in Figure 9. Hamatsumae is located on a shore, the shape of which is convex to the sea. There is no special topography such as a V-shaped bay which suggests a local amplification effect.

This high runup may be (1) a result of the refraction effect of the Aonae Spur, (2) a result of the superposition of the tsunami trapped around the island, or (3) a result of the superposition of the tsunami generated by the crustal motion mentioned in Section 6.3 and the tsunamis which were generated by the major faults and trapped around the island.

6.5. Tsunami Trapped around the Island of Okushiri

A remarkable output of the authors' numerical simulation and CG animation was the entrapment of the tsunami around the island of Okushiri. In order to provide data for further study of a trapped tsunami, the field survey team was asked to increase the measurement points of runup heights on the east coast, even though damage was minor and the runups were less high there. The result was a spatial fluctuation of runup distribution as shown in Figure 2.

7. Conclusion

Since the 1993 Hokkaido Nansei-oki earthquake tsunami was generated at night, it was very difficult to collect visual data of the tsunami, such as photos and videos. The authors mostly collected tsunami data with a few witnessed arrival times and a few tide records. The weakness of runup data is that they do not impart their derivation.

On Okushiri Island, which was most devastated by the tsunami, there are no tide records. The time history of the tsunami is unknown. We must reconstruct the tsunami with the runup data, taking unreliable witnessed arrival times into consideration.

Special features of the tsunami are summarized in Section 6, which should be clarified by further study.

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