The Chile Tsunami of 1960 Observed along the Sanriku Coast of Japan

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Abstract

On the occasion of the Chile Tsunami of 1960, the Geophysical Institute of Tôhoku University made observations in the affected areas of the Sanriku Coastal region. In this report the distribution of the water heights in this region is shown with tables and maps, and some observed features of the invaded waves are described, with emphasis on the different natures between distant and near tsunamis.

1 Introduction

Before dawn of May 24, 1960, the Pacific Coast of Japan was attacked by the tsunami due to the Chilean earthquake (magnitude 8.5, origin time $19^h\ 11^m$, May 22, GMT), with an epicenter at 41.0° S, 73.5° W. Damages in the Tôhoku and Hokkaido districts were most severe in Japan, being comparable to those caused by earlier tsunamis of nearby origin. The Sanriku Coast is well known for disastrous tsunamis of which the frequency and severity have been attributed respectively to the high seismicity in the adjacent seas and abundance of V-shaped bays. Undoubtedly several tsunamis of South American origin had reached Japan earlier, without causing noticable damage. Because of the slight damage these tsunamis have not been given much attention as compared with other ones from the near seas of Japan, Kamchatka Peninsula and Aleutian Arcs. However, now that we have experienced the Chile tsunami, it is desirable for preventing calamities, to study the natures of very distant tsunami notwithstanding their rare occurrence.

Most characteristic features of the Chile Tsunami are that it traveled a distance of about 17000 km across the Pacific Ocean, and its period is very long even near its origin (about one hour). In these respects this tsunami constrasts strikingly with earlier ones of nearby origin, giving quite characteristic effects on the shores of Japan.

Some members of our Institute made observations along the Sanriku Coastal Region to collect data on the natures of the waves of the tsunami and their effects on the bays lying abundantly along the coast. Observed features related with the distribution of wave heights in the bays and along the open coasts are compared with the corresponding features for the Sanriku Tsunami of 1933. All data referred to in this report with respect to the Sanriku Tsunami are based upon the report [1] published by the Earthquake Research Institute, Tokyo.

2 Maximum Water Level attained by the Waves

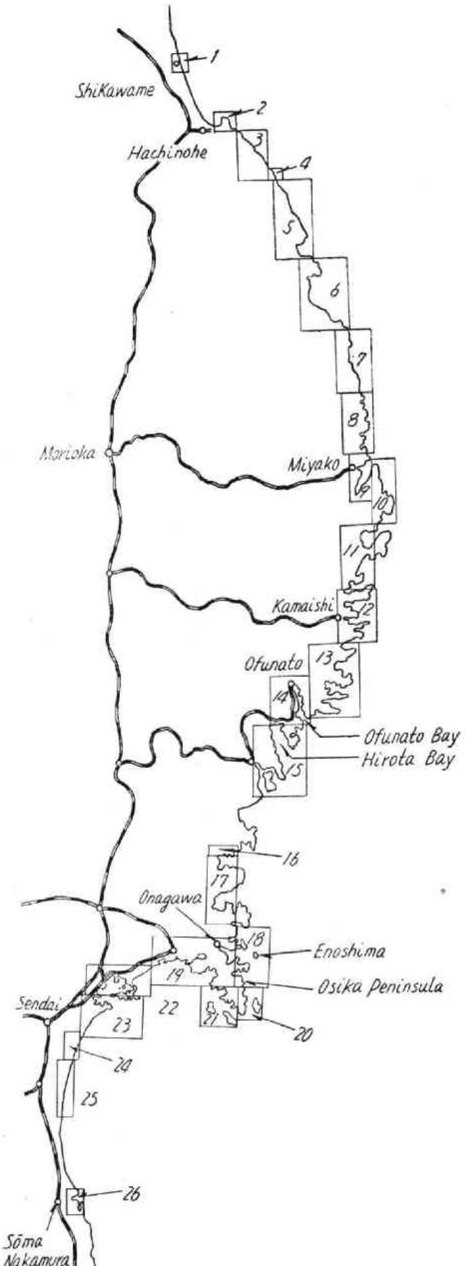

Fig. 1. Index map. Numerals refer to the map-numbers in annexed maps at the end of this report.

Since the most obvious and yet important features of the effects of tsunami upon coastal areas is the maximum height of water traced by the waves, we made it our chief object to measure it as accurately as possible. The measurements were made mainly by means of hand-level and tape, along the coastline ranging from Shikawame (Aomori Prefecture) to Sôma-Nakamura (Fukushima Prefecture). The objects for measurements were found mostly in the traces left by the waves, such marks on the walls of houses and on other constructions, rocks and grass on a bluff discoloured by the sea water, and debris left on the shore. But where no trace of the tsunami was found, we were obliged to estimate the maximum height basing on the informations supplied by the inhabitants.

The measured heights are reduced to the mean sea level in Tokyo Bay, corrections being made by means of Tide Table. Both the measured and reduced heights are listed in the table at the end of this report. The reduced heights are also indicated by the numerals in red in the annexed maps following the table. The map numbers are shown in the index map in Fig. 1. The spot numbers in the table are assigned for each map, from the north along the coastline, but, in the annexed maps, they are omitted to avoid confusion.

The table also contains the time and date of measurements, the names of the tide stations which supplied the tide curves necessary for the reduction, and the degrees of reliability of measurements in alphabetical order.

3 Observed Features about the Distribution of the Maximum Height of Water

From the distribution of the maximum heights of water, we can find some distinctive features which seem to be attributable to the remote origin and very long periods of the waves. In treating of these features it should be noticed that the Sanriku Coastal Region contains numerous bays, the seiche periods of which range from about 5 to 50 minutes. Under this situation there is little doubt that the incoming waves are affected by those bays, resulting in much more varied heights of water in the bays than at the shorelines. Considering this circumstance, we will first describe the features of wave heights along the coastline by ignoring the presence of bays, and later, the modification due to the bays will be discussed separately.

(a) General Features of Wave Height Distribution

When the bay effect is ignored, the main feature of the water height distribution along the whole coastlines may be as shown in Fig. 2. The maximum height of water is about 2–3 m, in the region south of Kuji, generally being less than 2.5 m, while a conspicuous increase in height is seen along the coast to the north of Kuji, the maximum height amounting to 5.5 m. This is a striking phenomenon which was not observed in the tsunami of 1933.

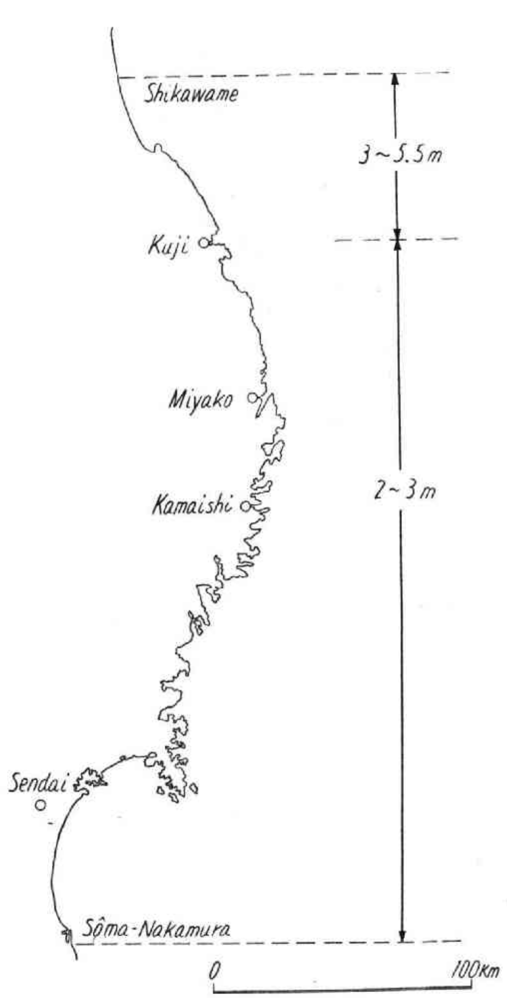

Fig. 2. General feature of the distribution of water heights when the modifications due to bays are ignored.

To account for this phenomenon, we have made the following consideration (Ref. Fig. 3). Imaginary wave fronts of long waves are constructed from five point sources located at Hachinohe, Miyako and Ayukawa, Onahama and Chôshi

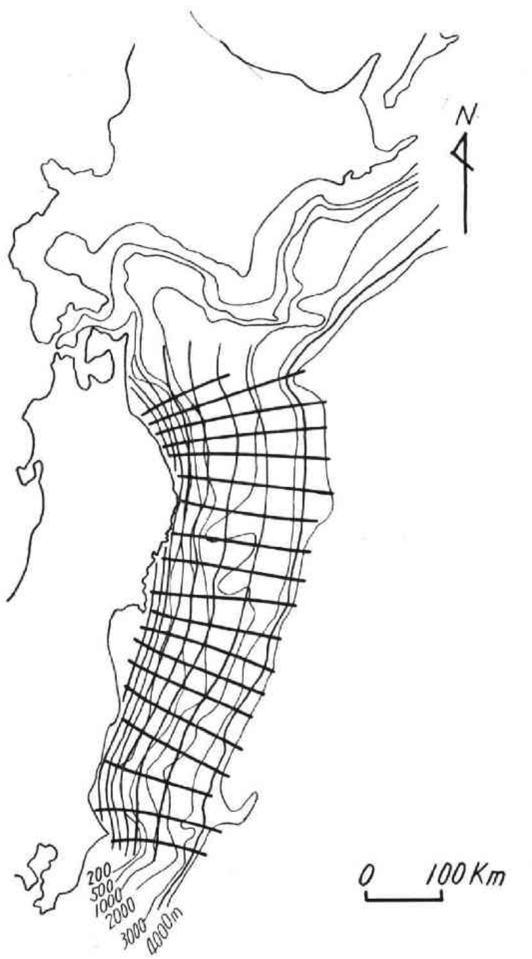

Fig. 3. Refraction diagram which shows the convergence of the Tsunami of 1960 on the coast line north to Kuji.

with different origin times determined from the tide-gauge records taken at those places. We can find that an envelope (of the five wave fronts)

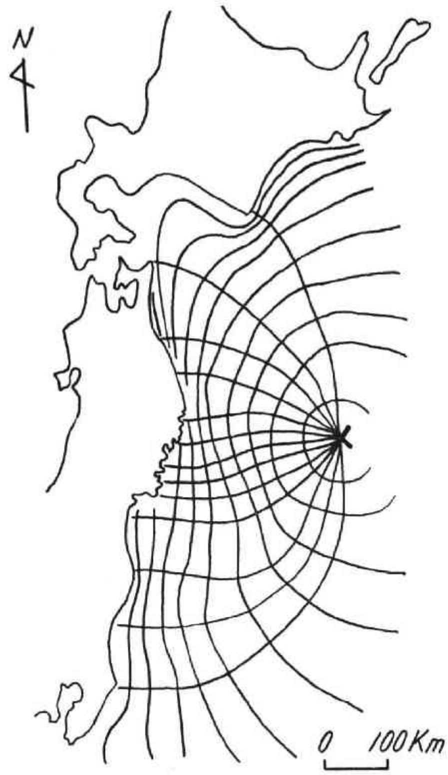

Fig. 4. Refraction diagram of the Sanriku Tsunami of 1933.

corresponding to about 30 minutes after the initial time of Miyako coincides fairly well with a wave front of the diffraction diagram with a source at the epicenter, the position of coincidence being at about 4000 m contour line off the Sanriku Coast. Then a refraction diagram is constructed back toward the coast, the source being assumed as the envelope stated above. By drawing orthogonal trajectories which start from the points of equal distance on the envelope, it is made clear, from the aspect of convergence of the orthogonal trajectories that the waves increase in height at the coastline north to Kuji.

The refraction diagram of the Sanriku Tsunami of 1933 is shown in Fig. 4, from which we can easily see that no convergence of the waves occur on the coast north to Kuji, and that the waves become very high along the coast near the source area.

(b) Diffraction of the Tsunamis by Ojika Peninsula

Since the Sanriku Tsunami of 1933 has its origin only about 200 km off Miyako, the direction of approach to Ojika Peninsula (see Fig. 1) is somewhat different from that of the Chile Tsunami. On the other hand, there is a wide difference between the periods of the tsunamis; the period of the Chile Tsunami was about 60 minutes, while that of the Sanriku Tsunami was about 16 minutes, as seen in the next section.

Under these circumstances, it will be expected that the western sea of the peninsula becomes a conspicuous shadow zone for the waves of the Sanriku Tsunami, but probably does not for the waves of the Chile Tsunami.

Observed results are just as we expected. In Fig. 5, are shown the ratios of the height of water at the eastern coast to that at the western coast, for several distances along the length of the peninsula, where empty and solid colums indicate the values for the Chile and Sanriku Tsunamis, respectively. We see that the ratios for the Chile Tsunami are alomst unity, while those for the Sanriku Tsunami exceed unity at every measured site, the maximum ratio amounting to about 2.

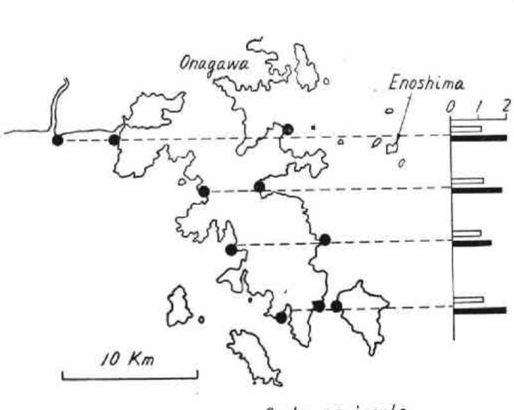

Fig. 5. Ratios of the height of water at the eastern coast to that at the western coast of Ojika Peninsula.

It is worthwhile to note that, in near tsunamis, because of the short periods which constitute the main part of the spectrum, the directions of approach to bay mouths often produces a great influence upon the distribution of wave heights. Two examples related to these problems have been shown for the case of Tokachi Tsunami of 1952, a very near tsunami [3], [4].

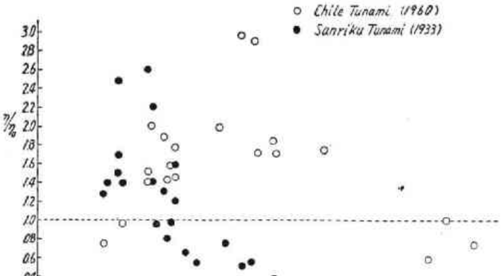

Fig. 6. Ratio η/η_0 for some bays of water heights between head and mouth against seiche period T_0.

4 Effect of Bay upon the Wave Height

The Sanriku Coast is rich in bays, large and small of various shapes, so that it is quite possible for some bays to become resonant with the incident waves of the tsunami. Fig. 6 shows the relationship between the seiche period T_0 and the ratio η/η_0 of the water height at the head to that at the mouth, the plots by solid and empty circles corresponding respectively to the 1933 and 1960 tsunamis. We note that a few plots for T_0-values larger than 50 minutes for the Chile Tsunami are made on the data of bays situated other than along the Sanriku Coast, as it lacks in bays with such long periods of seiche.

We can estimate from Fig. 5 the period of invaded waves of the Sanriku Tsunami to be about 16 minutes, whereas the corresponding period of the Chile Tsunami can not be determined owing to the scanty plots for T_0-values longer than 50 minutes. However, readings of the initial parts of the tide-gauge records taken at many stations, especially the inspection of the marigram at Enoshima, an island off Onagawa (see Fig. 1), make it possible to determine the period of incident waves of the Chile Tsunami to be 60–70 minutes.

Because of quite different natures of the incident waves in the 1933 and 1960 tsunamis, the modes of distribution of the wave heights in certain bays are very characteristic for respective tsunamis. For instance, the distributions of wave height

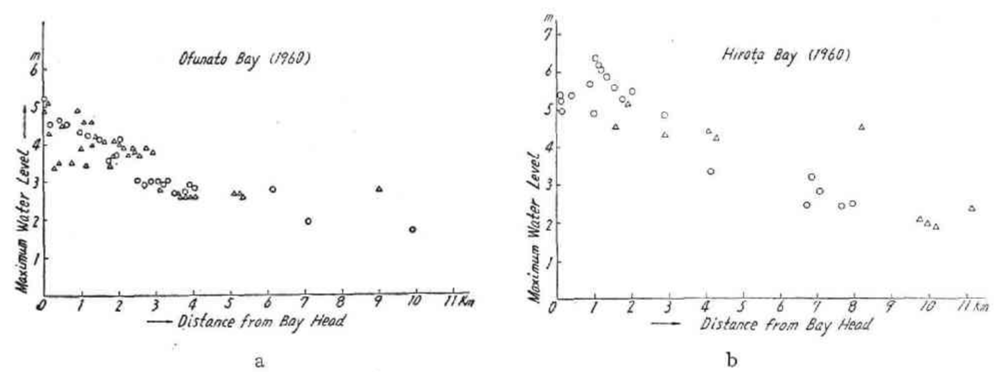

Fig. 7. a, b. Distribution of water heights for the Chilean tsunami of 1950. Circles and triangles show values on the eastern and western coasts, respectively.

in Ôfunato and Hirota bays (See Fig. 1) are shown in Figs. 7, a, b where the abscissa indicates the distance from the bay heads along the median lines of the bays, and the ordinate shows the observed height of water.

A very remarkable difference is seen in the distribution of water height, that is, the height of water in the 1960 tsunami increases with the distance from the mouth, and vice versa in the 1933 tsunami. The fact that the 1933 tsunami decreases in height as it proceeds to a bay head, has been pointed out by R. TAKAHASHI [5] for Ôfunato Bay, and by Y. OTUKA [6] for may other bays lying along the Sanriku Coast.

It is seen from Fig. 7 that, in the 1960 tsunami, the incident wave is amplified 2–3 times at the head. While, it was reported that, in the 1933 tsunami, the height at the head reduced to about 0.6 times the value at the mouth.

This phenomenon is commonly seen in many other bays, and its cause may be sought in the distinct differences in natures of the incident waves of the tsunamis. It is almost probable that the remarkable increase in water height at the head in the 1960 tsunami is a result of a resonance of the bay water induced by the tsunami waves to a considerable extent. The problem of the motion of bay water due to a wave packet incident upon the bay mouth was treated theoretically by the staff of our Institute [7]. As the two bays mentioned above have nothing peculiar about width or depth, it may be admissible that the degree of excitation of seiche is governed by the period and duration of the incident waves and eddy viscosity specifying the degree of turbulent motion of the bay water.

A fact that the Chile Tsunami has a long period (accordingly small eddy viscosity) and composed of several crests and troughs, is very favourable to the strong excitation of the seiche, while the short period and short duration of principal wave packet which characterize the Sanriku Tsunami are the unfavourable elements for the occurrence of seiche.

The decrease of the height of water in the case of the 1933 tsunami is attributed mainly to the turbulent motion of the bay water due to the bottom topography and the complicated shorelines of the bays, the violent turbidity resulting in the decay of height of the waves as they proceed toward the head.

Comparison of the wave heights attained by the tsunami of 1960 with those by the tsunami of 1933 was made in detail by our staffs [8], and the general features about the response of bay to incident waves were found.

5 Some Remarks

Tsunamis of South American origin, if they were strong enough to affect the Pacific Coast of Japan, would have comparatively long period, since shorter period waves are subject to heavier attenuation than longer period ones through their reflection and refraction by islands and reefs. On the other hand, because of very long traveled distance, the waves that traversed the Pacific Ocean are somewhat deformed owing to the dispersive property of the waves through the ocean with layered structure and interference of waves which traveled different paths. However, it seems that bottom topography near the coast and deep submarine trenchs play a more important role in deforming the form of the waves in their approach to the coast; banks of trench and a continental shelf can change the amplitude and period of a tsunami, and, if the condition favours, it is possible for the waves of long period to excite strongly the shelf seiche of relatively large scale. Under these circumstances, it may be expected that waves invading into the bay take a form of wave packet with several crests and troughs as recorded at Enoshima. This situation is particularly important in studying distant tsunamis, as well as in planning defense works against tsunamis.

Acknowledgement: We thank gratefully all those persons in the visited districts for their assistance in collecting data. We also acknowledge the financial aid of the Ministry of Education.

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				h m				
1	1	Shikawame	June, 9	15.08	3.06	3.4	A	Hachinohe
1	2	〃	〃	14.45	3.15	3.5	A	〃
1	3	〃	〃	14.25	3.05	3.3	A	〃
2	1	Hachinohe(Mutsu minato)	〃	07.45	3.94	3.4	A	〃
2	2	〃	〃	07.06	4.73	4.3	B	〃
2	3	〃	〃	07.25	4.64	4.2	A	〃
2	4	Minatomachi Shirogane	June, 8	20.17	4.60	4.6	A	〃
2	5	Same	〃	19.30	3.82	3.9	A	〃
2	6	〃	〃	19.10	3.65	3.7	A	〃
2	7	〃	〃	18.42	4.08	4.2	A	〃
2	8	〃	〃	18.35	4.28	4.4	A	〃
2	9	Shirahama	〃	17.38	4.39	4.6	A	〃
2	10	〃	〃	17.50	4.52	4.7	A	〃
2	11	Tanesashi	〃	17.06	3.83	4.1	A	〃
3	1	Ôhebi	〃	16.10	4.51	4.9	B	〃
3	2	〃	〃	16.04	4.00	4.4	A	〃
3	3	〃 (Arayahama)	〃	15.59	4.15	4.5	A	〃
3	4	(Arayahama)	〃	15.48	4.45	4.8	A	〃
3	5	Kawajiri	〃	14.19	3.78	4.1	C	〃
3	6	〃	〃	14.35	4.06	4.3	B	〃
3	7	Taneichi	〃	15.07	4.70	5.1	B	〃
4	1	Rikuchûyagi	〃	12.20	2.75	2.7	A	〃
4	2	〃	〃	12.07	2.62	2.6	A	〃
4	3	〃	〃	11.44	3.01	2.9	A	〃
4	4	〃	〃	11.34	3.05	2.9	B	〃
4	5	〃	〃	11.30	3.10	2.9	B	〃
5	1	Mugio	〃	09.00	2.73	2.2	A	〃
5	2	〃	〃	09.16	3.32	2.8	B	〃
5	3	〃	〃	09.30	4.08	3.6	C	〃
5	4	〃	〃	09.42	4.08	3.6	C	〃
5	5	Hansaki	June, 7	19.10	3.82	3.9	A	〃
5	6	〃	〃	18.54	3.80	3.8	A	〃
5	7	〃	〃	18.46	3.94	4.0	A	〃
5	8	Kuji	〃	17.28	3.64	3.8	A	〃
5	9	〃	〃	17.40	3.79	3.9	A	〃
5	10	Tamanowaki	〃	16.26	3.65	4.0	A	〃
5	11	Funato	〃	16.10	3.65	4.1	B	〃
5	12	Ôjiri	〃	15.32	4.05	4.4	B	〃
6	1	Kosode	〃	15.08	2.70	3.1	B	〃
6	2	Kuki	〃	10.10	4.21	4.0	A	〃
6	3	〃	〃	10.17	4.65	4.4	A	〃
6	4	Nodaminato	〃	10.55	4.97	4.9	A	〃
6	5	〃	〃	11.05	5.27	5.2	A	〃
6	6	Maeda	〃	12.05	4.82	4.9	A	〃
6	7	Tamagawa	〃	08.15	6.33	5.9	A	〃
6	8	〃	〃	08.26	6.37	5.9	A	〃
6	9	Akkagawa	〃	07.30	3.18	2.7	A	〃
6	10	〃	〃	07.00	3.18	2.8	A	〃
6	11	〃	〃	07.12	3.12	2.7	A	〃
6	12	Ôtanabe	June, 6	17.15	2.40	2.5	A	Miyako
7	1	Hiraiga	〃	14.40	2.47	2.8	B	〃
7	2	Shimanokoshi	〃	14.10	1.80	2.1	A	〃
7	3	Sukudo	〃	08.13	1.55	1.3	A	〃
7	4	Omoto	〃	09.30	2.89	2.8	A	〃
7	5	〃	〃	09.10	2.80	2.6	A	〃
8	1	Settai	〃	07.10	2.80	2.5	B	〃
8	2	〃	〃	07.20	2.95	2.6	A	〃
8	3	Aonotaki	June, 5	17.36	2.45	2.4	A	〃
8	4	Kominato	〃	16.13	2.20	2.3	A	〃
8	5	〃	〃	15.55	2.44	2.5	A	〃
8	6	Tarô	〃	14.40	1.67	1.8	A	〃
8	7	〃	〃	14.45	1.62	1.8	A	〃

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				h m				
8	8	Kashinai	June, 5	11.55	2.53	2.8	B	Miyako
8	9	Nakanohama	〃	07.38	2.95	2.8	B	〃
8	10	Hidejima	〃	09.10	2.33	2.4	A	〃
9	1	Miyakowan	June, 4	10.55	2.20	2.4	A	〃
9	2	〃	〃	10.30	1.62	1.8	A	〃
9	3	〃	〃	10.30	1.95	2.2	A	〃
9	4	〃	〃	10.23	2.18	2.2	A	〃
9	5	〃	〃	10.10	2.03	2.1	A	〃
9	6	〃	〃	09.50	1.76	1.9	A	〃
9	7	Hujiwara	〃	18.45	4.18	4.2	A	〃
9	8	Takahama	〃	19.15	4.20	4.3	A	〃
9	9	Kanahama	〃	19.30	4.76	4.9	A	〃
9	10	Norinowaki	〃	20.00	4.75	4.9	A	〃
9	11	Horiuchi	〃	13.10	4.90	5.0	A	〃
9	12	〃	〃	12.50	5.09	5.2	A	〃
9	31	Ôtanohama	〃	12.34	3.10	3.2	A	〃
9	14	Shirahama	〃	12.11	2.90	3.1	A	〃
9	15	〃	〃	12.02	2.96	3.1	A	〃
10	1	Uranosawa	〃	17.40	1.68	1.6	A	〃
10	2	Sainokami	〃	16.28	2.18	2.1	B	〃
10	3	Uiso	〃	15.54	2.62	2.5	B	〃
10	4	Aramaki	〃	14.42	2.63	2.6	A	〃
10	5	Otobe	〃	14.30	2.07	2.0	B	〃
10	6	〃	〃	14.20	2.48	2.5	A	〃
11	1	Funakoshi	May, 28	07.33	2.75	2.6	B	〃
11	2	〃	〃	08.00	3.90	3.8	B	〃
11	3	〃	〃	08.10	3.70	3.6	B	〃
11	4	Ôtsuchi	May, 27	07.30	3.40	3.5	B	〃
11	5	〃	〃	08.10	3.65	3.6	A	〃
12	1	Kamaishi	〃	31.55	2.20	2.1	A	〃
13	1	Yoshihama	〃	31.55	4.30	4.1	A	〃
13	2	Okirai	〃	12.10	4.40	3.9	A	〃
13	3	Ryoriwan Shirahama	June, 5	07.26	4.1	4.0	B	〃
13	4	〃	〃	07.58	2.2	2.1	B	〃
13	5	Ryori	June, 4	17.45	2.7	2.7	B	〃
13	6	〃	〃	17.23	2.9	3.0	B	〃
13	7	〃	〃	17.05	2.3	2.3	B	〃
13	8	〃	〃	18.03	3.0	3.0	B	〃
13	9	Attari	〃	15.30	1.7	1.7	B	〃
13	10	Nagasaki	〃	14.20	1.6	1.7	B	〃
13	11	〃	〃	13.50	1.8	1.9	B	〃
14	1	Osakimisaki	〃	13.32	2.5	2.8	A	〃
14	2	Shimotakonoura	〃	11.00	2.5	2.8	A	〃
14	3	Kamitakonoura	June, 5	10.24	2.65	2.9	A	〃
14	4	〃	〃	10.34	2.76	3.0	A	〃
14	5	〃	〃	10.39	2.41	2.7	A	〃
14	6	〃	〃	10.56	2.60	2.9	A	〃
14	7	Shimizu	〃	11.04	2.50	2.8	A	〃
14	8	〃	〃	11.12	2.65	3.0	A	〃
14	9	〃	〃	11.18	2.68	3.0	A	〃
14	10	Koura	〃	12.00	2.58	2.9	A	〃
14	11	〃	〃	12.24	2.60	3.0	A	〃
14	12	Nagahama	〃	12.48	3.40	3.7	A	〃
14	13	〃	〃	13.03	2.75	3.1	A	〃
14	14	〃	〃	31.13	2.90	3.2	A	〃
14	15	〃	〃	13.26	2.50	2.8	A	〃
14	16	〃	〃	31.38	2.95	3.2	A	〃
14	17	Bentenmisaki	〃	31.57	3.80	4.1	A	〃
14	18	〃	〃	14.07	3.00	3.3	A	〃
14	19	〃	〃	14.18	3.20	3.5	A	〃
14	20	Bentenmisaki	〃	14.27	3.85	4.1	A	〃
14	21	〃	〃	14.40	3.96	4.2	A	〃
14	22	Yamaguchi	〃	15.10	4.25	4.3	A	〃

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				h m				
14	23	Ikugata	June, 5	15.30	4.30	4.5	A	Miyako
14	24	〃	〃	15.36	4.42	4.6	A	〃
14	25	〃	〃	15.57	4.70	4.5	A	〃
14	26-27	Shuku				4.9-5.2	A	〃
14	28	〃				3.2	A	〃
14	29	Reclaimed land of Sakari River	〃	16.46	4.10	4.2	A	〃
14	30	Ôfunato	June, 6	05.42	3.10	2.9	A	〃
14	31	〃	〃	05.50	3.70	3.5	A	〃
14	32	〃	〃	06.04	2.90	2.7	A	〃
14	33	〃	〃	06.10	3.40	3.2	A	〃
14	34	〃	June, 5	12.00	4.70	5.1	A	〃
14	35	〃	〃	06.19	4.50	4.3	A	〃
14	36	〃	〃	06.29	3.60	3.4	A	〃
14	37	〃	〃	11.10	4.2	4.6	B	〃
14	38	〃	〃	06.36	3.76	3.5	A	〃
14	39	〃	〃	06.42	3.65	3.4	A	〃
14	40	〃	〃	08.25	4.75	4.5	A	〃
14	41	〃	〃	08.33	3.75	3.5	A	〃
14	42	〃	〃	08.40	4.10	3.9	A	〃
14	43	〃	〃	08.50	3.50	3.3	A	〃
14	44	〃	〃	09.08	4.20	4.0	A	〃
14	45	〃	〃	09.16	4.30	4.2	A	〃
14	46	〃	〃	09.18	4.15	4.1	A	〃
14	47	〃	〃	09.25	3.45	3.3	A	〃
14	48	〃	〃	09.30	3.80	3.7	A	〃
14	49	〃	〃	09.35	4.05	4.0	A	〃
14	50	〃	〃	09.45	3.95	3.9	A	〃
14	51	Ôfunato	〃	09.49	3.80	3.7	A	〃
14	52	〃	June, 6	10.00	3.90	3.9	A	〃
14	53	〃	〃	10.25	3.85	3.9	A	〃
14	54	〃	〃	10.36	3.75	3.8	A	〃
14	55	〃	〃	10.48	2.71	2.8	A	〃
14	56	〃	〃	10.58	2.50	2.7	A	〃
14	57	〃	〃	11.12	2.40	2.6	A	〃
14	58	〃	〃	11.29	2.40	2.6	A	〃
14	59	〃	〃	11.40	2.25	2.6	A	〃
14	60	Ishihama	June, 5	08.35	4.7	5.0	A	〃
14	61	Hosoura	〃	12.53	2.15	2.6	A	〃
14	62	〃	〃	13.10	2.30	2.7	A	〃
14	63	〃	June, 4	14.30	2.60	2.6	A	〃
14	64	〃	〃	14.20	2.9	3.2	A	〃
14	65	Hamasuna	〃	10.20	4.4	5.3	A	〃
14	66	Wakinosawa	〃	09.45	5.1	5.4	A	〃
14	67	〃	〃	09.30	4.8	5.0	A	〃
15	1	Goishimisaki	June, 5	15.25	2.6	2.8	B	Ayukawa
15	2	Tomari	〃	15.00	3.2	3.4	A	〃
15	3	〃	〃	14.55	2.5	2.7	A	〃
15	4	Nishidate	〃	14.25	4.0	4.2	A	〃
15	5	Kadonohama	〃	14.00	4.1	4.4	A	〃
15	6	〃	〃	13.45	4.5	4.8	A	〃
15	7	〃	〃	13.35	4.4	4.7	B	〃
15	8	Tadaide	〃	16.30	3.6	3.7	A	〃
15	9	Ôno	June, 6	08.10	5.3	5.0	A	〃
15	10	Atsumari	〃	09.00	3.2	3.2	B	〃
15	11	〃	〃	09.30	2.7	2.6	A	〃
15	12	〃	〃	09.35	2.6	2.5	B	〃
15	31	Kubo	〃	09.50	3.0	2.9	A	〃
15	14	Tomariwan	〃	10.15	3.3	3.3	A	〃
15	15	〃	〃	10.25	2.5	2.5	B	〃
15	16	Taiyô	〃	11.00	3.3	3.4	A	〃
15	17	〃	〃	10.55	3.2	3.3	A	〃
15	18	Usozawa	〃	11.15	4.7	4.9	A	〃
15	19	Yanoura	〃	11.40	5.2	5.5	A	〃

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				h m				
15	20	Yanoura	June, 6	11.45	5.0	5.3	A	Ayukawa
15	21	〃	〃	11.50	5.3	5.6	A	〃
15	22	Torishima	〃	12.10	5.6	5.9	A	〃
15	23	Shioya	〃	12.15	5.9	6.2	A	〃
15	24	〃	〃	12.25	5.7	6.1	A	〃
15	25	Mikkaichi	June, 4	11.05	6.1	6.4	A	〃
15	26	Ryôgae	〃	10.50	4.6	4.9	A	〃
15	27	〃	June, 5	17.30	5.7	5.7	A	〃
15	28	〃	June, 4	10.30	5.1	5.4	A	〃
15	29	Futsukaichi	June, 3	12.50	4.6	4.6	A	〃
15	30	Osabe	〃	13.10	5.2	5.2	A	〃
15	31	Fukubushi	〃	14.00	4.5	4.4	A	〃
15	32	Ôsawa	〃	15.05	4.7	4.5	A	〃
15	33	〃	〃	15.00	4.5	4.3	A	〃
15	34	Tadakoshi	〃	16.15	4.7	4.6	B	〃
15	35	Takaishihama	〃	17.09	2.20	2.2	B	〃
15	36	〃	〃	16.15	2.10	2.1	B	〃
15	37	Ishihama	〃	15.36	2.10	2.0	B	〃
15	38	Baba	〃	14.25	2.65	2.5	B	〃
15	39	Syôhokaigan	〃	12.38	3.70	3.8	C	〃
15	40	〃	〃	11.40	1.05	1.3	C	〃
15	41	Misakimisaki	〃	09.55	1.00	1.3	C	〃
15	42	Kesennuma	May, 25	13.30	2.00	2.3	C	〃
15	43	〃	〃	14.40	2.20	1.7	C	〃
16	1	Shizugawa	May, 31	14.26	4.3	4.0	A	〃
17	1	Shizugawa Oritate	〃	14.06	4.0	3.6	C	〃
18	1	Koyatori	May, 29	12.50	3.25	2.7	A	〃
18	2	〃	〃	12.22	3.89	3.3	A	〃
18	3	Yoriisonatsuhama	〃	11.18	3.74	3.2	B	〃
18	4	Yoriiso	〃	11.45	3.92	3.4	B	〃
18	5	Tomari	June, 3	14.45	1.9	1.8	A	〃
18	6	〃	〃	15.27	2.3	2.1	A	〃
18	7	Between Tomari and Shin yamahama	〃	17.08	2.2	2.2	A	〃
18	8	〃	〃	17.16	1.9	1.9	A	〃
19	1	Oura	May, 28	19.20	2.49	3.0	A	〃
19	2	〃	〃	19.33	1.94	2.5	B	〃
19	3	〃	〃	19.10	2.10	2.6	A	〃
19	4	〃	〃	18.53	2.41	2.9	A	〃
19	5	Takenoura	〃	18.20	2.64	3.1	B	〃
19	6	〃	〃	18.05	3.03	3.5	A	〃
19	7	〃	〃	17.57	2.85	3.3	A	〃
19	8	〃	〃	17.43	2.82	3.3	A	〃
19	9	Kirigasaki	〃	17.20	2.95	3.4	A	〃
19	10	〃	〃	17.12	3.11	3.5	B	〃
19	11	Koshirahama	〃	16.50	3.33	3.7	A	〃
19	12	〃	〃	16.44	3.37	3.8	A	〃
19	13	Onagawamachi	〃	16.10	3.33	3.6	A	〃
19	14	〃	〃	15.51	3.77	4.0	A	〃
19	15	〃	〃	15.40	3.36	3.6	A	〃
19	16	〃	〃	15.40	3.36	4.0	A	〃
19	17	〃	〃	15.40	3.36	3.8	A	〃
19	18	〃	〃	15.40	3.36	3.9	A	〃
19	19	〃	〃	15.40	3.36	4.0	A	〃
19	20	〃	〃	15.40	3.36	4.2	A	〃
19	21	Onagawa	〃	〃	〃	3.9	A	〃
19	22	〃	〃	〃	〃	4.0	A	〃
19	23	〃	〃	〃	〃	3.5	A	〃
19	24	〃	〃	〃	〃	3.8	A	〃
19	25	〃	〃	〃	〃	3.8	A	〃
19	26	〃	〃	〃	〃	3.9	A	〃
19	27	〃	〃	〃	〃	4.2	A	〃

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				m h				
19	28	Onagawa	May,28	15.40	3.36	4.0	A	Ayukawa
19	29	〃	〃	〃	〃	3.8	A	〃
19	30	〃	〃	〃	〃	3.7	A	〃
19	31	〃	〃	〃	〃	3.7	A	〃
19	32	〃	〃	〃	〃	3.6	A	〃
19	33	〃	〃	〃	〃	3.9	A	〃
19	34	〃	〃	〃	〃		A	〃
19	35	〃	〃	〃	〃	4.3	A	〃
19	36	〃	〃	10.45	4.08	3.6	A	〃
19	37	Takashiro	〃	17.10	3.24	3.6	A	〃
19	38	Yokoura	〃	15.58	3.75	3.8	A	〃
19	39	Ôishihara	〃	15.40	3.95	3.9	A	〃
19	40	Nonohama	〃	15.25	4.15	4.1	A	〃
19	41	〃	〃	15.19	4.33	4.2	A	〃
19	42	〃	〃	15.10	4.06	3.9	A	〃
19	43	Iinokohama	〃	14.51	3.89	3.7	A	〃
19	44	〃	〃	14.45	3.69	3.5	A	〃
19	45	Tsukahama	〃	13.45	3.78	3.4	A	〃
19	46	〃	〃	13.17	4.07	3.6	A	〃
19	47	〃	〃	13.38	4.38	3.9	A	〃
19	48	Samenoura	June, 4	08.01	4.9	5.0	A	〃
19	49	〃	〃	08.27	4.6	4.8	A	〃
19	50	〃	〃	08.57	4.6	4.8	A	〃
19	51	〃	〃	08.57	4.5	4.7	A	〃
19	52	〃	〃	09.11	4.1	4.3	A	〃
19	53	〃	〃	09.11	4.0	4.2	A	〃
19	54	〃	〃	09.35	4.3	4.5	A	〃
19	55	Ôyagawa	〃	10.18	4.9	5.2	A	〃
19	56	〃	〃	10.50	4.6	4.9	A	〃
19	57	〃	〃	10.37	5.2	5.5	C	〃
19	58	Yagawa	〃	13.16	4.4	4.6	C	〃
19	59	〃	〃	13.34	3.7	3.9	C	〃
19	60	〃	〃	13.34	4.2	4.4	A	〃
19	61	Iwainohama	〃	14.13	3.4	3.5	C	〃
19	62	Kagenohama	〃	14.43	3.5	3.5	A	〃
19	63	〃	〃	14.53	3.2	3.2	A	〃
19	64	Shimizuda	〃	11.22	3.9	3.3	A	〃
19	65	Koamikura	〃	11.40	3.2	3.6	A	〃
19	66	Oginohama	〃	13.03	3.8	4.5	C	〃
19	67	〃	〃	12.35	5.0	4.6	A	〃
19	68	Momonoura	〃	14.05	4.	4.8	A	〃
19	69	〃	〃	14.25	4.5	4.5	A	〃
19	70	Hamagurihama	〃	17.49	4.3	4.4	A	〃
19	71	〃	〃	16.52	4.3	4.4	A	〃
19	72	〃	〃	16.38	4.8	5.0	A	〃
19	73	Orinohama	〃	15.53	4.0	4.3	A	〃
19	74	Between Orinohama and Kotake	〃	14.00	3.1	3.5	A	〃
19	75	Kotake	〃	13.09	2.6	3.0	A	〃
19	76	〃	〃	13.09	2.5	2.9	A	〃
19	77	Ozaki	〃	11.32	3.1	3.3	A	〃
19	78	Between Ozaki and Sasuhama	〃	11.15	3.3	3.4	A	〃
19	79	〃	〃	11.15	3.1	3.2	A	〃
19	80	〃	〃	10.50	2.6	2.7	A	〃
19	81	Sasuhama	June, 6	10.15	3.3	3.3	A	Ayukawa
19	82	〃	〃	10.15	3.0	3.0	A	〃
19	83	〃	〃	10.15	3.3	3.3	A	〃
19	84	Between Iwaide and Sasuhama	〃	09.43	2.7	2.6	A	〃
19	85	Watanoha	May,11	09.30	3.3	2.7	A	〃
19	86	〃	May,28	15.45	2.0	2.2	A	〃
19	87	〃	〃	15.40	1.8	2.0	A	〃

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				h m				
19	88	Mankokuura Iwaide	May,28	15.25	2.0	2.2	C	Ayukawa
19	89	Mankokuura Urayado	〃	10.35	0.8	0.1	C	〃
19	90	Mankokuura Anjyu	〃	11.58	1.4-1.2	0.7-0.5	C	〃
19	91	Mankokuura Tomanoura	〃	12.28	〈1.2	〈0.6	C	〃
19	92	Mankokuura Oritate	〃	11.20	1.2	0.5	C	〃
19	93	Mankokuura Sawada	June,11	12.55	1.4	0.9	C	〃
19	94	〃	〃	13.02	1.5	1.1	C	〃
19	95	〃	〃	13.13	1.2	0.8	C	〃
19	96	Ishinomaki	May,27	08.43	2.4	2.2	A	〃
19	97	〃	〃	08.37	2.2	2.0	A	〃
20	1	Yamadori	June, 5	12.12	1.9	2.2	C	〃
20	2	Between Ayukawa and Yamadori	〃	09.52	1.7	1.9	A	〃
20	3	〃	〃	09.54	1.8	2.0	A	〃
20	4	Ayukawa	May,27	11.12	2.1	1.5	A	〃
20	5	Kinkasanmisaki	June, 2	15.37	2.8	2.6	A	〃
20	6	Between Kinkasan and Sasuhama	〃	14.56	2.4-2.8	2.2-2.6	A	〃
20	7	Between Kinkasan and Sunahama	〃	13.33	2.3	2.0	A	〃
20	8	Kinkasan Harbour	June, 3	12.45	2.3	2.3	A	〃
20	9	Kinkasan Wharf	〃	12.40	2.1	2.1	A	〃
20	10	Kinkasan Niôsaki	〃	10.53	2.6	2.8	A	〃
21	1	Kugunarihama	May,28	07.30	3.1	3.4	A	〃
21	2	〃	〃	08.00	3.6	3.6	A	〃
21	3	〃	〃	08.30	3.8	3.7	A	〃
21	4	Kobuchi	〃	09.00	3.3	2.9	A	〃
21	5	〃	〃	09.25	3.2	2.9	A	〃
21	6	Kyûfuhama	〃	10.05	3.9	3.4	A	〃
21	7	Ôhara	〃	10.30	3.1	2.5	A	〃
21	8	Ajishima Fusawatashi	May,27	12.48	2.2	1.8	C	〃
21	9	Ajishimaaji	〃		2.3	2.5	A	〃
21	10	〃	〃	13.50	2.59	2.7	A	〃
21	11	〃	〃	16.00	2.3	2.7	A	〃
21	12	Ajishima Ikenohama	〃	14.32	2.3	2.3	A	〃
22	1	Nobiru				1.7		〃
22	2	Matsushima	May,26	17.50	0.84	1.4	A	〃
22	3	Hamada	〃	17.10	0.65	1.2	A	〃
23	1	Shiogama	May,25	13.25	2.70	2.7	A	〃
23	2	〃	〃			2.4		〃
23	3	Yògai				2.2		〃
23	4	Tôgûhama	May,26	14.30	1.60	1.7	B	〃
23	5	Nishihama	〃	13.45	0.80	0.8	B	〃
23	6	Yogasaki	〃	13.30	2.40	2.3	B	〃
23	7	Yogasakihama	〃	13.10	2.95	2.8	A	〃
23	8	〃				3.0		〃
23	9	〃	May,26	12.25	3.25	3.0	C	〃
23	10	Yoshidahama	〃	12.05	3.15	2.7	A	〃
23	11	Hanabuchihama	May,26	11.40	3.70	3.2	A	〃
23	12	〃	May,25	16.35	1.39	1.9	A	〃
23	13	Takayama	〃		2.30	2.8	A	〃

Map Number	Spot Number	Spot Measured	Date	Time Measured	Observed Height	Reduced Height	Degree of Reliability	Referred Tide Station
				h m				
23	14	Gamô	May, 27	16.00	2.90	2.4	A	Ayukawa
24	1	Yuriage	〃	12.10	1.95	2.4	B	〃
25	1	Arahama		16.35		1.1		
25	2	〃	June, 4	13.10	2.10	2.2	C	Onahama
26	1	Harakama	〃	15.50	2.50	2.4	B	〃
26	2	Ohama	〃	16.10	2.30	2.2	B	〃

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Photo. 1. Photos. 1-5. show the tsunami invading the River Ishinomaki, Miyagi Prefecture. Photographs were taken from Utsumi bridge on the river. Photographs courtesy of Hukuzo Kanomata, Minatomachi, Ishinomaki.

Photo. 2. Estimated height of tsunami is about 2 m.

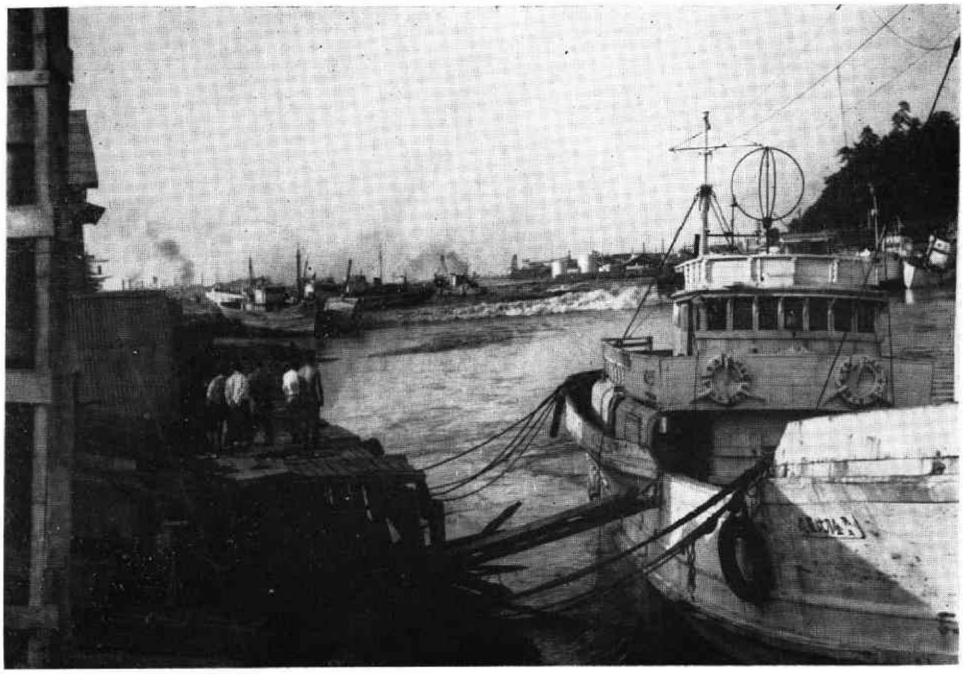


Photo. 3.

Photo. 4.

Photo. 5. Immediately after this moment, the ship in front side of the photograph dashed into the house in the left side, and was smashed.

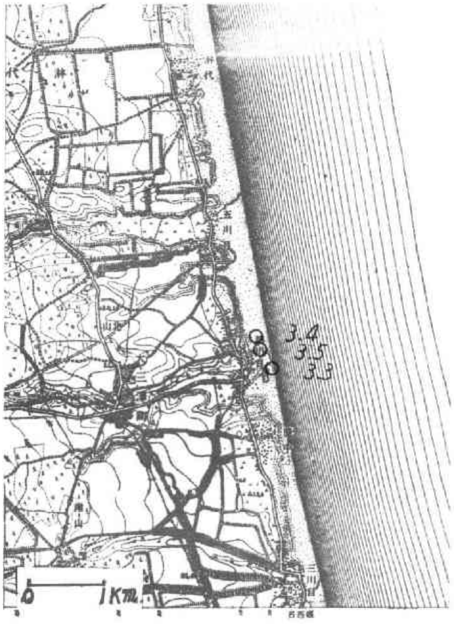
Photo. 6. Photos. 6-9 show the tsunami inundating the open space in front of Onagawa Station, Miyagi Prefecture.

Photo. 7.

Photo. 8. Immediately after this moment water height reached the maximum.

Photo. 9. Tsunami retreated lieving timbers, buoys for oyster-planting rafts, and other debris.

Photo. 10. Water height (about 4 m) is shown by the mark left by tsunami on the wall of Onagawa Station.

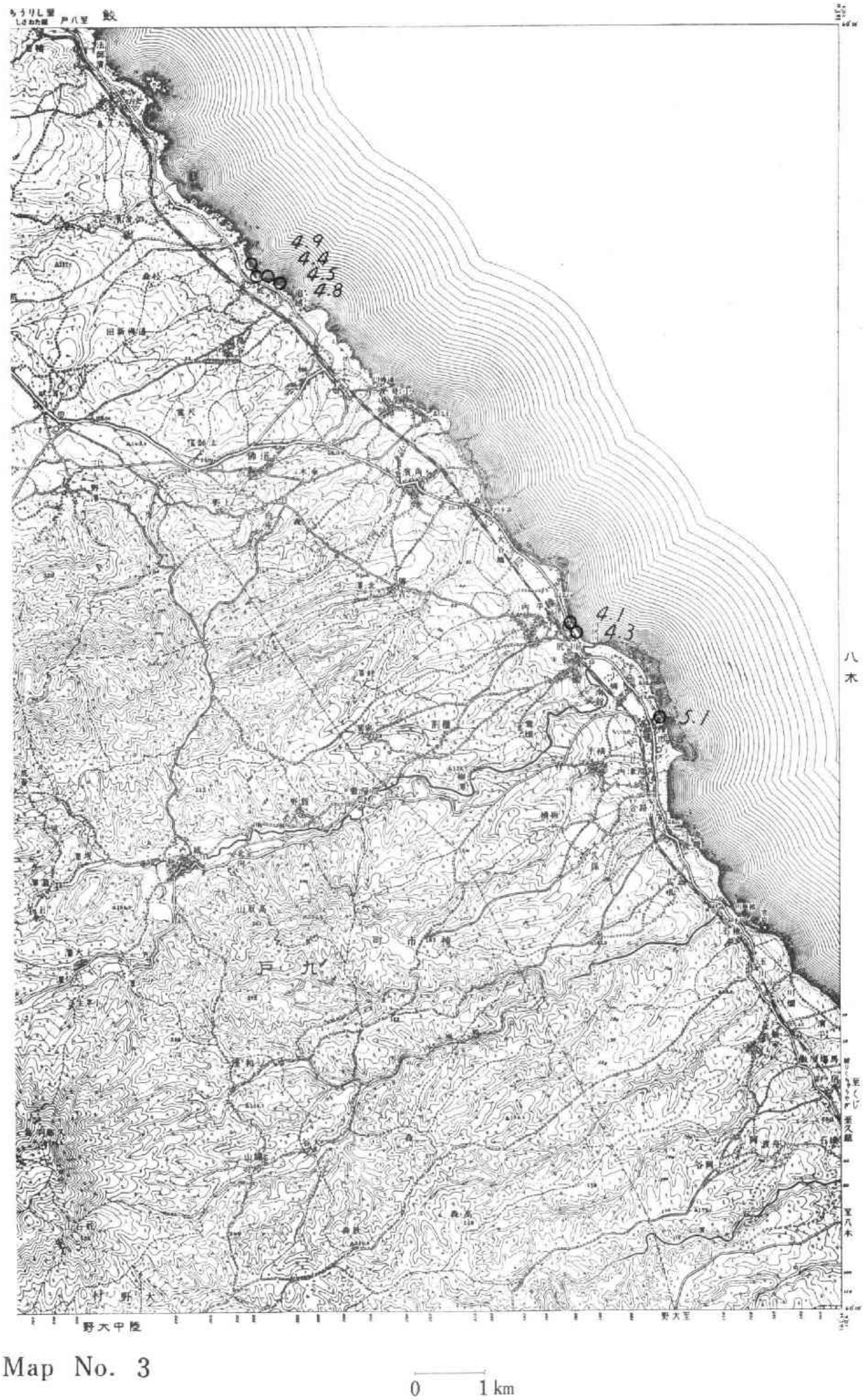


Map No. 1

0 1 km

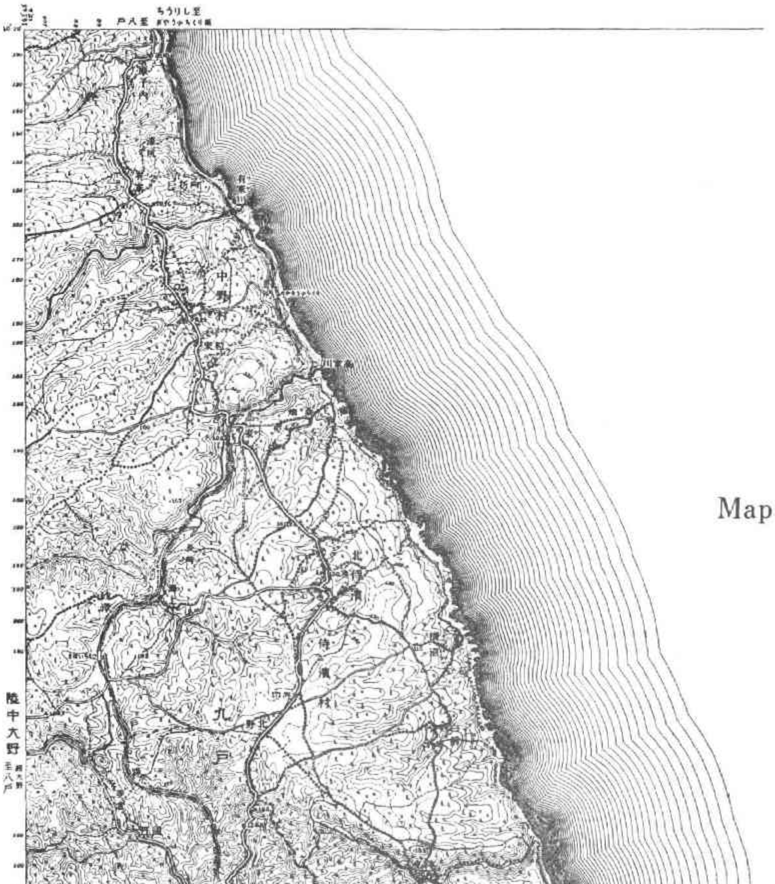
Map No. 2

0 1 km



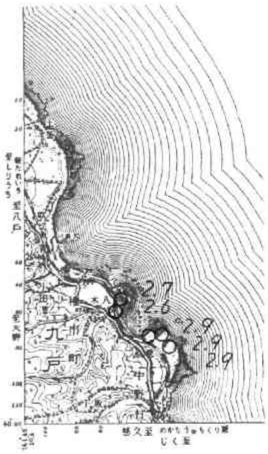
Map No. 3

0 1 km



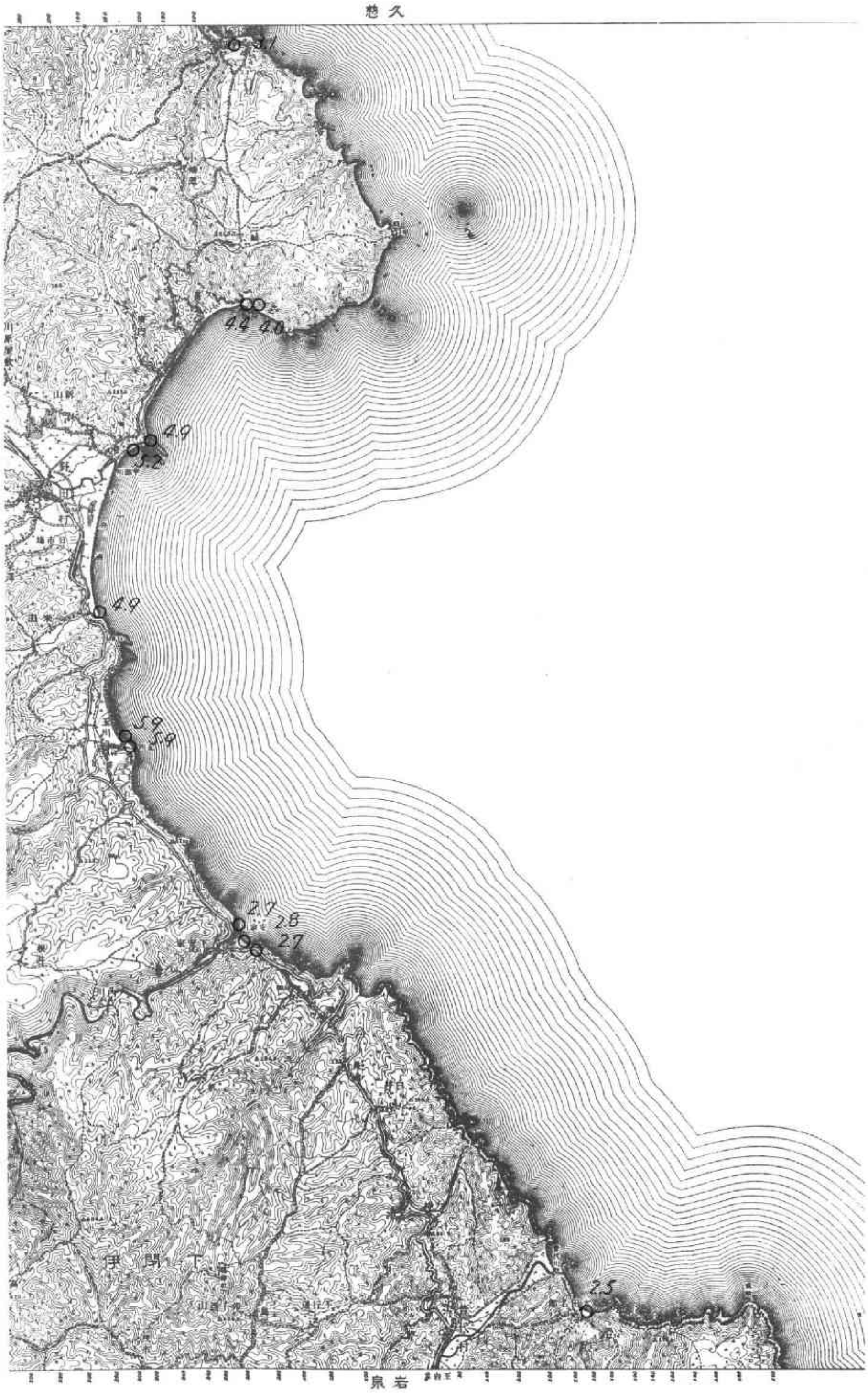
Map No. 5

0 1 km



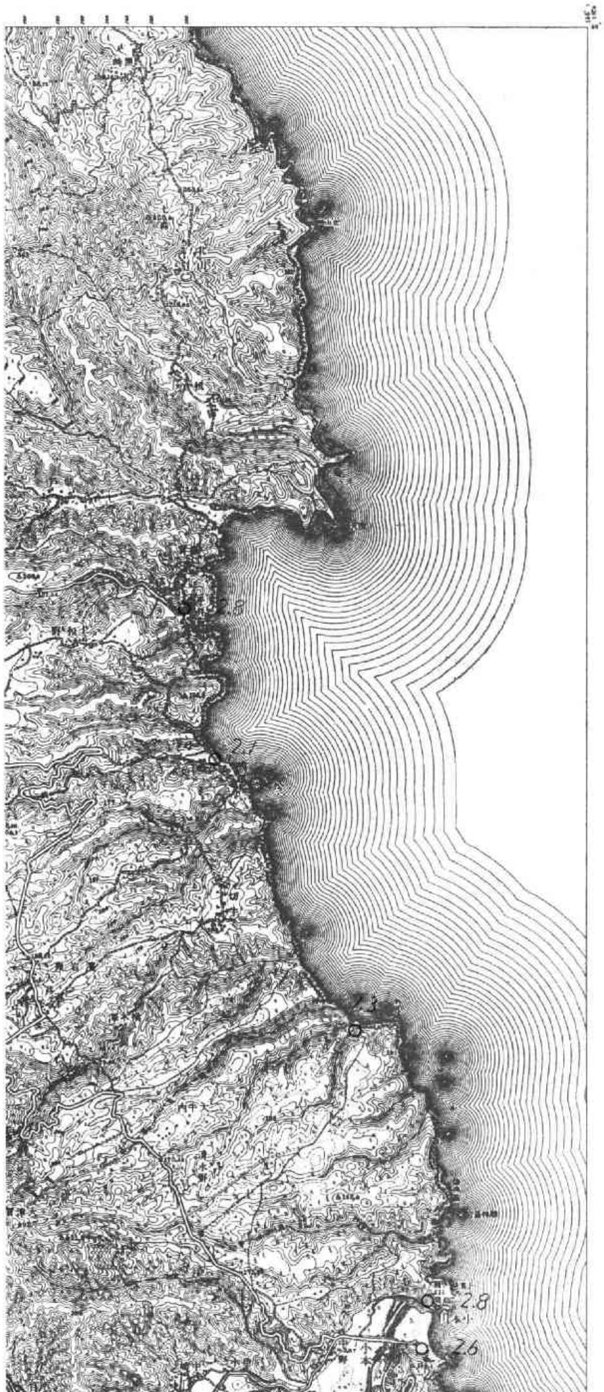
Map No. 4

0 1 km



Map No. 6

0 1 km



Map No. 7

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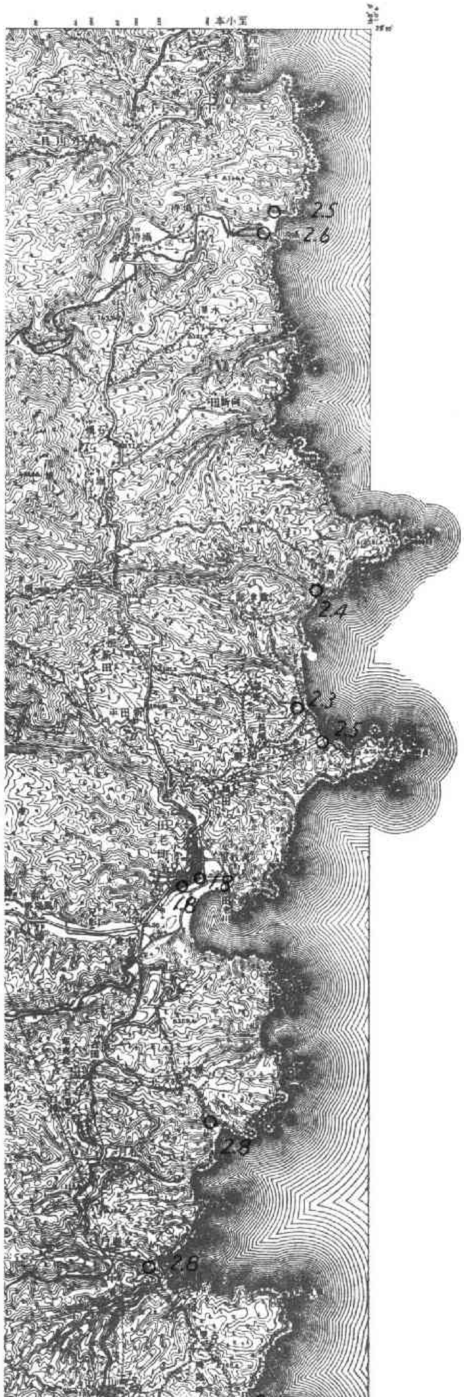

Map No. 8

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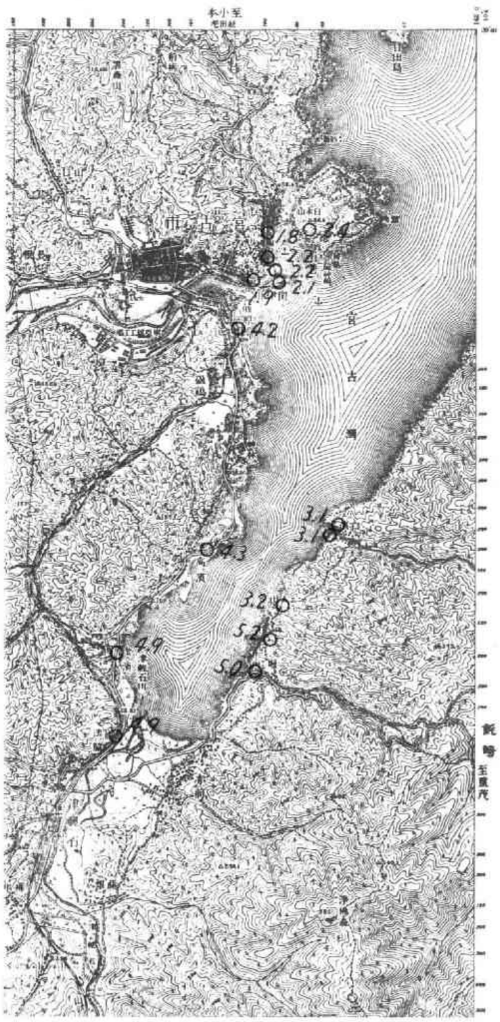

Map No. 9

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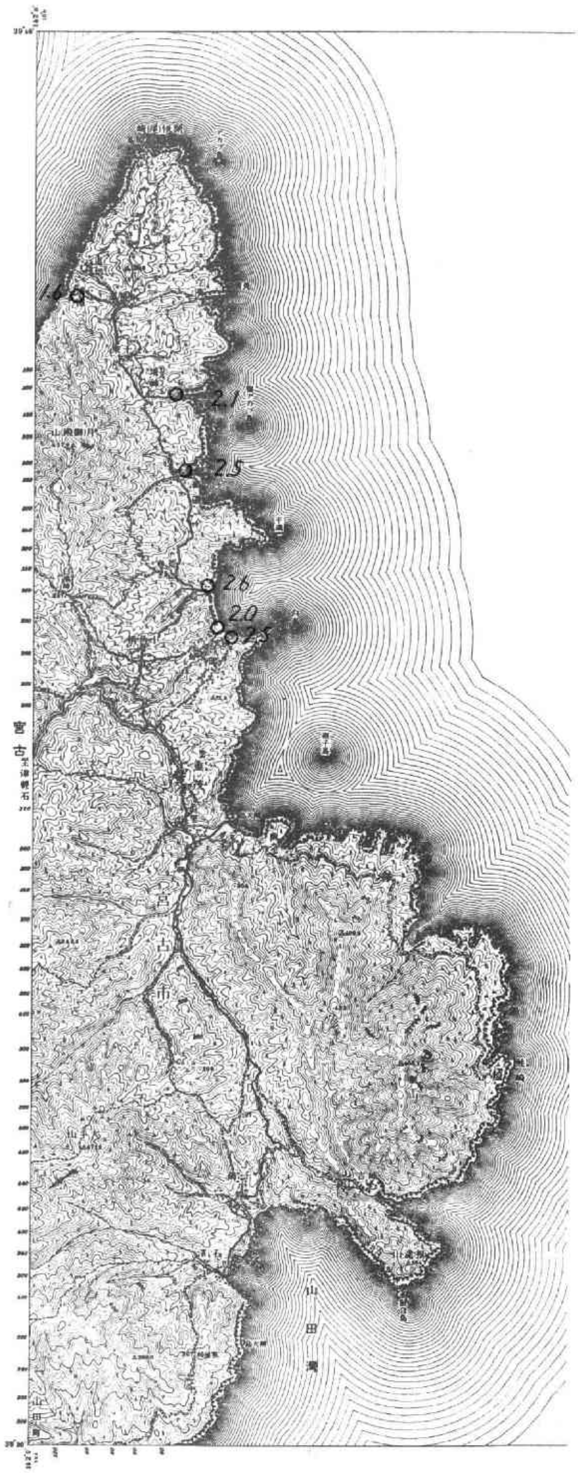

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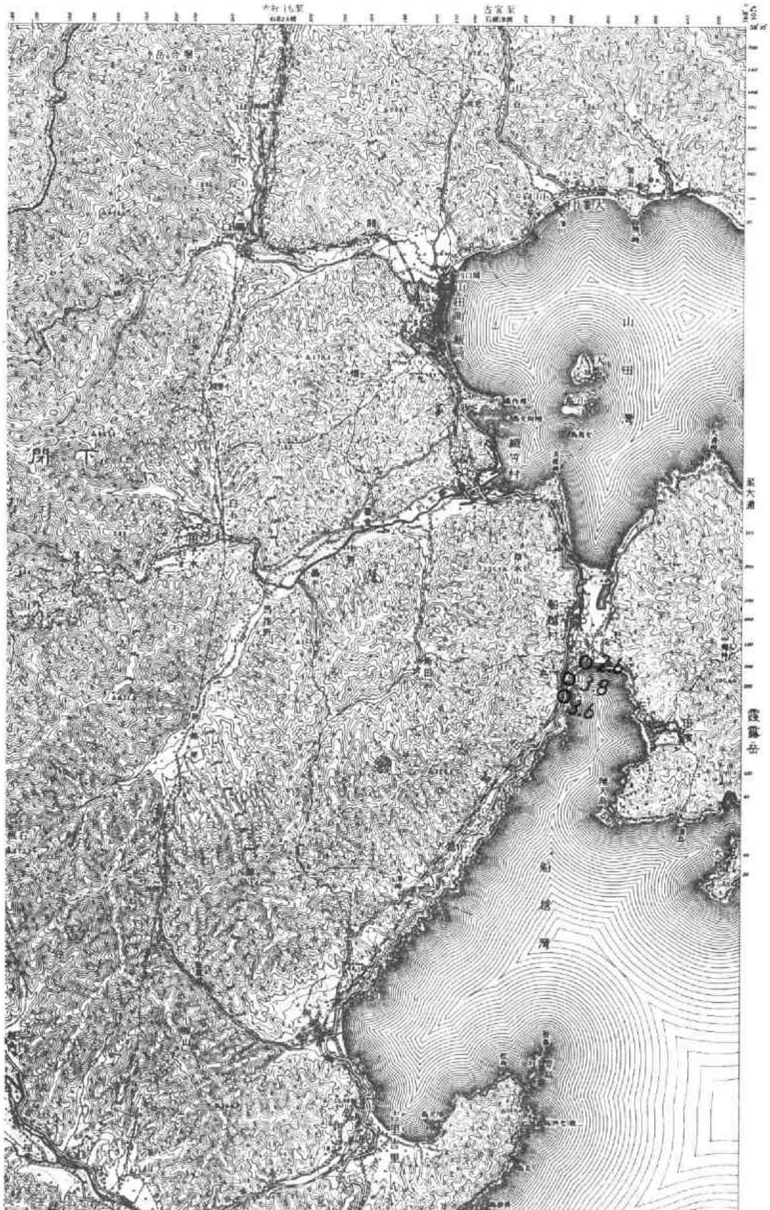

Map No. 11

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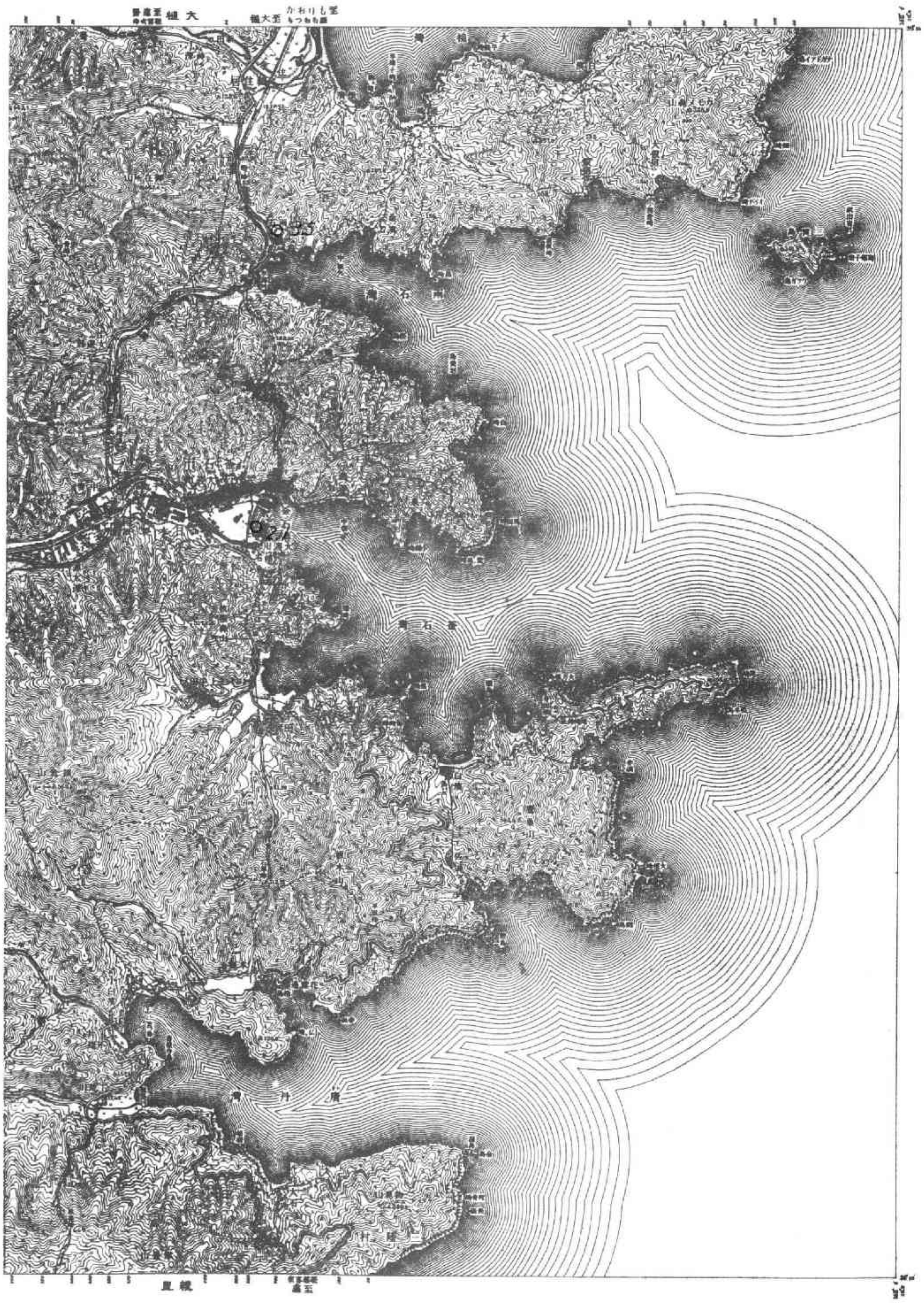
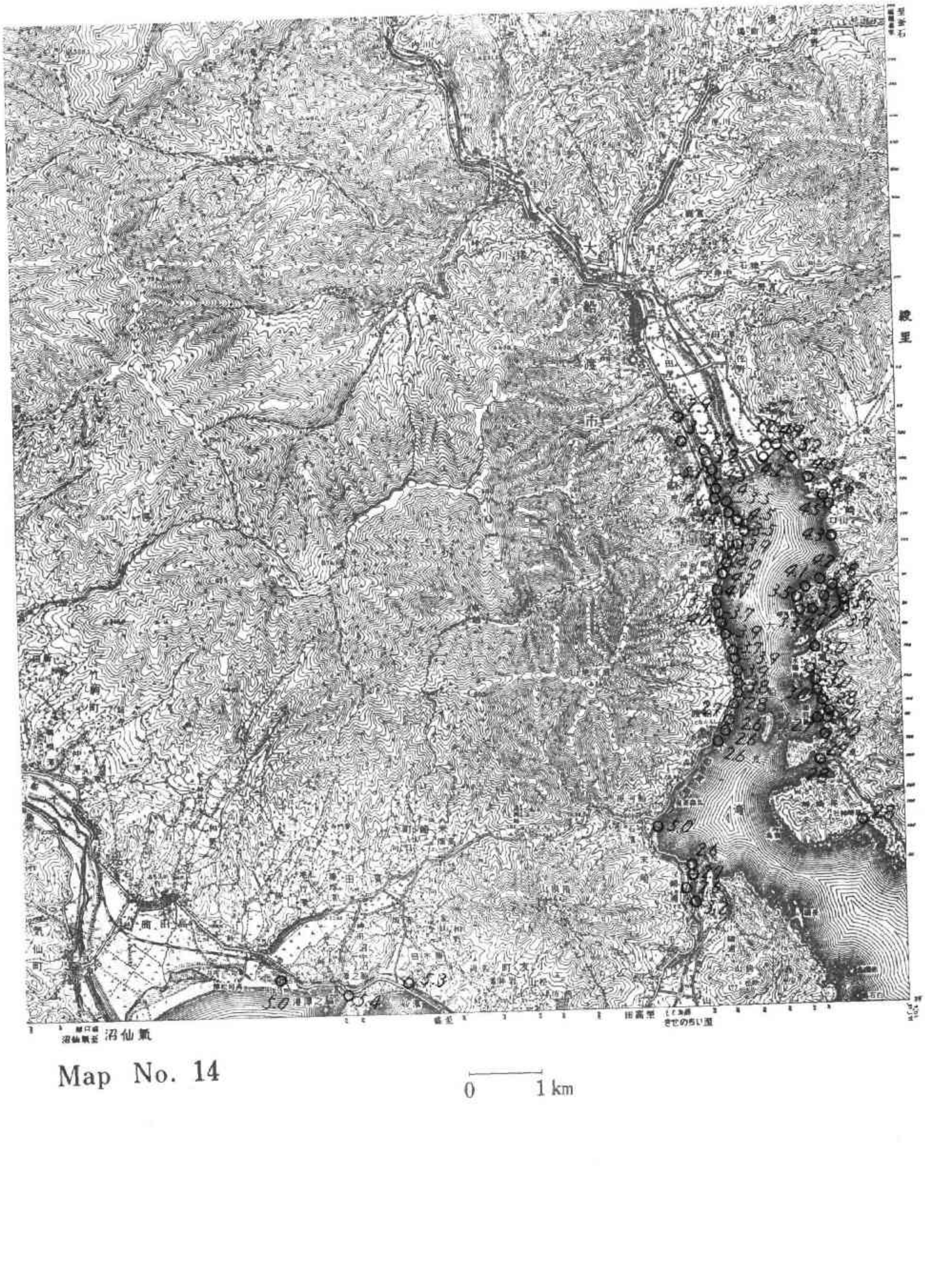


Map No. 12

0 1 km

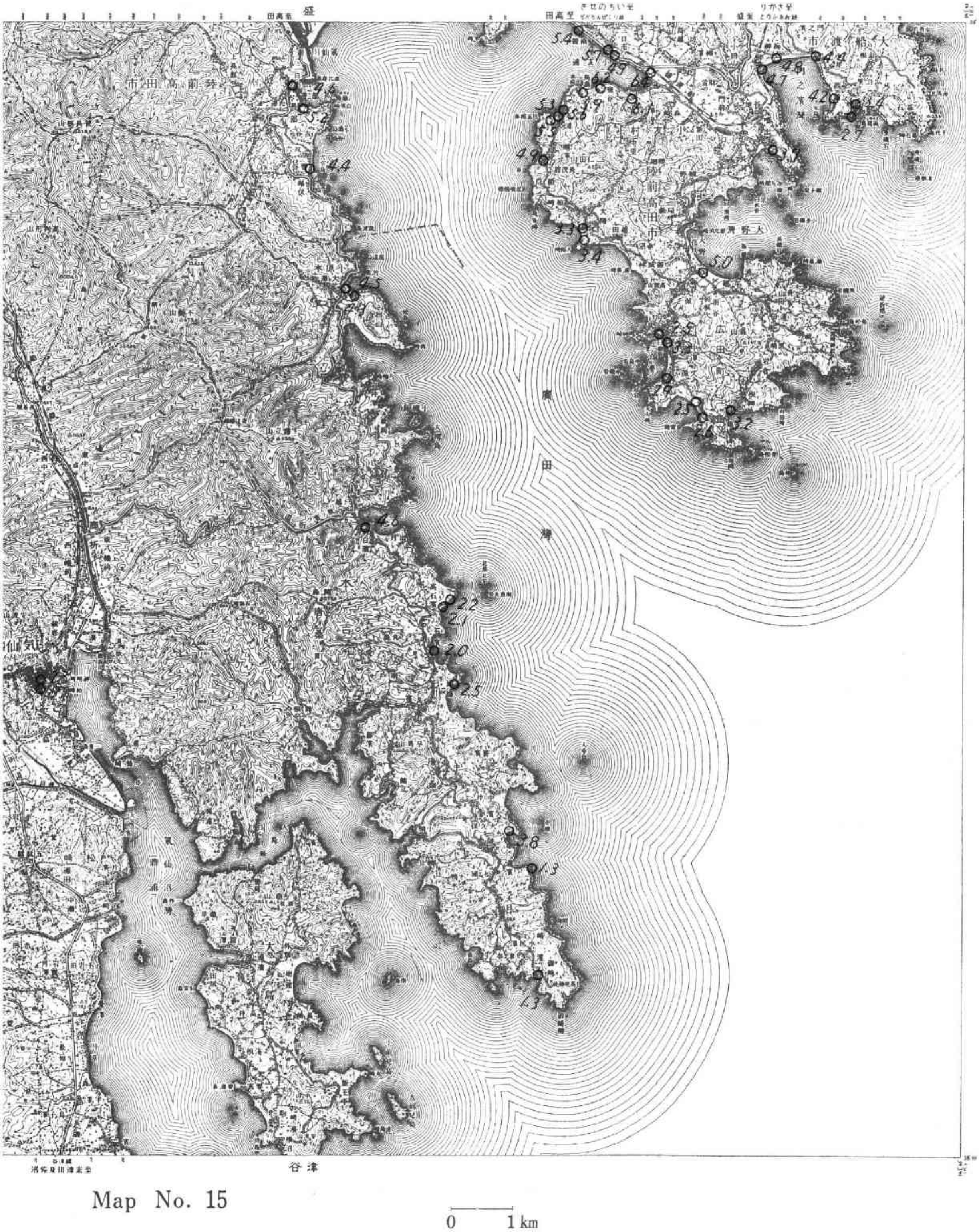
Map No. 13

0 1 km



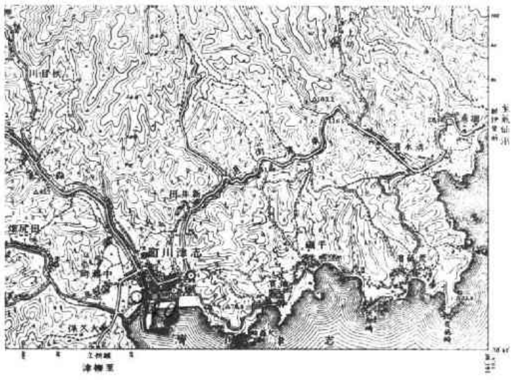
Map No. 14

0 1 km



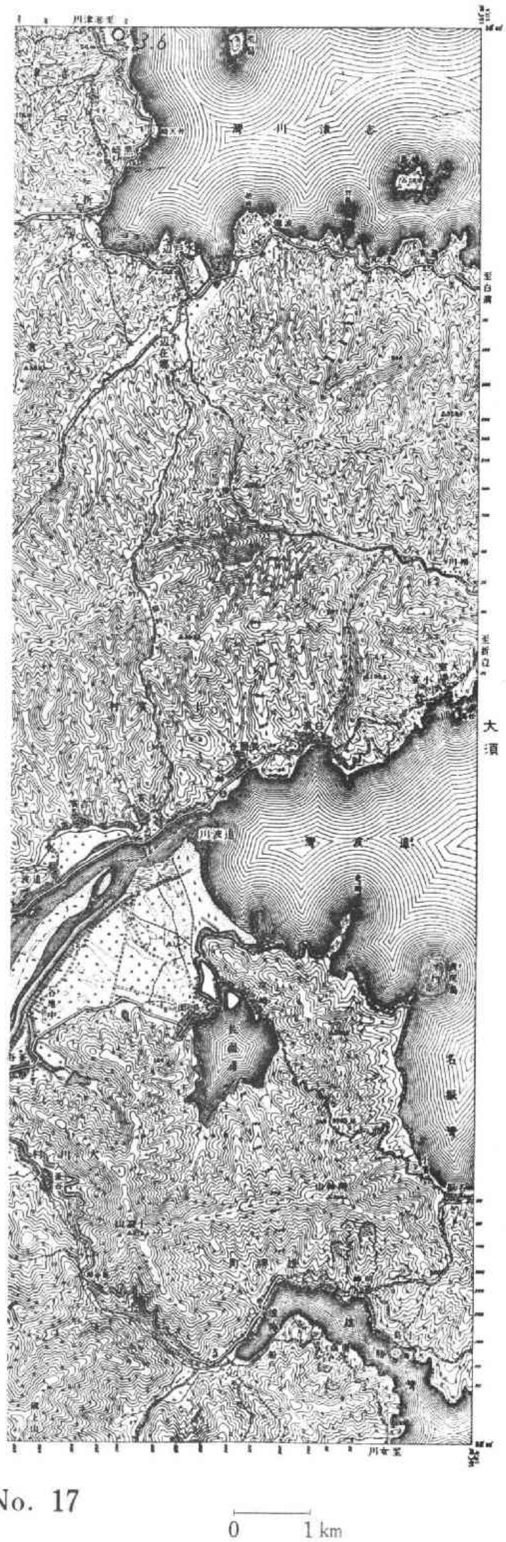
Map No. 15

0　1 km



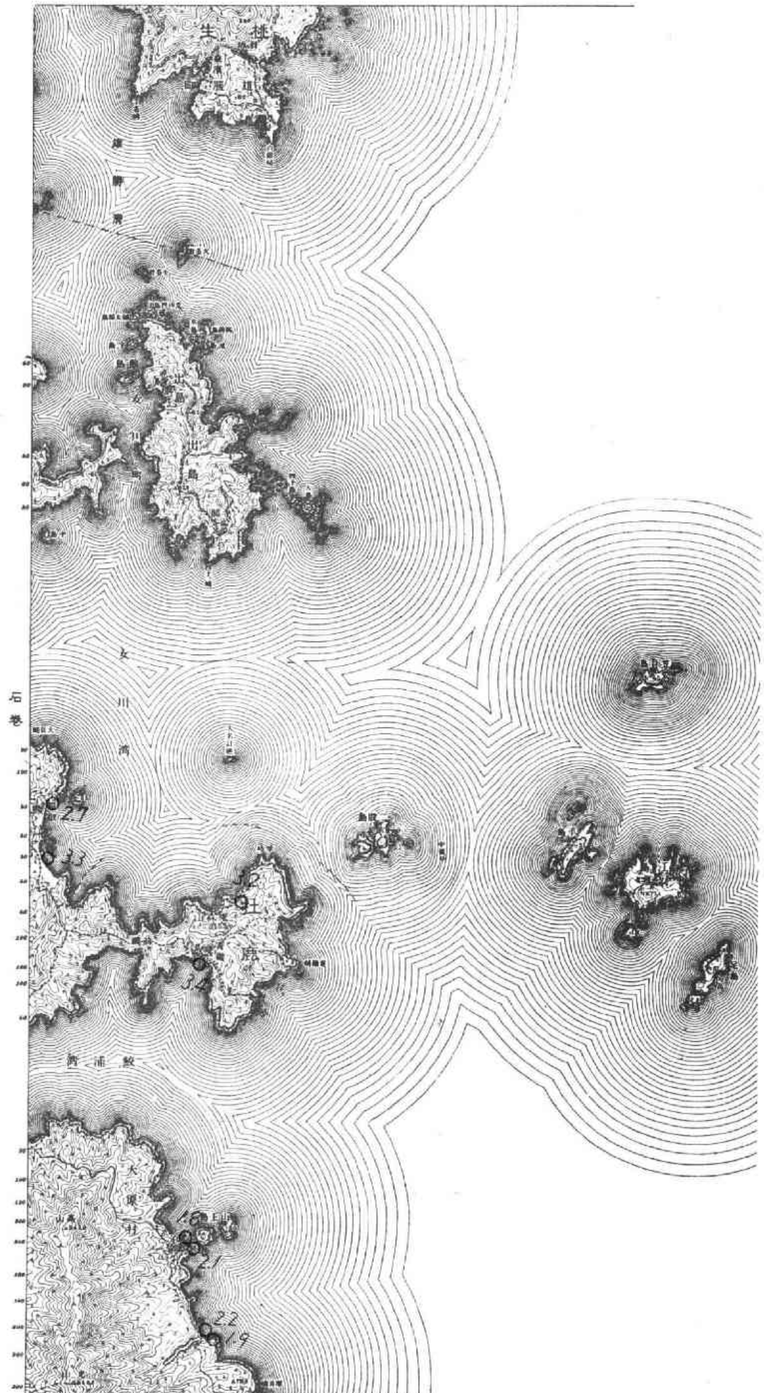
Map No. 16

0 1 km



Map No. 17

0 1 km

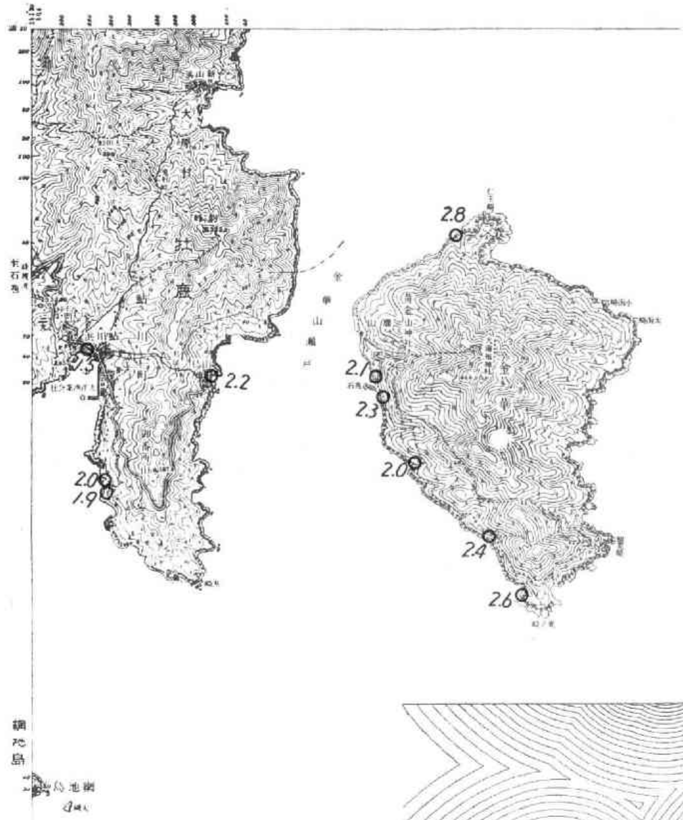


Map No. 18

0 1 km

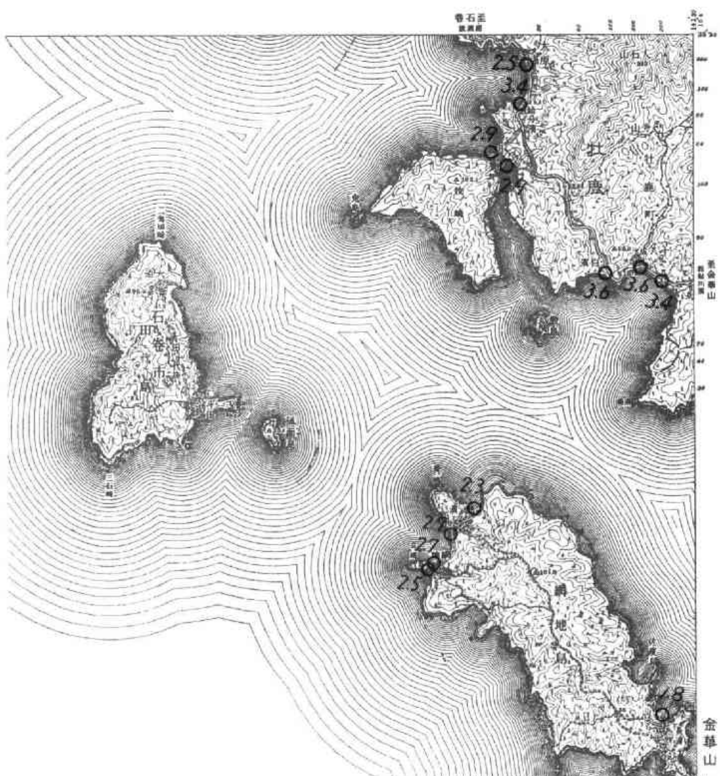
Map No 19

0 1 km



Map No. 20

0 1 km



Map No. 21

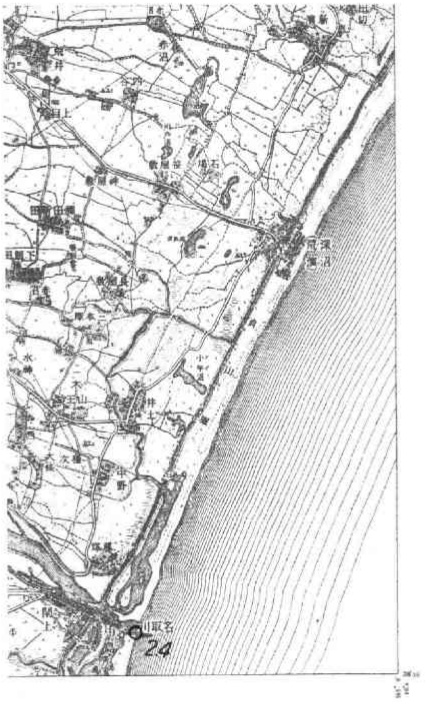
0 1 km

Map No. 22

0 1 km

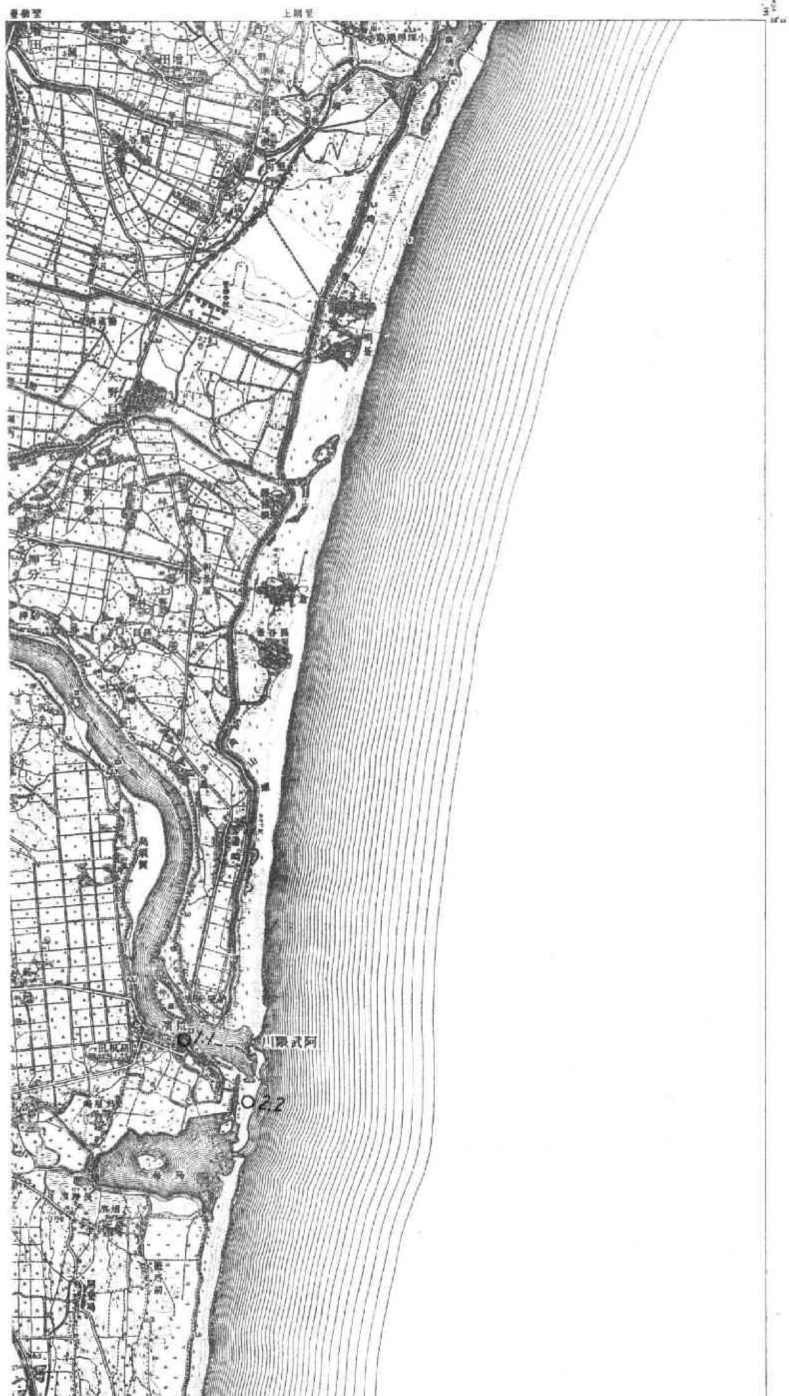
Map No. 23

0 1 km



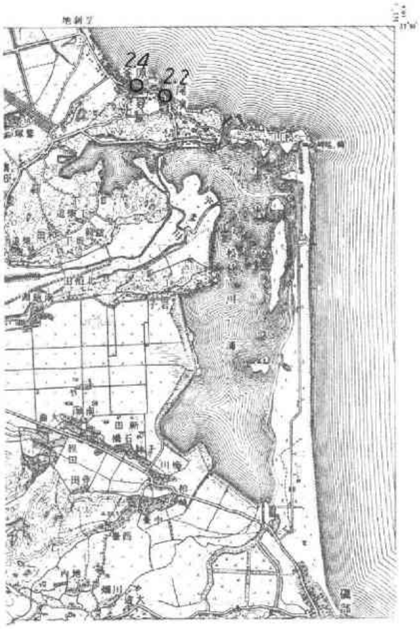
Map No. 24

0 1 km



Map No. 25

0 1 km



Map No. 26

0 1 km